FAECAL SLUDGE REUSE IN URBAN AND PERI-URBAN CROP PRODUCTION

BY

ERIC GBENATEY NARTEY

(10208696)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL ENVIRONMENTAL SCIENCE DEGREE

JUNE, 2013

Project Leader

Dr. Philip Amoah

International Water Management Institute (IWMI), West African Office, Accra – Ghana

Student

Nartey Eric Gbenatey

Supervisory Committee

Prof. K. G. Ofosu – Budu
Institute of Agric. Research
College of Agric. and Consumer Sciences
University of Ghana

Dr. S. D. Boateng
Department of Extension
College of Agric. and Consumer Sciences
University of Ghana

Foreign Discussion Partners

Dr. Josiane Nikiema

Dr. Surendra Pradhan

International Water Management Institute (IWMI), West African Office, Accra – Ghana

DECLARATION

I hereby declare that this submission is my original research work towards the MPhil. Environmental Science, carried out under the supervision of the under listed. It contains no material already published by another person or materials which has been accepted for the award of any other degree in this university or elsewhere, except where due acknowledgement has been made in the text.

Signature: ..... Signature.....

Eric Gbenatey Nartey Prof. K. G. Ofosu – Budu

(Student)

Signature: .....

Dr. S. D. Boateng

DEDICATION

I dedicate this thesis to my parents, Mr and Mrs Joseph Nartey, for struggling to educate me.

ACKNOWLEDGEMENT

I wish to express my sincerest gratitude to the Father Almighty for bringing this endeavour to a successful end. He did not promise a smooth flight but said we could count of Him for safe landing.

I owe a debt of gratitude to my supervisors Prof. K. G. Ofosu-Budu, Dr S. D. Boateng, Dr Philip Amoah and the foreign discussion partners Dr Josiane Nikiema and Dr Surendra Pradhan whose guidance, assistance, patience and constructive criticism have given me the courage to go on.

I would like to express my sincerest appreciation to the sponsor of this thesis, International Water Management Institute (IWMI), through financial support from African Water Facility (AWF) - the African Developments Bank (AfDB) and the University of Berkeley through the project dubbed "Design for reuse – harvesting the value of effluents for sustaining the nutrients for sustaining the operation of sanitation facilities". The sponsorship provided chemicals and logistics which made it possible for this work to achieve success. My thanks also go to the technicians in Ecolab and the staff of IWMI for their immense support.

I would have made a big mistake if I did not acknowledge personalities like Mr Isaac Fenning, Mr Joe Mensah, Mr Kaya, and all other staff of FOHCREC, Kade. Martha Annan, Robert Impraim, Derrick Nartey, Nana–Oduro Osei Bonsu, Kwabena Danful, Akosua Asare Yeboa, Bright Agbomadzi stuck by me and were there when it became critical. Kudos guys!

Last but not the least, I would like to thank my parents, brothers and the entire family for their immense love and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

ABSTRACT

Organic wastes, such as faecal sludge (FS), cocoa pod husk (CPH) and empty fruit bunch (EFB) abound in large quantities in the Ghanaian environment. They contain considerable amounts of nutrients and organic matter which can be recycled to improve soil organic matter content and boost soil fertility status. This study was conducted to characterize and quantify FS produced in Sekondi-Takoradi metropolis (STMA), co-compost FS with EFB and CPH, evaluate the suitability of the co-composts and compost tea as a growing medium and nutrient source, respectively and then ascertain the perception of farmers and consumers on FS composting and use in crop production. Samples of FS were collected from the new liquid waste treatment facility in Sekondi-Takoradi and analysed for physico-chemical parameters (pH, EC, TS, BOD, COD, N, NH_4-N, NO_3-N, P and K) and pathogens (*E. coli,* faecal coliforms and helminth eggs). Dewatered FS was co-composted with EFB and CPH at 5 different treatment ratios: 1FS:1EFB, 1FS:1CPH; and FS: EFB: CPH in ratios of 1:1:1, 2:1:1, and 2:2:1. Temperature, pH, pathogen reduction, and nutrient content were monitored. One co-compost was evaluated for its suitability as a potting medium and compost tea for raising pepper and tomato transplants. Media treatments were prepared by mixing carbonated rice husk (CRH) and co-compost at 5 different ratios 0:1, 1:3, 1:1, 3:1 and 1:0 ratio v/v. The compost teas were prepared by steeping 2.5 kg of compost in 15 L of distilled following the bucket-fermentation method. Questionnaires were administered to 10 vegetable farmers and 10 consumers in Accra to ascertain their perception on human waste composting and use in crop production. Results from this study showed that, the average biological oxygen demand (BOD) of septage and public toilet sludge in STMA were 1080 and 6200

mg/L respectively. This showed the septage was more stabilised than the public toilet sludge. Co-composting FS, EFB and CPH was viable and the process lasted for 12 weeks, however not all treatment ratios produced sanitized co-composts. This was because the different feedstock affected the C/N ratio, temperature, pH and the microbial community in each treatment. The feedstock: FS, EFB and CPH in the ratio of 2: 2: 1 was found to be the best quality co-compost and this ratio supports the idea of using composting as a waste management solution as more human waste is used which can subsequently improve sanitation. The best growth media for tomato transplant production was compost and CRH ratio of 1:1, whiles the ratio of 1: 1 to 1: 0 was found to be optimum for pepper transplants. These ratios provided the optimum nutrient balance and EC for transplant growth. Compost tea had positive effect on both transplant growth, however it was comparable to the inorganic N fertilizer of 100 mg N/L for pepper transplants. Only 33% of vegetable farmers interviewed had knowledge about the use of human waste reuse. However, they were willing to compost FS and subsequently apply to their crops provided training could be offered to them.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 BACKGROUND

Agriculture within and close to the cities (Peri-urban) could play a major role towards achieving the UN Millennium Development Goal—to reduce the number of people suffering from hunger by one-half between 1990 and 2015. In addition to supplementing rural agriculture in food supply, agriculture in urban and peri-urban areas creates an avenue for recycling readily available urban wastes, thereby improving the productivity of farming systems as well as environmental health (Cofie *et al.*, 2004).

Soil fertility in peri-urban agriculture relies heavily on inorganic fertilizers to replenish the soil and provide nutrients for the growth and yield of these crops. More often than not, inorganic fertilizers are not easily available to the farmers and prices are also high beyond their reach. In addition, fertilizers on the local market do not contain micronutrients that are also essential for plant growth. According to SRI, (2009) most soils in Ghana are low in organic matter content (0.72 %) and over 68 % of the soils have low concentration of nitrogen (< 0.1%), available phosphorus (< 10 ppm) and cation exchange capacity (< 15 me/100g) which could be attributed to the large scale soil erosion and poor farming practices. These inappropriate agricultural production practices, coupled with high soil temperature and rainfall in these areas, promote rapid organic matter decomposition resulting in low organic matter and plant nutrient depletion (Bationo *et al*., 1998). The decline in soil fertility in Ghana has affected agriculture production which is the mainstay of the economy.

The maintenance of soil organic matter content is paramount for the maintenance of soil fertility. To sustain high crop production, ensure food security and protect the environment, soil organic matter and soil nutrient base as well as water resources need to be properly managed and conserved (Adamtey, 2010). The content and quality of soil organic matter are the most important factors in the maintenance of the quality and fertility of soils (Reeves, 1997). Therefore there is the need to develop strategies to ensure the return of organic matter in cultivated areas.

In the midst of having challenges with maintaining soil fertility with inorganic fertilizers, there is a challenge with the disposal of faecal sludge (FS) as city authorities are struggling to cope up with strategies to contain the challenge. In Ghana currently, FS generated within the major cities along the coastal areas are disposed of into the marine environment untreated. The pond system which is the main method being used to treat sludge from on-site sanitation facilities such as pit latrines, KVIP, septic tanks is inefficient, leading to pollution of nearby water bodies (Kone, 2004). Although, human FS contains plant nutrients, the raw sludge also contains high pathogen concentrations and using it without prior treatment puts both farmers and consumers at risks of diseases arising from pathogenic infections. It is therefore important to add value to the raw human waste such as composting before it can be used safely in agriculture.

Empty fruit bunches (EFB) and cocoa pod husks (CPH) are two most important agro-industrial wastes produced in large quantities in the country but lack proper management and disposal. The EFB contributes a significant portion of the solid waste stream from oil palm plantations worldwide. In Ghana, based on an annual production of approximately 3,135,000 tons of fresh fruit bunches (FFB), it is

estimated that 721,050 metric tonnes of EFB are produced annually (Adamtey, 2005). The current options employed for EFB disposal are by burning (incineration) and indiscriminately dumping at dump sites whiles some small quantities serve as mulch on the plantations. The impact of the current management practice on the environment is widespread. The incineration of EFB emits particulates into the atmosphere and the indiscriminate dumping of EFB causes methane emission which is a Green House Gas into the atmosphere thereby contributing to global warming. Similarly, cocoa is an important agricultural export commodity. Currently Ghana, producing about 700,000 tons of cocoa beans annually, is ranked second in the world, after her Western neighbour Cote d'Ivoire (Ntiamoah and Afrane, 2008). Each ton of dry seeds (beans) represents about 10 tons of husks (fresh weight) (Olugbenga *et al.*, 2011). In present times, CPH are wastes from the cocoa industry, and present a serious disposal problem. They become a significant source of disease inoculums when used as mulch in cocoa plantation (Figueira *et al.*, 1993).

There is great potential in using of these agro-industrial wastes that are easily available in the forest areas of Ghana for co-composting with FS. This could be seen as one of the possible ways of addressing food security and waste management in peri-urban areas of the West African sub-region, though there may be challenges with its acceptance. One of the major challenges that might threaten the full integration and acceptance of human waste composting into agriculture is the negative perception farmers and consumers have towards human waste. Compost has numerous benefits and nearly all crop farmers like to apply good-quality composts to their fields (Hogarh *et al.*, 2008). The quality of a

specific type of compost is a function of its chemical, biological, and physical characteristics (Waste Balkan Network, 2011).

1.2 PROBLEM STATEMENT

Increasing human population and industrial activities have generated huge quantities of organic waste. Municipal solid waste (MSW) and human excreta (FS) constitute the major components of the urban waste stream in the country. Their management has become an important environmental challenge for municipal authorities (Adamtey, 2010). It is on record that about 1.8 million people, mostly children under five, die every year from diarrheal disease (UNESCO, 2006) as a result of inappropriate and inadequate waste management options.

A nationwide survey conducted by International Water Management Institute (IWMI) in 2008 revealed that less than 20% of FS and wastewater generated in urban settlements received some form of treatment. The remaining 80% is left in the environment untreated (IWMI, 2009). In Accra alone, an average of 700 m^3 of FS from an average of 100 tankers is disposed of at Korle Gonno every day. In 2006, over 200,000 m^3 was disposed into the marine environment from this point (Boot & Scott, 2008). This represents a huge chunk of plant nutrients going to waste and at the same time causing serious environmental pollution. Based on earlier studies conducted by IWMI, (2003), Cofie *et al.*, (2004), Adamtey *et al.*, (2010), and many others in Ghana, FS can be a useful raw material for composting. Some studies have indicated that addition of mixtures, as bulking matrices or composting additives, is important for maintaining an aerobic thermophilic condition and their types greatly influence the process of organic

decomposition and nitrification (Eklind and Kirchman, 2000a; Eklind and Kirchman, 2000b) and to some extent, nutrient mineralization. Co-composting FS with EFB and CPH can provide an alternative sustainable way of reducing the abundance of human excreta and organic wastes that would have otherwise ended up in the environment unmanaged.

Though, composting of FS is not entirely new in Ghana, as faecal biosolids from stabilisation ponds are mixed with sawdust (Cofie *et al.,* 2008), and some farmers, have also composted raw excreta with maize stubble in the northern part of Ghana (Cofie *et al.,* 2005). There are challenges and hindrances as to why composting of human waste has not been fully integrated into or accepted into crop production in our society. This has been due to 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

Reuse of FS in agriculture falls under the new paradigm shift towards recycling of wastes of organic origin into useful materials (compost) for crop production. Co-composting of FS 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).

The use of composted FS in agriculture is not a new concept. It has been used effectively in Asia for centuries. However, its use in sub-Saharan Africa is relatively new, and the West Africa office of IWMI has been exploring the

potential it could hold for agriculture in the sub region since 2001 (Davelaar, 2012). In Ghana, agro-industrial residues such as EFB and CPH are a menace to the environment. These organic residues over the years have been composted elsewhere with other organic materials and the outcomes well documented in literature but not with FS. Though there is a great possibility of co-composting FS with EFB and CPH by virtue of their physical and chemical characteristics, the possibility has received very little research attention. At the moment, very little study or none at all has been conducted into the process dynamics involved in the co-composing of FS with EFB and CPH. There is therefore a huge knowledge gap existing on process description and dynamics.

1.4 OBJECTIVES

The main focus of this study is to co-compost FS with agricultural waste in the system to reduce environmental pollution and also to enhance the recycling of plant nutrients for crop production.

Specific objectives

1. To characterise and quantify FS generated in Sekondi-Takoradi Metropolitan Area.
2. To co-compost FS with EFB and CPH at different ratios to determine its effect on pathogen reduction, nutrient content and percentage volume reduction.
3. To evaluate the suitability of co-composts as a growing medium for vegetable transplant production.
4. To evaluate the efficacy of the co-compost as an N source for vegetable transplant production.

5. To ascertain the perception of farmers and consumers on human waste (FS) composting and use in crop production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Faecal sludge management and the need for composting

Human excreta also referred to as faecal sludge, consist of faeces and urine. Both are waste products of body metabolism. The appearance, physical and chemical characteristics of urine and faeces depend largely on the health of the person excreting the material, as well as on the amount and type of food and liquid consumed (Lentner *et al*., 1981; Feachem *et al*., 1983). To achieve complete sanitation, human excreta management should comprise of four stages or should follow the following management pathway listed below (Torondel, 2010):

1. collection of excreta
2. transportation of excreta to a suitable location
3. storage and/or treatment of excreta.
4. reusing and/or returning excreta to the environment.

However for most urban populace in developing countries, the only real sanitation options available are the 'on-site sanitation systems' and sadly these systems rarely include all the four management pathways indicated above to achieve complete sanitation. On-site Sanitation (OSS) systems represent the predominant form of excreta disposal for the majority of urban dwellers in Africa and Asia as well as for a considerable proportion in Latin America (Strauss *et al*., 2000). These differ from sewer based systems commonly used in developed countries. The OSS systems comprise of non-sewered household and public toilets, aqua privies and septic tanks (EAWAG-SANDEC, 2006). In sub-Saharan

Africa, more than 80% of houses in large cities and up to 100% in towns are served by on-site sanitation facilities (Strauss *et al*., 2000).

Every day, thousands of tons of sludge from OSS installations are disposed of untreated. They are either used in agriculture in their raw state or discharged indiscriminately into lanes, drainage ditches, onto open urban spaces and into inland waters, estuaries and the sea, causing serious health impacts, water pollution and eye and nose sores (Ingallinella *et al*., 2002). In cases where they are used in agriculture in their raw untreated state, they promote the recycling of nutrients and organic matter in the excreta. However, because the organic matter is not stabilised and the pathogens are not inactivated, direct use in agriculture may become detrimental to both plants and humans.

Water scarcity, intermittent water supply services, lack of technical expertise, financial and economic reasons make sewered sanitation an unsuitable option in most urban settlements. It is unlikely, though, that sewerage will be the predominant sanitation option of choice in developing countries in the foreseeable future. The OSS installations will serve the growing urban populations in developing countries for decades to come. As a consequence, growing quantities of faecal sludge will have to be managed (EAWAG-SANDEC, 2006).

Aerobic composting still remains the most suitable option among the others for the safe handling and utilisation of faecal sludge in agriculture. Composts represent an important resource to maintain and restore soil fertility and are of great values nowadays, particularly in those countries where the organic matter content of soil is low (Castaldi *et al*., 2004). Soil organic matter plays a major role in maintaining soil quality (Pedra *et al*., 2007). In addition to supplying plant

nutrients, the type and amount of soil organic matter influence several soil properties (Araujo *et al.,* 2008).

2.1.1 Generation rate of faecal sludge

The amount of faeces produced by a person depends on the composition of the food consumed. Foods low in fibres, such as meat, result in smaller amounts (mass and volume) of faeces than foods high in fibre (Guyton, 1992). The faecal production in the developed countries is approximately 80-140 gram per person per day (g/p/d) (wet weight) of faeces, corresponding to about 25- 40 g/p/d of dry matter (Lentner *et al*., 1981; Feachem *et al*., 1983; Jönsson *et al.*, 2005; Vinnerås *et al*., 2006). Faecal excretion rate in the developing countries is on average 350 g/p/d in rural areas and 250 g/p/d in urban areas (Feachem *et al*., 1983). In China, Gao *et al*. (2002) measured 315 g/p/d while Pieper (1987) measured 520 g/p/d in Kenya. Schouw *et al*. (2002) measured faecal generation of 15 individuals in three different areas in Southern Thailand and obtained wet faecal generation rates of 120-400 g/p/d. Faecal excretion rate is on average one stool per person per day, but it may vary from one stool per week up to five stools per day (Lentner *et al*., 1981; Feachem *et al*., 1983).

The quantity of urine excreted depends on how much a person drinks and sweats, and also on other factors such as diet, physical activity and climate (Lentner *et al*., 1981; Feachem *et al*., 1983). Excessive sweating results in concentrated urine, while consumption of large amounts of liquid dilutes the urine. The urine generation rate for most adults is between 1000 and 1300 g/p/d (Feachem *et al*., 1983). Vinnerås *et al*. (2006) suggested a design value for urine generation to be 1500 g/p/d based on measurements in Sweden, while Schouw *et al*., (2002) found

that in Southern Thailand between 600-1200 g/p/d of urine were produced. Based on measurements in Switzerland, Rossi *et al*., (2009) reported a urine generation rate of 637 g/p/d on working days and 922 g/p/d on weekends, which is in agreement with 610-1090 g/p/d reported by Jönsson *et al*. (1999) based on measurements in Sweden.

2.1.2 Nutrient Content of faecal sludge

The nutrient content of faeces originates from the food consumed. It is estimated that the food nutrient content is distributed to the faecal fraction in the proportions: 10-20% nitrogen (N), 20-50% phosphorus (P) and 10-20% potassium (K) (Berger, 1960; Lentner *et al*., 1981; Guyton, 1992; Vinnerås *et al*., 2006). About 20% of faecal nitrogen is ammonia, biochemically degraded from proteins, peptides and amino acids, some 17% is found in living bacteria and the remainder is organic nitrogen combined in molecules such as uric acid and enzymes (Lentner *et al*., 1981). The nutrients contained in faeces in Sweden are on average 550 g N, 183 g P and 365 g K per person per year (Jönsson *et al*. 2005; Vinnerås *et al*., 2006). Urine contains the largest proportion of plant nutrients found in the household waste and wastewater fractions. The amount of plant nutrients excreted via urine per person per year has been measured at 2.5-4.3 kg N, 0.4-1.0 kg P and 0.9-1.0 kg K (Lentner *et al*., 1981; Vinnerås *et al*., 2006).

Jönsson *et al*. (2005) and Vinnerås *et al*. (2006) analysed measurements on the nutrient content of urine, including previous studies, and found the annual excretion rate per person in Sweden to be about 4000 g N, 330-365 g P and 1000 g K. Together, the nutrients in urine and faeces in Sweden add up to some 4500-

4600 g N, 500-550 g P and 1400 g K per person per year (Jönsson *et al*., 2005; Vinnerås *et al*., 2006). Based on FAO data on food supply, Jönsson and Vinnerås (2004) estimated the quantity of nutrients in Ugandan excreta to be 2500 g N and 400 g per person per year.

2.1.3 Pathogens in faecal sludge

Apart from the beneficial macronutrients in faecal sludge, it also harbours a host of disease - causing organisms which can contaminate the environment to infect innocent people when human excrement is discarded as a waste material. In fact, even a healthy person apparently free of disease can pass potentially dangerous pathogens through their faecal material, simply by being a carrier (Jenkins, 1999). The pathogens that can exist in human faeces are divided into four general categories; viruses, bacteria, protozoa and worms (helminths). Helminths and bactera have been used as indicators of faecal contamination.

However, the most persistent pathogens seem to be the helminths and in particular the roundworm (*Ascaris lumbricoides*). The egg of the roundworm is protected by an outer covering which resists chemicals and protects it from adverse environmental conditions. Estimates of the survival time of Ascaris eggs in certain soil types under certain conditions are as high as ten years. Although the Ascaris eggs are readily destroyed by thermophilic composting, they may survive in conditions generated by a low-temperature toilet (Jenkins, 1999).

2.2 Faecal sludge co-composting

Faecal sludge application to land is considered an attractive alternative to other forms of disposal. However, plants may not necessarily benefit from direct soil

incorporation of untreated faecal sludge. The high pathogen content and offensive odour make it a health concern for handlers (farmers), farm workers and to some extent consumers of the farm produce. Stabilisation of faecal sludge by composting prior to land application is highly desirable to eliminate odour, to make nutrients in the wastes, particularly N, readily available for plant use, and to prevent the sludge incorporated into the soil from being phytotoxic to plant growth (Kuo *et al*., 2004).

Faecal sludge has been co-composted with other organic wastes. In Ghana, faecal sludge has been co-composted mainly with municipal solid waste (MSW), market waste (MW), domestic solid waste and sawdust (Obeng and Wright, 1987; IWMI, 2003; Kone *et al*., 2007 and Cofie e*t al.*, 2009). According to Cofie *et al.* (2009), composting faecal sludge with market waste is more preferable than with household waste at a ratio of 2:1 (FS: MW). So far, organic materials used in co-composting faecal sludge have been limited to those listed above.

Elsewhere, faecal sludge has been used indirectly as part of sewage sludge. Sewage sludge has over the years been composted with other organic materials such as sawdust (Bazrafshan *et al*., 2006) and oil palm wastes (Kala *et al.*, 2009; Kala *et al*., 2012). The main challenges associated with faecal sludge/ sewage sludge composting and for that matter aerobic composting in general is nutrient loss during the process. Jeong and Kim (2001) reports that, up to 50% of the nutrient content of the initial materials especially N could be lost due to ammonia volatilization.

Co-composting FS and agricultural residues (EFB and CPH) have not been studied in literature. These combinations are beneficial because the characteristics of the agricultural residues compliment the characteristics of the FS for

composting. The FS is relatively high in nitrogen content whiles the two organic residues have relatively high carbon content thus very good bulking quality. High temperatures attained during the co-composting process are effective in inactivating excreted pathogens contained in the FS and will convert both wastes into a hygienically safe product for crop production.

2.3 Reuse potential of human excreta and agricultural residues in urban and peri-urban agriculture in Ghana

2.3.1 Reuse potential of faecal sludge in Ghana

The use of human excreta is not a new practice; the Chinese have been composting human excreta for a thousand years and the Japanese introduced excreta use in the 13th century. There is potential for faecal sludge or human excreta recycling into urban and peri-urban crop production in Ghana. Human excreta are a rich source of organic matter and inorganic plant nutrients. The organic matter content serves as a soil conditioner and humus replenisher which are of great importance to crop production, an asset not shared by any chemical fertilizer (IWMI, 2003).

According to Drangert (1998), the fertilising equivalent of excreta per person is nearly sufficient to grow the person's own food (Table 2.1). Urban and peri-urban agricultural soils are greatly depleted of organic matter and nutrients and in a recent material flow study conducted in the City of Kumasi, Ghana, it was found that for urban and peri-urban agricultural soils, nutrients (N and P, Organic matter) could be fully replenished by using all the human waste and recycling all the organic market waste and the wastes from breweries, timber and food

processing factories and from chicken farms (most of the wastes would have to be treated prior to use, though) (Leitzinger, 2000; Belevi *et al.*, 2000).

Table 2.1: The fertilization equivalent of human excreta

	Nutrient in kg/ cap year			
Nutrient	In urine (500 L/year)	In faeces (50 L/ year)	Total	Required for 250 kg of cereals[1]
Nitrogen (as N)	4.0	0.5	4.5	5.6
Phosphorus (as P)	0.4	0.2	0.6	0.7
Potassium (as K)	0.9	0.3	1.2	1.2
Carbon (as C)[2]	2.9	8.8	11.7	

1= the yearly food equivalent required for one person, 2= indicative of the potential for soil conditioner, normally not designated a nutrient. Source: Drangert, 1998.

2.3.2 Reuse potential of agricultural residues in Ghana

Agriculture remains the main backbone of Ghana's economy, as it is the single major contributor to the nation's gross domestic product (GDP). It contributes 36% of the GDP and employs 60% of Ghana's labour force. The average annual *per capita* income of those employed in agriculture is estimated at US$390 (CIA, 2005). Agriculture therefore plays an important role in economic growth, food security, poverty reduction, livelihoods, rural development and the environment (Green *et al.*, 2005).

Agricultural production leaves considerable amounts of wastes and residues. Some of the residues are recycled back into the agricultural production as mulch, while large amounts remain unused – and in many instances pose a disposal

problem. However, these residues can be considered as resources because of their usefulness as raw materials for composting. They are good sources of organic matter (carbon), nitrogen, potassium and other nutrients needed by plants. In some agricultural industries, large amounts of residues are already concentrated and readily available for utilisation. In Ghana, two of the biggest sources of agricultural residues are the palm oil industry and the cocoa industry. The palm oil industry, for instance, produces significant amounts of empty fruit bunches (EFB) that can be recycled (Udoetok, 2012). The cocoa industry equally generates huge amounts of cocoa pod husks (CPH) that need attention (Adamafio, 2013). With efficient collection systems, residue from agricultural production can be composted for urban and peri-urban agriculture.

Empty Fruit Bunches (EFB)

Oil palm production is a major agricultural industry worldwide. The industry churns out millions of tonnes of oil palm biomass annually. This oil palm biomass can be categorized as a form of empty fruit bunches (EFB), oil palm trunks (OPT) and oil palm fronds (OPF) and the rest are palm oil mill effluent (POME) (Baharuddin *et al*., 2009). A fresh fruit bunch produces 20% oil, 25% nuts (5% kernels, 13% fibre and 7% shell) and 23% EFB (Pehnelt and Vietze, 2011). Using these ratios, the annual production of EFB in Ghana can be estimated based on annual production of approximately 3,135,000 tonnes of fresh oil palm fruit bunches (calculation based on average yield of 11 tonnes per hectare (Toledano *et al.*, 2004). The EFB contains 50% cellulose, 30% hemicelluloses and 30% lignin and the nutrient composition shown in Table 2.2 (Elbersen *et al.*, 2005).

Table 2.2: Nutrient composition of empty fruit bunch

DM Per ton of CPO	H_2O (%)	N (% DM)	P (% DM)	K (% DM)	Mg (% DM)	Ca (% DM)
0.32 -0.42	58	0.80	0.06	0.24	0.18	-

DM= Dry matter, CPO= Crude palm oil. Source: Elbersen *et al.*, 2005.

Cocoa Pod Husks (CPH)

In Ghana, approximately 400,000 tonnes of cocoa beans are produced annually (Ofosu-Budu *et al.*, 2001) and based on this annual production, an estimated 550,750 tonnes of dry cocoa husk is produced (Adamtey, 2005). Cocoa pod husk (CPH) is the major by-product of the cocoa industry. They are produced after the removal of the cocoa bean from the fruit. Basically, each ton of dry cocoa beans is equivalent to about 10 tons of cocoa pod husks (Olugbenga *et al.*, 2011). Some of the CPH are used for mulching, soap making and as part of animal feed. However most of the husks are disposed of as waste which in turn results in landfill problem. This is because the use of CPH is limited to livestock feed because of the theobromine content which also serves as disease inoculum (Serra and Ventura, 1999). Cocoa pods contain about 9% ash, 8- 10% crude protein, 2 - 3% ether extract and 35% crude fibre. The potassium (K) content (3.2%) is higher compared to other roughages, but less calcium (Ca) (0.3) % and phosphorus (P) (0.1 – 0.2%). Others are 11% hemicelluloses, 35% cellulose, 15% lignin and 6% pectin (Sobamiwa and Longe, 1994).

2.4 Composting and co-composting: Process definition and description

2.4.1 Process definition

Composting

Composting is defined as the aerobic, or oxygen requiring process during which organic matter is decomposed by micro-organisms under controlled conditions to a biologically stable end product (Waste Balkan Network, 2011). During composting the microorganisms consume oxygen for the bio-oxidation of the organic matter resulting in the generation of heat, carbon dioxide and water vapor, which are released into the atmosphere (Epstein, 1997; Ipek *et al*., 2002) leading to the significant reduction in volume and mass of the organic raw material.

Co-Composting

Some organic materials cannot be composted alone because of their physical and chemical characteristics such as low porosity, high moisture content and low C/N ratio which can adversely affect the composting process. Such organic materials must be composted with other organic materials in a process called Co-composting. Co-composting is therefore a waste treatment method in which different types of waste are composted together (Angelidake and Ahring, 1997).

2.4.2 Process description

There are basically three types of composting namely; aerobic, anaerobic and vermicomposting. However the basic composting process consists of the following steps:

Pre-processing

The material to be composted must be porous, structurally stable, and capable of self-sustaining the decomposition reaction. If required, bulking agents for porosity and moisture control (e.g. recycled compost, wood chips, and so on) or feed amendments for a source of limiting nutrients such as carbon (for example, sawdust, rice hulls, and so on) are added to the dewatered biosolids/sludge to provide a mixture suitable for composting (USEPA, 1979).

Composting process

The composting process can generally be divided into two major stages. The first stage consist of the ‘‘active phase’’ of the process which mainly involves the development of bio-oxidation reactions. Therefore, the readily available organic matter is used as energy source by microorganisms for their metabolic activities. The second phase of the composting process, known as ‘‘curing phase’’, involves the production of organic macromolecules humus-like substances for the formation of mature compost (Cooperband, 2000). All reactions are based on numerous biological, thermal and physicochemical phenomena and involve oxygen consumption, as well as heat, water and carbon dioxide production (Waste Balkan Network, 2011).

Post processing

This consists of grinding or sieving, de-stoning and other steps undertaken to prepare the compost for utilization and marketing (Epstein, 1997).

Aerobic composting

Aerobic composting is defined as the process in which, under suitable environmental conditions, facultative aerobic organisms, principally, thermophilic, utilize considerable amounts of oxygen in decomposing organic

matter to fairly stable humus material (Gotaas, 1976). It is the most widely accepted means of stabilizing organic wastes and converting them to a usable, and value added compost product. In this process, relatively higher temperatures (above 60 ^{o}C) can be reached and both mesophilic and thermophilic micro-organisms are involved in the composting process (Baffour-Asare, 2009).

Anaerobic composting

Anaerobic composting is the putretive breakdown of organic matter by reduction in the absence of oxygen where end products such as methane (CH_4) and hydrogen sulfide (H_2S) are released (Gotaas, 1976). Anaerobic decomposition of organic matter is, however, often associated with the formation of foul smelling gasses such as indol, skatol and mercaptans (any sulfur-containing organic compound). This method of composting involves little or no work, however, the maturation of the pile is usually prolonged and the process does not generate enough heat to safely kill pathogens and weed seeds. The process usually takes place at temperatures between 8 ^{o}C and 45 ^{o}C, with mesophilic microorganisms breaking down the soluble and readily degradable compounds (Baffour-Asare, 2009).

Vermicomposting

Vermicomposting is the term given to the process of conversion of biodegradable matter by earthworms into vermicast. In the process, a major fraction of the nutrients contained in the organic matter is converted to more bioavailable forms. The first step in vermicomposting occurs when earthworms break the substrate down to small fragments as a prelude to ingesting the substrate (Gajalakshmi and Abbasi, 2008). The earthworms possess a grinding gizzard that enables the

mincing of the substrate. This increases the surface area of the substrate, facilitating microbial action (Chan and Griffiths, 1988). The substrate is then ingested and goes through a process of "digestion" brought about by numerous species of bacteria and enzymes present in the worm gut. During this process, important plant nutrients such as nitrogen, potassium, phosphorus, and calcium present in the feed material are converted into forms that are much more water-soluble and bioavailable to the plants than those in the parent substrate (Gajalakshmi and Abbasi, 2008).

2.4.3 Composting systems

The currently available compost systems can be generally classified into two broad categories the "windrow" and the "in-vessel" composting systems (Waste Balkan Network, 2011). Depending on the location, the type of substrate to be used, the scale of operation and the skills and machinery available, one or the other type of composting system can be used (Gajalakshmi and Abbasi, 2008).

Windrow composting system

Windrow systems are further subdivided on the basis of the aeration method of the substrate into "turned windrow" and "forced air windrow or static pile" (Waste Balkan Network, 2011). In windrow composting, the biowaste is laid out in parallel rows, 2–3 m high and 3–4 m wide across the base. Windrows naturally acquire a trapezoidal shape, with angles of repose depending on the nature of material. The actual dimensions of the windrows depend on the type of equipment that is used to turn the material to be composted. Before forming the windrows, the material is processed by shredding and screening it to approximately 3 to 9 cm size range (thickness). The moisture content is adjusted

to 50–60%. If such a windrow is left without any mechanical agitation or turning, limited aeration would occur naturally via diffusion and convection currents, but the composting would proceed very slowly, requiring more than a year for completion (Gajalakshmi and Abbasi, 2008).

Forced air windrow – Aerated static system

In a forced air windrow or aerated static composting system, air is either forced upwards through the composting mass or is pulled downwards and through it (Shammas and Wang, 2009). In both instances, the composting mass is not disturbed. The forced aeration composting systems usually involves a combination of drawing air into and through the pile, followed by air forcing upward through the pile. The air that leaves the substrate is either discharged directly into the environment, or is forced through a cone-shaped biofilter (e.g. finished compost or other "stable" organic matter) (Waste Balkan Network, 2011).

Turned Windrow System

The turned windrow method is the one that traditionally and conventionally has been associated with composting. The term "turned" applies to the method used for aeration. Aeration of the windrow is achieved by agitation of the substrate using tractors with front end loaders or any other appropriate machinery which tears down the piles and reconstructs them. Turning not only promotes aeration, but it also ensures uniformity of decomposition by exposing at one time or another all of the composting material to the particularly active interior zone of a pile (Waste Balkan Network, 2011). In addition, the mechanical agitation of the substrate reduces to some extent the particle size of the organic material, whereas

water loss due to evaporation (elevated temperatures) is accelerated (Cornell University, 2010).

In-Vessel composting systems

In-vessel composting occurs within a contained vessel, enabling the operator to maintain closer control over the process in comparison with other composting methods. The in-vessel systems are designed to minimize odors (e.g. biofilter) and process time by controlling environmental conditions such as air flow, temperature, and oxygen concentration. In this section the term "in-vessel" or "reactor" is applied to the unit or set of units in which the "active" stage of composting takes place. These units are also called bioreactors, since composting essentially is a biological process. In general, bioreactors can be divided into two main types (1) vertical and (2) horizontal (Haug, 1993). Horizontal bioreactors are further categorized into (1) channels, (2) cells (3) containers (4) tunnels and (5) "inclined" reactors or rotating drums (Crowe *et al*., 2002). The primary objective of the in-vessel design is to provide the best environmental conditions, particularly aeration, temperature, and moisture. Nearly all in-vessel systems use forced aeration in combination with stirring, tumbling, or both (Waste Balkan Network, 2011).

2.4.4 Compost rate determining factors

The principal factors which affect the rates of composting (Poincelot, 1977) include the following:

Moisture

Decomposition of organic matter is dependent upon moisture, since water provides the medium for biochemical reactions, transportation of nutrients and

allows the microorganisms to move about (Gajalakshmi and Abbasi, 2008). The lowest moisture content at which bacterial activity takes place is from 12 to 15%; however, less than 40% moisture may limit the rate of decomposition. The optimum moisture content is in the range of 50–60%. If the mixture is over 60% water, the proper structural integrity will not be obtained (Shammas and Wang, 2007). However, the optimal moisture level is depended upon the composted material and more specifically on its porosity (Diaz and Savage, 2007). Organic mix with a low porosity requires higher moisture content than a substrate with a higher porosity level (Diaz and Savage, 2007). Moisture content, which is lower or higher than the optimum range, results in the inhibition of the microbial activity due to early dehydration and the formation of anaerobic conditions respectively (Gajalakshmi and Abbasi, 2008; de Bertoldi *et al.*, 1983).

Temperature

For the most efficient operation, the temperature in the compost should range between 55 and 65 °C (130–150 °F) but not above 80 °C (176 °F). High temperatures are also required for the inactivation of human pathogens in the biosolids (Shammas and Wang, 2007). According to Epstein (1997) and Miller (1992), thermophilic microorganisms become less active at elevated temperatures between 60 and 70 °C and thus the microbial activity is reduced. At even higher levels (>70 °C) Finstein *et al.* (1986), Fermor *et al.* (1989) and Mena *et al.* (2003) indicate that the microorganisms suffer the effects of high temperatures (inactivation or elimination) and the process slows down until the microorganisms can recover. The importance of temperature monitoring lies on the fact that it reflects the activity of microorganisms in the substrate and it

represents an indicator of the proper evolution and occurrence of the composting process (Diaz and Savage, 2007).

pH

The optimum pH range for growth of most bacteria is between 6 and 7.5 and for fungi between 5.5 and 8.0 (US Composting Council, 2000). The pH varies throughout the pile, and throughout the composting operation, but it is essentially self-regulating. A high initial pH resulting from the use of lime for dewatering will solubilise nitrogen in the compost and contribute to the loss of nitrogen by ammonia volatilization. It is difficult to alter the pH in the pile for optimum biological growth, and this has not been found to be an effective operation control (Shammas and Wang, 2007).

Nutrient concentration

Both carbon and nitrogen are required as energy sources for organism growth. Thirty parts by weight of carbon (C) are used by microorganisms for each part of nitrogen (N); a C/N ratio of 30 is, therefore, the most desirable for efficient composting. Carbon: nitrogen ratios between 25 and 35 provide the best conditions (USEPA, 2002). The carbon considered in this ratio is biodegradable carbon. Lower C/N ratios increase the loss of nitrogen by volatilization as ammonia and higher C/N ratio values lead to progressively longer composting times as nitrogen becomes limiting (Poincelot, 1977). No other macro-nutrients or trace nutrients have been found to be rate limiting in composting municipal wastewater biosolids.

Availability and concentration of oxygen

According to Miller, (1992) the optimum O_2 concentration is between 15 and 20%. Oxygen consumption during composting is directly proportional to the microbial activity providing a direct relationship between oxygen consumption, temperature, moisture and aeration (EA, 2001). Therefore, aeration is a key factor for composting, since proper aeration controls the temperature, removes excess moisture and CO_2 and provides O_2 for the biological processes. If there is insufficient oxygen, the process can become anaerobic involving a different set of micro-organisms and different biochemical reactions which result in the production of methane gas and malodorous compounds, such as hydrogen sulfide gas and ammonia (Waste Balkan Network, 2011). Aeration of the organic substrate is achieved through agitation, active aeration (air blowing) and/or passive aeration (natural diffusion of air though negative pressure) (IWMI, 2003).

2.4.5 Compost stability

Compost stability refers to the stage of composting process where microbial activity diminishes with a corresponding decrease of energy sources (viz., available organic carbon). Stability is sometimes related to compost colour, which often changes from light brown to dark brown/black as biological activity subsides (Evanylo, 2006). There is an index that describes the stability of composts called the Stability Index. This index shows or measures the level of microbial activity in a sample based on respiration monitoring (Evanylo, 2006).

2.4.6 Compost maturity

Compost maturity is one of the most important factors affecting the safe use of these composts for agricultural, municipal, industrial and domestic purposes. Maturity of compost is defined as the final stable state of the composted matter which is safe for agricultural applications (HMJ, 2008). Composts maintain and/or increase crop production and reduce soil exposure to degradation, erosion, desertification and pollution. The agronomically efficient and environmentally safe use of composts require an adequate control of the chemical quality of the humic substance (HS)-like fractions retention, which is an important indicator of the maturity and stability achieved by the compost (Senesi *et al*., 2007). As a matter of fact, immature compost may stunt, infest, damage, or even kill plants, rather than acting as growth enhancer due to the presence of undecomposed, phytotoxic compounds (e.g., n-hexadecane, pyrene and benzo(a)pyrene) and high microbial activity which can compete for the available nutrients in the soil (Francou *et al*., 2005; Haderlein *et al.*, 2006).

Existing literature suggests that the most significant effect of immature compost is the biological blockage of soil-available nitrogen (N) which may give rise to critical N-deficiencies in crops with consequent depressive effects (Jiménez and Garcia, 1989). The rapid decomposition of immature compost may cause a decrease of the O_2-concentration and soil pH as a result, leads to the creation of an anaerobic and strongly-reducing environment surrounding the root system. The low pH of soil could cause an increase in the solubility of heavy metals in the soil and inhibition of plant seed germination by the production of phytotoxic substances (Rosen *et al*., 1997), ammonia, ethylene oxide and organic acids (Sellami *et al.*, 2008). Furthermore, the inhibitory environment causes plants to

lower their metabolic rate, reduce root respiration, decrease nutrient absorption and slow the gibberellin and cytokinin synthesis and transport. For these reasons, compost maturity is one of the most important parameters for determining the grade of compost worldwide.

Generally, some of the under listed parameters are used to determine compost maturity (Baffour-Asare, 2009):

- physical parameters: temperature, odour, colour, particle size, water and air retention capacities (Garcia *et al*., 1992).
- chemical parameters: C/N ratio in solid and water phases, cation exchange capacities, elemental concentrations, organic matter level, water-soluble organic matter and humification indexes (Hsu and Lo, 1999).
- spectroscopic analysis: Nuclear magnetic resonance spectroscopy (NMR), Fourier transform infrared spectroscopy (FTIR) and fluorescence (Chen and Inbar, 1993).
- biochemical parameters: total and specific enzyme activity (Grebus *et al.*, 1994).
- microbiological parameters: oxygen and carbon dioxide (CO_2) respirometery, bioassay responses such as: germination index and plant growth bioassays (Grebus *et al*., 1994).

2.4.7 Compost quality

Compost has been widely used for decades in organic farming, but issues concerning composition and quality have only recently emerged largely by external pressure. According to Brinton (2000), there has been a steady progression of definitions of contaminant limits when considering compost

quality. The very first compost quality limits published pertained to heavy metals seen in the late 70's in Europe. In the mid to late 80's contaminants generally entered the discussion, followed by compost maturity and plant-growth properties. These standards and pertinent discussion include:

1. heavy metal allowable levels
2. physical composition and inert contamination
3. pathogenic bacteriology and phytopathogens
4. PTE's (Potentially Toxic Elements)
5. maturity and plant growth performance.

Thus, the quality of a specific type of compost is therefore a function of its chemical, biological, and physical characteristics which are determined by the composition and characteristics of the input material (feedstock) used in the production of the compost and the type and thoroughness of the process used to remove impurities (Waste Balkan Network, 2011). For example, USA which has championed the concept of pathogen reduction as a number one quality standard defines two types/classes of biosolids (sludges) which can be used for composting (USEPA , 1993). The types are classes A and B and the difference is defined by the degree of pathogen reduction in solids. Classes A biosolids (sludges) contain pathogens well below detectable levels and Classes B biosolids (sludges) contain pathogen levels that do not pose threat to public health and the environment.

The period of time biosolids are composted at a specific temperature is also important in determining the eventual outcome and use of the compost end product. The 40 CFR Part 503 (USEPA, 1993) defines the time and temperature requirements for both classes A and B products (Table 2.3).

Table 2.3: Time and temperature requirements for biosolids composting in the USA.

Product	Regulatory requirements
Class A	Aerated static pile or in-vessel: 55°C for at least 3 days Windrow: 55°C for at least 15 days with 5 turns
Class B	About 40°C or higher for 5 days during which temperature exceed 55°C for at least 4 hour

Source: USEPA, 2002; USEPA, 1993

2.5 Compost application and utilisation

Due to its beneficial characteristics, compost has a variety of potential applications and can be used by several market segments. Some of the markets include (Waste Balkan Network, 2011):

- agriculture (small- and large-scale);
- landscaping;
- gardening (residential, community);
- nurseries;
- top dressing (e.g., golf courses, parks, median strips);
- land reclamation or rehabilitation (landfills, surface mines, and others);
- erosion control

The markets or uses listed above are controlled by: (1) the characteristics of the compost, (2) the limitations applicable to its use, and (3) pertinent laws and regulations (Alexander, 2000; Harrison *et al*., 2003).

2.5.1 Compost use in container crop production: Vegetable and horticultural crop production

Recently, production of large quantities of composts has made possible using compost commercially in vegetable crop production systems (Roe *et al.*, 1997). Compost effects on crop production can vary according to the feedstock, compost production methods, storage, and use rates and methods (Wong and Chu, 1985; Vega-Sanchez *et al*., 1987; Diaz-Ravina *et al*., 1989; Roe and Kostewicz, 1992). Compost as a growing media in vegetable transplant production has been used with encouraging results as a partial amendment or complete replacement for traditional growing media. Growing media amended with composted sewage sludge have shown to be effective for growing bedding plants and vegetable transplants (Chaney *et al.*, 1980; Chaney, 1982; Chaney *et al*., 1982; Gouia, 1982; Sterrett *et al*., 1983; Falahi-Ardakani *et al*, 1987a and Falahi-Ardakani *et al*, 1987b). However, elevated levels of trace elements and heavy metals in plant tissues are of major concern when plants are grown in media containing composted sewage sludge (Falahi-Ardakani *et al.*, 1988). Many other studies have reported that organic wastes composts, such as from municipal solid waste (Ostos *et al.*, 2008), animal manure (Atiyeh *et al.*, 2001; Eklind *et al.*, 2001), green waste (Grigatti *et al.*, 2007; Ribeiro *et al.*, 2007) and agro-industrial waste (Baran *et al.*, 2001; Garcia-Gomez *et al.*, 2002; Papafotiou *et al.*, 2004; Bustamante *et al.*, 2008) can be used with very good results as growth media instead of peat.

Composts effects on container crops

Container crops or containerized plants are organic plants that are grown in small containers in a greenhouse. When organic plants are grown in small containers

there are many requirements to the structure, stability and nutrient content of the growing medium. Peat is approved as an organic substrate but increased concern has risen due to the exploitation of these slowly renewable natural resources (Dresboll, 2004). Thus, alternatives to peat are desirable in organic greenhouse Production. One such alternative is composts. When compost is used as a growing medium in organic greenhouse production a number of requirements should be fulfilled. First, the compost structure must be suitable for plant growth. Water retention, air filled porosity and volume weights are important parameters in a growing medium (Gruda and Schnitzler, 2004) and are dependent on particle size and geometry.

Several investigators (Sanderson, 1980; Rosen *et al*., 1993; Fitzpatrick, 2001 and Sterrett, 2001) have reviewed the uses of composts in container production systems. There is no single recommended amount of compost to use in growing media that applies to all situations. The amount of the compost component in a growing medium depends on the type of compost, the plant species to be grown and grower cultural practices. Yard debris composts were shown to increase vinca (Hartz and Giannini, 1998), chrysanthemum and fuchsia growth as compost percentages in the media increased (Hummel *et al.*, 2001). Spiers and Fietje (2000) suggested that composted leaves and woody materials could be a component of high quality growing media, but should only be used up to 30% of the volume to avoid phytotoxicity due to high soluble salts. Beeson Jr. (1996) found azalea plants grew larger than control plants in a pine, peat and sand mix when 40% composted yard debris replaced peat in the potting media. Biosolids were an effective peat substitute for marigolds when co-composted with sawdust (Freeman and Cawthon, 1999) and increased growth of *Photinia* and *Thuja* was

observed when biosolids compost as a medium component was increased from 25 to 50% (Ticknor *et al.,* 1985). Different plant species may show more consistent performance in biosolids compost than comparable composts made from other waste streams (Bugbee, 2002). A variety of annuals, perennials, and woody ornamental plants performed best in 50% and 100% biosolid compost (Bugbee, 2002).

The greenhouse industry applies more fertilizer per unit area than other agricultural systems (Moliter, 1990). However, fertilizer applications can be reduced when composts with high nutrient concentrations are substituted for peat. Even when fertilizer is added to media containing composts, plant growth increases are usually not as dramatic as the growth increase seen when fertilizer is added to conventional media (Bugbee *et al*., 1991). According to Jespersen and Willumsen (1993), compost is suitable to replace peat up to 20-40% by volume and to replace most of the fertilizer used in commercial peat growing mixes.

2.5.2 Compost tea

Compost tea is a liquid extract made by steeping compost in water using a variety of preparation methods (Scheuerell, 2002; Ingham, 2005). Other terms used interchangeably to describe compost tea are: “Watery Fermented Compost Extracts”, “Compost steepage”, “Organic Tea” and “Compost leachate” (Scheuerell, 2002). However, according to Diver (2002), these terms can be distinguished from compost tea based on the method of production and the way they are used.

Types of compost teas

There are two types of compost teas based on their methods of production. Thus the two methods described by Dearborn (2011) are as follows:

Non-Aerated Compost Tea (NCT): This is the traditional method and it involves a "passive" brewing process where no oxygen input is required. This method produces Non-aerated Compost Tea (NCT). The NCT relies on the use of stable compost without sugar additives, under low oxygen with occasional stirring of the extract. The term anaerobic (no oxygen) has been used to refer to NCT in some recent literature. However, since the process occurs in an open fermentation vessel, the term anaerobic- does not accurately define this brewing method. Average NCT brewing period is 14 days.

Aerated Compost Tea (ACT): This is a more recent approach adopted by compost tea brewers involving an "active" process which relies on the use of an aerator to oxygenate the mixture during the fermentation process, thereby producing ACT in a shorter brewing time ranging from 12 hours to 3-days. Often, nutrient additives and fermentation products rich in microorganisms are added during the brewing process to increase the beneficial microbes' concentration in the brew.

Compost tea quality

According to Scheuerell and Mahaffee (2006), there are little data in scientific literature that directly compare compost tea production processes. However, available data suggests that both aerated and non-aerated compost tea can be inconsistent from batch to batch (Dearborn, 2011). The inconsistency has been associated with to a number of factors that affect the production process (Ingham,

2005; Scheuerell and Mahaffee, 2006; Hsiang and Tian, 2007; Ingram and Miller, 2007). These factors include:

- compost Grade
- compost to water ratio
- brewing time
- fermentation nutrients
- microbial Supplements
- aeration
- filtration and dilution before application

The factors are discussed as follows:

Compost Grade

The feedstock that make up mature compost include animal manure, landscape and agricultural plant material, biosolids and food waste. Each has characteristics that influence the quality of the mature compost (Scheuerell, 2002) which could in turn impact the efficacy of compost tea made from the compost (Scheuerell and Mahaffee, 2002). Some research suggests composition of microorganisms in compost depends on the feedstock. For example, carbon rich feedstock (e.g. dry leaves, sawdust, wood chips, shredded newspaper), produce a compost with a higher fungal content while nitrogen rich feedstock (hay weeds, coffee grounds, herbaceous material and manures) produce compost with higher bacterial content (Scheuerell and Mahaffee, 2006). Similarly, vermicompost is used as an ingredient in many compost tea recipes. This compost is typically the highest in available nutrients.

Therefore selection of compost regardless of the production method depends on its intended use. Mature Compost should be stable and free of pathogens. Due to the potential for transferring detrimental effects, compost for compost tea should be certified free of human pathogens and residual herbicides (Scheuerell and Mahaffee, 2002). Research at Wood Ends Laboratory indicated that many immature types of compost are available on the market, with little or no quality testing behind them (Brinton *et al.,* 2004). The immature compost is less stable and may harbour pathogens. In California, commercial composters are required to meet specific regulatory requirements on the compost process itself that protect health and safety. The most important indicators of compost stability are the temperature cycles in composting process and the carbon to nitrogen content (C: N). The C: N ratio decreases as compost becomes more mature or stable.

Compost to water ratio

The ratio of compost to water (volume: volume) in published studies starts at 1:1 (Zhang *et al.,* 1998) and reaches 1: 50 (Weltzien, 1990). However the ratios tend to vary for each production method. For NCT, the majority of studies use a 1:3-1:10 ratios (Scheuerell and Mahaffee, 2002) which also coincide with the methodology developed by the Weltzien's laboratory. For ACT, the ratio depends on type of equipment and is usually suggested by the compost tea equipment suppliers. Potable water that is free of chlorine or chloramines is recommended for making compost tea or any dilution thereof regardless of the production method. Chlorine or chloramines are added to potable water as a sanitizing agent(s); when present in the water, these chemicals can inhibit growth and propagation of microorganisms during the brewing process.

Weltzien (1990) reviewed a number of host-pathogen systems that had significant foliar suppression with NCT, no difference in suppression was observed for fermentation ratios between 1:3 and 1:10. However, the suppression of *Phytophthora infectans*, increasing the fermentation ratio to 1:50 resulted in loss of activity (Weltzien, 1990). In general, diluting the final spray would likely have a different effect than diluting the initial fermentation ratio because the initial ratio can influence the rate of oxygen depletion during fermentation (Cronin *et al.*, 1996). It is still unclear how the compost to water ratio of NCT impacts disease suppression, but limiting the ratio to 1:10 is apparently effective (Scheuerell and Mahaffee, 2002).

Brewing Time

Several studies on disease suppression properties of NCT have indicated that NCT brewing time of 8-16 days is optimal fermentation time for any level of disease control (Scheuerell, 2002). It has been proposed that the longer brewing period promotes greater amount of nutrients to be extracted from the compost and enables accumulation of antibiotics that activate natural plant defence responses and help in disease suppression. A significant advantage reported by the manufacturers and the users of ACT is the short brewing time of 18 hrs to 3 days which makes the tea readily available. It has been proposed that that optimal brew time of 18-24 hours coincides with maximum activity of microbial population in the tea (Ingham, 2005).

Fermentation nutrients

Optional nutrients can be added at the beginning or during fermentation resulting in an unknown selective enrichment of the fermenting community (Bess, 2000).

Nutrients such as kelp, fish hydrolysate, molasses and humic acid are added as catalysts or microbial starter (Scheuerell and Mahaffee, 2002 and Naidu *et al.*, 2010) during the brewing process. For both ACT and NCT, fermentation nutrients have the ability to inhibit or increase growth rates for different types of organisms (Scheuerell and Mahaffee, 2004). However, nutrients should be added with extreme caution (Scheuerell and Mahaffee, 2004, Ingham, 2005). Recent studies show that compost tea supplemented with molasses or other simple sugars, tends to promote growth of human pathogens such as Salmonella and E. coli, when residual levels of these organisms are present in the compost source (Ingram and Miller, 2007).

Microbial supplements

It is well established that compost contains a diverse group of organisms dominated by bacteria and fungi participating in decomposition of organic matter (Droffner *et al.*, 1995; Brinton, 2000). Bacteria can grow and multiply in both oxygen rich (Aerobic) and low or no oxygen (Anaerobic) environments. Bacteria from genera such as *Enterobacteria, Serratia, Nitrobacter, Pseudomonads, Bacillus, Staphylococcus* and various *Actinomycetes* as well as fungi such as *Trichoderma spp.* have been isolated from mature composts (Droffner *et al.*, 1995). Subsets of these species known as "facultative anaerobes" thrive in low oxygen environment but are able to grow under aerobic conditions. It is proposed that presence of facultative anaerobes in mature compost is likely associated with disease suppressive traits. Studies have shown various fungal root rot diseases have been suppressed by incorporating compost into soil or soil-less growing media (Hoitink *et al.*, 1993).

Similarly, the microbial populations of NCT (Weltzien, 1991) and ACT (Ingham, 2005) have been described as being dominated by bacteria. It is stated that with ACT aerobic bacteria predominate (Ingham, 2005), while with NCT the population of bacteria is mainly facultative anaerobes (Weltzien, 1991, Scheuerell and Mahaffee, 2004). There is considerable interest among growers, producers and scientific community in manipulating the brewing processes to obtain optimum composition of beneficial microbes that include both aerobic and facultative anaerobic groups. To date, populations of organisms have been variable with both NCT and ACT making any comparison of available scientific experimental results difficult (Scheuerell and Mahaffee, 2004). In addition, lack of a uniform standard method for reporting the compost tea microbiology adds to complexity of the brewing process. Commercial suppliers advertize pre-packaged microbial inoculums that can be brewed on their own, added to the compost source or to ACT following the brewing process. One of the popular microbial inoculums is "Effective Microorganisms" EM•1® developed by Dr. Teru Higa in Japan. EM•1® is a cocktail comprised of large population of facultative bacteria, yeast, enzymes, trace minerals, vitamins and organic acids.

Many of the claims made for compost tea such as plant promoting growth, and disease suppressive traits are also made for EM•1®. The groups of organisms present in the EM•1® include lactic acid bacteria, phototrophic or photosynthetic bacteria and yeast, with the diversity of species within each organism group. Material safety data sheet provided by suppliers does not identify exact species or supplements included in the cocktail. There is considerable evidence in microbiology books on benefits of lactic acid bacteria and yeast in fermentation and decomposition processes. Photosynthetic bacteria can assist in converting

energy into food sources for plants. However, claims supporting the roles of these beneficial microbes in plant disease suppression remain elusive. Equally unknown is the effectiveness of balance of species in compost tea amended with EM•1®. Other microbial formulations include Fungi in the genus *Trichoderma* that have been known since at least the 1920s for their ability to act as biocontrol agents (a term coined for beneficial organisms with ability to suppress pathogens) with successful results in maize (Harman, 2006). *Trichoderma* species grow naturally around the plant roots and feed or parasitize on pathogenic fungi. However, if pathogenic fungi are not present in the soil, addition of *Trichoderma* can have little or no benefits as they will die-off without feeding on pathogens (Ingham, 2005). Increasing the microbial diversity without understanding the role of each species in the context of the plant's natural environment can be risky, but is a power concept that needs to be explored further under controlled scientific experiments in the field.

Aeration

Oxygen is required by all aerobic organisms. A large problem in making highly beneficial teas is when microbial growth rapidly uses up a significant portion of the oxygen such that anaerobic conditions ensue, and materials that are toxic to plant growth are produced in the tea (Ingham, 2005). It has been suggested that aeration or oxygenation during ACT brewing process encourages growth and propagation of diverse group of good microbes extracted from the compost (Ingham, 2005), while limited or lack of oxygen during NCT brewing process may support growth of human and plant pathogens (Ingham, 2005; Scheuerell and Mahaffee, 2004, Brinton *et al.*, 2004). However, there are no available scientific data that support the popular claim that only low oxygen conditions are

ideal for most pathogens to grow or only aerobic condition encourages growth of beneficial microbes (Scheuerell, 2002).

Early studies with non-aerated compost teas (NCTs) indicated that brewing conditions that favour a brief period of low oxygen may in fact increase diversity of active microorganisms and disease suppressive properties of NCT (Scheuerell and Mahaffee, 2004) while sterilization of NCT eliminates the microbial population and disease suppression observed in the laboratory studies (Scheuerell, 2002). In a more recent study, NCT and ACT brewing techniques were compared with or without aeration, and in presence or absence of nutrient additive for suppression of fungus *Pythium* damping off of cucumber seedling. The study showed that no significant correlation could be drawn between the microbial population in the compost tea brewed under continuous aeration, and disease suppression. However, addition of nutrients to ACT during the brewing process showed the most consistent suppression of *Pythium* damping off, suggesting nutrient and not necessarily aeration support the microbial activity in ACT (Scheuerell and Mahaffee, 2006).

Aeration during compost tea production process produces less foul odours than the non-aerated production process. For NCT, foul odour has been reported only under conditions where nutrient additives were added during the fermentation process (Scheuerell and Mahaffee, 2002; Scheuerell and Mahaffee, 2006). It remains unclear whether it is necessary to aerate during compost tea production. It should be noted that aerated compost tea or oxygenated tea in practice becomes non-aerated if not used immediately. The producers and users of ACT must take into consideration the added cost of the brewing process.

Filtration and dilution before application

Filtration and dilution are often necessary when the tea is applied through irrigation system or sprayers to avoid clogging the nozzle. For both NCT and ACT, filtration may remove suspended particles in the compost tea that contain beneficial microbes (Scheuerell, 2002). Similarly, dilution of the tea prior to foliar application may reduce the nutrients and microbial population.

For soil application, it has been recommended to use a volume sufficient to reach the root area (Brinton and Droffner, 1995, Scheuerell, 2002, Ingham, 2005). Soil application is thought to protect the roots from potential colonization of root pathogens and promote healthier plants. For foliar application, compost tea is diluted 1:4 or 1:6 with water prior to application. It has been proposed that maximum coverage of leaf surface area may be necessary for the beneficial microbes in the tea to outcompete colonization by plant pathogens, however, frequent and repeated applications are needed to maintain the surface coverage (Ingham, 2005).

2.5.3 Compost tea application

There are two different, but not mutually exclusive, ways of applying compost tea: as a soil drench or as a foliar spray.

***Foliar applications**:*

a. Apply beneficial organisms to plant aboveground surfaces, so disease-causing organisms cannot find infection sites or food resources (i.e., pro-biotic approach).
b. Provide nutrients as a foliar feed.

***Soil applications**:*

a) Help develop the biological barrier around roots (i.e., pro-biotic approach),
b) Provide nutrients for roots to improve plant growth,
c) Improve life in the soil in general, with effects on soil structure, water holding, root depth,
d) Improve nutrient cycling, nutrient retention and disease-suppressiveness.

2.5.4 Benefits of compost tea usage/application

Plant disease suppression

Biological interactions that result in disease suppression of plant and soil borne pathogens are complex because diseases caused by pathogens occur in a dynamic environment. These interactions are thought to occur through the following mechanisms, which are not necessarily mutually exclusive.

- Antibiosis: Some beneficial organisms can produce antibiotics or other substances that are toxic to the pathogenic organisms. For example, bacteria *Pseudomonas* fluorescens strain CHAO produces hydrogen cyanide, 2, 4-diacetylphloroglucinol, and pyoluteorin, which directly interfere with growth of various pathogens. Other bacteria including *Bacillus, Serrantia and fungi such as Thrichoderma* and *Gliocladium* can produce antimicrobial compounds effective against plant root pathogens (Handelsman and Stabb, 1996; Haas and Defago, 2005; Weltzien, 1991).

- Competition- when beneficial microorganisms are present in a growing medium they tend to out compete pathogenic bacteria or fungi for food source (Hoitink *et al.*, 1993).
- Induced Resistance: Some Beneficial microbes colonizing on plant roots or foliage are documented to confer resistance to plant by turning on genes that increase plant tolerance to infection by pathogens (Haas and Defago, 2005).
- Parasitism: Certain beneficial microbes can feed on specific pathogens. For example, Trichoderma species are shown in various studies to secrete enzymes that digest the cell wall of some fungal root pathogens (Handelsman and Stabb, 1996).

The available literature suggests these mechanisms may be involved in compost or NCT-mediated suppression, but the mechanisms of suppression are not yet determined with ACT.

Improve soil structure and plant vitality

Compost comprises a large and diverse community of microbes, humic acids and other chemical nutrients such as carbon and nitrogen that support soil and healthy plant growth. Although not a fertilizer (compost feed the soil, fertilizers feed the plant), good quality compost as an organic rich soil amendment can improve soil porosity, density and improve nutrient uptake by the plant. Reviews of literature suggest compost tea may retain to varying degrees some of the same beneficial attributes of compost. Primary interest in application of compost tea versus compost is due to the fact that composts act more slowly over a long period of time and much larger amount is required. On golf greens organic matter is

undesirable, and composts are typically not recommended. Part of the reason is that they encourage earthworms.

Compost tea can be prepared in a shorter period of time and can be applied directly onto plant surface. However, effects of compost tea are short lived and frequent and repeat applications are required to replenish plant or soil surface with nutrient and/or beneficial microbes (Brinton and Droffner, 1995; Scheuerell, 2002; Ingham, 2005).

2.5.5 Potential problems associated with compost tea

Contamination with human pathogens

Yohalem *et al.* (1994) raised the concern that fermenting compost could potentially support the growth of enteric pathogens, evidenced by the Enterobacteriaceae CFU from NCT reported by Urban and Trankner (1993). Welke (1999) tracked faecal coliform and *Salmonella* populations from the source compost, through NCT fermentation, to samples of broccoli and leek sprayed and grown under field conditions. The data suggests that human pathogens can be transferred from naturally contaminated compost to food surfaces with NCT. Additional evidence indicating a variety of enteric pathogens can increase during ACT and NCT production, if fermentation nutrients are used in conjunction with compost that has been inoculated with pathogens. Pathogens growth does not appear to be supported when ACT or NCT is made without fermentation nutrients (Scheuerell and Mahaffe, 2002) similar results have been observed with ACT made from compost that naturally contained a low level of *E coli* (Bess *et al.,* 2002). Their results suggest that naturally occurring *E. coli* can

be reduced or eliminated by avoiding the addition of sugars during ACT production.

Contamination with Plant Pathogens

Reviews published by authors, suggest that temperature during the active phase of the composting process (although not the only determinant factor), is an important factor in elimination of most plant pathogens. For twenty seven (27) out of thirty two (32) pathogenic fungi, seven (7) bacterial pathogens and nine (9) nematodes, and three (3) out of nine (9) plant viruses, a peak temperature of 64 – 70°C and a duration of 21 days were sufficient to reduce numbers to below, or close to the detection limits of the tests used. Therefore, it is essential that the source compost is of good quality and meets the NOSP guidelines to avoid recurrent growth of all pathogens.

2.6 Compost (organic fertilizer) versus chemical (inorganic) fertilizer

The idea that compost is significantly different from inorganic fertilizers is not new; however, until recently the unique properties of compost were overlooked (Brinton, 2000). Under this heading, the unique properties of composts are discussed and compared with the conventional inorganic chemical fertilizers. Table 2.4 shows a comparison between composts and inorganic chemical fertilizer.

Table 2.4: Comparison between composts and inorganic chemical fertilizer.

	Composts	Inorganic chemical fertilizer
Source and preparation	Produced or prepared from organic materials (wastes, by-products etc) under controlled natural conditions.	Artificially Produced from synthetic materials
Cost	Cheap	Costly
Nutrients	Have unequal distribution of essential nutrients: nitrogen, phosphorus and potassium.	Have equal distribution of essential nutrients; nitrogen, phosphorus and potassium
Rate of nutrient release	Slow release	Immediate release after application.
Organic matter	Adds organic matter to soil which improves soil structure, improves water holding capacity and reduces erosion.	Absent in chemical fertilizers.

Source:http://www.diffen.com/difference/Chemical_Fertilizer_vs_Organic_Fertilizer

2.7 Environmental impacts of composting and compost application to land

The impacts of composting and compost application to land can either be beneficial or detrimental to the environment. The beneficial impacts of composting for which it has grown in popularity are:

a. reduction in the amount of biodegradable waste going to landfills.

b. recycling of valuable resources.

c. ease of storage, handling, and use of composted product.

d. emphasize on beneficial reuse at state, and local levels.

On the negative side, composting may include the following disadvantages: (Epstein and Parr, 1977; USEPA, 2000)

a. odour production at the composting site.

b. survival and presence of primary pathogens in the product.

c. dispersion of secondary pathogens such as *Aspergillus fumigatus*, particulate matter, other airborne allergens.

d. lack of consistency in product quality with reference to metals, stability, and maturity.

Application of compost to land as soil conditioner results in the following environmental benefits (Epstein and Parr, 1977; Iglesias *et al*., 1989; USEPA, 2000):

a. the recycling of a valuable resource.

b. reduction of dependence on chemical fertilizers.

c. offsetting the use of natural resources such as trees or peat moss as mulch material.

d. provides organic nitrogen, phosphorus, and potassium.

e. provides essential plant micronutrients.

f. can reduce the need for pesticides.

g. increases water holding of soils.

h. increased aeration and drainage for clay soils.

i. increased permeability for clay soils.

j. greater root depth.

k. increased microbial population.

l. decreased surface crusting of soils.

The negative impacts associated with the application of composts to land especially to agricultural lands are:

a. soil pollution due to introduction of pollutants (Heavy metals, organic pollutants and pathogens).

b. water and air pollution.

c. human exposure to sludge borne pollutants.

d. degradation of agronomic value of agricultural lands (due to excessive accumulation of sludge borne pollutants).

2.8 Urban and peri-urban agriculture

Urban and peri-urban agriculture can be broadly defined as the production, processing and distribution of foodstuff from crop and animal production, fish, ornamentals and flowers within and around urban areas (Mougeot, 2000). Often, the terms "urban agriculture" and "peri-urban agriculture" are used synonymously. But Oboubie *et al.* (2006) defines or refers to "urban" as the administrative city boundary while "peri-urban" is used for lands outside the immediate perimeter of the city but within a radius of up to 40-km of the city center.

Urban agriculture is practiced by 800 million people worldwide and 200 million are considered to be market producers (UNDP, 1996). It helps low-income urban residents save money on food purchases. Urban and peri-urban agriculture can make an important contribution to household food security, especially in times of

crisis of food shortages (http://www.fao.org/urban-agriculture/en/). Produce is either consumed by the producers, or old in urban markets, such as the increasingly popular weekend farmers' market found in many cities. Vegetables have a short production cycle; some can be harvested within 60 days of planting, so are well suited for urban farming. Garden plots can be up to 15 times more productive than rural holdings. An area of just one square metre can provide 20 kg of food a year. However, in many countries, urban agriculture is still informal and sometimes illegal and so it goes unrecognized in agricultural policies and urban planning (http://www.fao.org/urban-agriculture/en/).

In Ghana, urban agriculture/crop farming comprises of two forms: (i) open-space production for the urban market, and (ii) backyard gardens cultivated mostly, but not only, for home consumption (Table 2.5)

Table 2.5: The two major categories of urban and peri-urban crop farming in Ghana.

Farming systems	Urban areas	Peri-urban areas
1. Market production (cultivated on undeveloped land)	Irrigated vegetables (year round or seasonal), flowers and ornamentals; rain-fed cereals	Irrigated vegetables (mostly seasonal), fruits; rain-fed cereals
2. Subsistence production (cultivation at the house)	Backyard or front yard farming	Home gardens; farming around homestead

Source: Drechsel *et al*. (2006a; simplified)

These forms of urban agriculture are found in many parts of Ghana. The major sites are found in the Accra, Kumasi and Tamale.

2.8.1 Major irrigated vegetable farming sites in Accra

In Accra, there are about 800-1000 vegetable farmers of whom 60% produce exotic and 40% indigenous local or traditional vegetables. Some of the modern or exotic crops cultivated are lettuce, cabbage, spring onions, and cauliflower while the more traditional crops are tomatoes, okro, garden eggs (aubergine) and hot pepper. Plot sizes under cultivation in the city range between 0.01-0.02 ha per farmer, and max. 2.0 ha in peri-urban areas. The plot sizes of most of these sites have diminished over time because of land loss to estate development and widening of drains. This has led to reduced land reservations along the drains which used to be cultivated. An additional problem faced by farmers in relation to their farm size is tenure insecurity and low soil fertility (Obuobie *et al.,* 2006).

Some major areas are:

- "**Marine drive**" at the Independence Square: Farming in the area began before 1983 by a religious organization and was aimed at providing employment for the youth and reclaiming the land. The land being cultivated belongs to the department of Parks and Gardens and was originally zoned by AMA as an open space in line with the beautification of the metropolis. However, lack of funds, time and logistics have motivated the Department of Parks and Gardens to enter into informal agreement with farmers and release the land to them to promote ''agro-forestry with inter-cropping''. Though they have no formal farmer's organization, farmers have a spokesman. The site currently has 98 farmers (97 male, 1 female) aged between 18 and 60 years. The potential farming area covers 3.6 ha. Water is provided

through a narrow wastewater drain connecting the inner-urban area called "Ministries" and the ocean (Obuobie *et al.,* 2006).

- "**Dzorwulu/Plant Pool**". The site covers an area of 15 ha. It is divided into two sites by a major road with in total about 60 male farmers and 2 female farmers. One part, "Plant Pool", next to the high-tension area of Volta River Authority (VRA) has 34 farmers, two of whom are women. The other side has 28 male farmers. A mutual agreement has been formalized with VRA for farming in the area as a way of maintaining it and to prevent any non-agricultural encroachment. River Onyasia cuts across the farming sites. The river is channeled in this part of Accra like a drain and has a similar function. Some farmers use pipe-borne water, most however water from the major drain or smaller drains channeled into shallow reservoirs (dug-outs). There are about 77 of such small ponds on this site. Some are also filled with piped water (Obuobie *et al.*, 2006).
- "**La**": This is the oldest and largest irrigated site in Accra with up to 400 vegetable farmers. The majority of them use wastewater from the drains of the nearby (military) "Burma" camp. About 50 farmers use pipe-borne water while five use water from a treatment pond of the only partially functioning treatment plant. It is the only site in Ghana where "treated" wastewater is used and in Accra where furrow irrigation is practiced. La is also unique as there are an equal number of men and women farming. The site has a functional farmers association and measures in total nearly 100 ha, with about 40% under irrigation, otherwise rainfed farming or fallow land (Obuobie *et al.,* 2006).

- "**Korle-bu**": The farming site neighbours the largest hospital in Ghana. Most farmers are junior hospital staff like watchmen, cleaners, etc. who farm to supplement their income. The cultivated land area covers about 10 ha, but is decreasing due to building activities. Several attempts have been made at forming a farmers' association but without success. The site has about 80 farmers (only one female), most of them being migrants from the northern regions of Ghana and Burkina Faso. The land belongs to the hospital and farming is done under an informal arrangement to keep the area clean and prevent non-agricultural encroachment. Water is derived from drains, which pass through the hospital compound and staff flats (Obuobie *et al*., 2006).
- Other sites are, for example in the Airport Residential Area around the CSIR and IWMI offices or close to the Ghana Broadcasting Company (GBC) (Obuobie *et al.*, 2006).

2.8.2 Major irrigated vegetable farming sites in Kumasi

In urban Kumasi, most land where farming is done belongs to government institutions, private developers etc. There are about 41 ha in the urban area under vegetable irrigation while the peri-urban area has more than 12,000 hectare under irrigated vegetable farming mostly during the dry season (Cornish and Lawrence, 2001), twice as much as under formal irrigation in the whole country.

Some well-known sites are:

- "Gyinyase/Engineering": This is the largest urban vegetable-farming site in Kumasi (21.8 ha). It is located next to the local university (KNUST2) in an inland valley. The site has a diversity of crops, and farmers practice in

part organic farming. Shallow wells are used extensively and there is a well-established farmers organization (Obuobie *et al.*, 2006).

- "**Georgia Hotel**": This farming site is located behind Georgia Hotel and covers about 0.4 ha. It has 3 male farmers with their families cultivating spring onions, cabbage, green pepper, garden eggs and red onions. The land belongs to the hotel and the farmers are allowed to cultivate it. This is the only urban site in Ghana where farmers use sprinkler irrigation so far. Farmers use pipe borne water although the pipe connection does not appear to follow official regulations (Obuobie *et al.*, 2006).
- "**D-Line/Weweso**": Covering an area of about 3.1 ha, this site is located beside the Kumasi-Accra road (next to the KNUST police station) and farmers predominantly cultivate spring onions. It has about 30 farmers organized in an association. The water source is a small stream, which receives untreated effluents from a significant number of households (Obuobie *et al.*, 2006).

2.8.3 Main irrigated vegetable farming sites in Tamale

As there is no main stream passing through Tamale and since the groundwater table is low, most farming is done along wastewater drains, near dams with small reservoirs, broken sewers or near dugouts. About 40% of the vegetable farmers are farming all year round. Fifty-two per cent depend on polluted water sources (Zibrilla and Salifu, 2004). Most attempts to explore groundwater in the municipality failed. The average depth of successful wells is about 60 meters.

Examples of some well-known urban farming sites are:

- "**Builpela (Bulpeila)**": this site is about 2 km from the center of Tamale. Farmers use a dam that was built in 1960 to supply water for domestic use, livestock and vegetable cultivation. The area under vegetable cultivation is about 2.6 ha. Other reports mention 6.8 ha (Zibrilla and Salifu, 2004).
- "**Sangani"**: it is located 2 km North-East of Tamale town center. Farmers use a dugout well meant for domestic use. Depending on the source, the area under cultivation varies between 0.5 to 4 ha.
- "**Water Works**": named after a dam originally built to provide water for Tamale Municipality, the reservoir is now heavily polluted. Water flows through it and is used by farmers who have farms next to the stream originating from the dam. Vegetable irrigation at Gumbihene Water Works, Gumbihene New Dam and Gumbihene Old Dam cover in total 13.5 to 22 ha.
- "**Zagyuri**": this site is near Kamina Barracks and farmers use untreated sewage from a broken sewer. The site is 8 km from the city center and covers according to different sources in total about 7-12 ha.

In Tamale, some farmer associations, NGOs, municipal authorities and research institutions form the 'Urban Agriculture Network – Northern Ghana' under facilitation of Action Aid. A main task of the network is advocacy for land security (Amarchey, 2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Organisation of study

The study was conducted in four phases: Phase I was carried out to characterise and quantify faecal sludge in the Sekondi – Takoradi Metropolitan Area. Phases II and III were both carried out at the University of Ghana- Forest and Horticultural Crops Research Centre (FOHCREC) near Kade in the Kwaebibirem District. In phase II, pre-treated (dewatered) faecal sludge was co-composted with empty fruit bunches and cocoa pod husks at different combinations to see which combination emerged the best in terms of pathogen inactivation, nutrient mineralisation and reduced nutrient loss. After the composting process, the best co-compost was evaluated for its suitability as a potting media (substrate) for the production of tomato and pepper transplants in phase III. In phase IV, a questionnaire survey was conducted to ascertain the perception/ knowledge of farmers and consumers on human faecal waste composting and recycling of nutrient in crop production.

3.1.1 Study areas

3.1.1.1 Sekondi – Takoradi Metropolitan Area

Sekondi –Takoradi Metropolitan Area (STMA) is the administrative capital of the Western Region of the Republic of Ghana and covers a land area of 385 km^2 with Sekondi as the administrative headquarters. The Metro is bordered to the West by Ahanta West District, to the North by Mpohor Wassa East, to the East by Komenda-Edina Eguafo-Abrem and to the South by the Gulf of Guinea (Figure

3.1). The Metropolis is strategically located on the south-western coast of Ghana, about 280 km west of Accra and 130 km East of La Cote D'Ivoire (STMA, 2012).

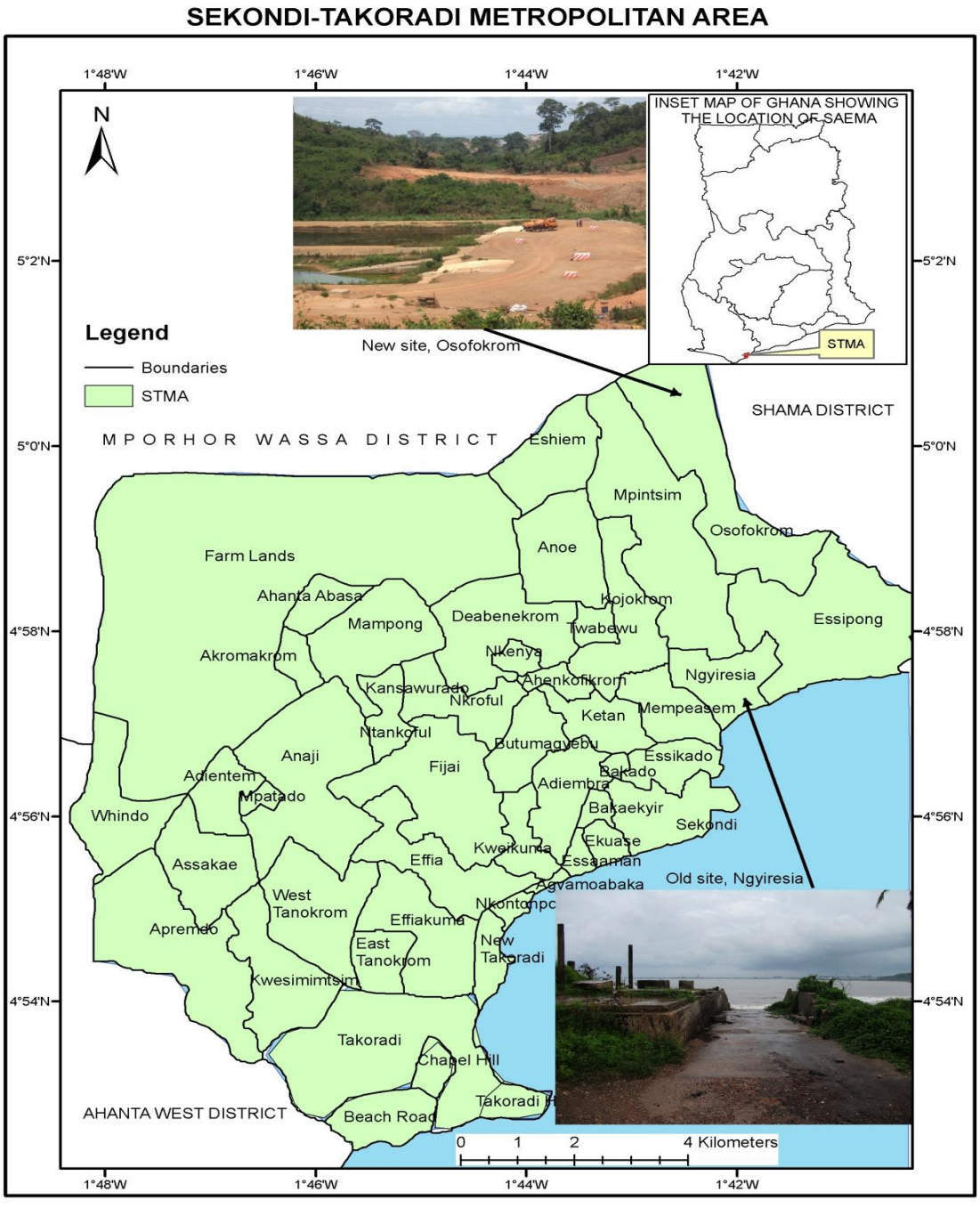

Figure 3.1: Map showing STMA with the different localities and faecal sludge disposal sites (both old and new).

Climate

The climate of the metropolis is equatorial, with an average annual temperature of about 22^0C. It has a mean annual rainfall of 2,350 mm, with a major rainy season in May and June and minor rains occurring between September and November (Kudom *et al.,* 2012).

Geology and drainage

The Sekondi-Takoradi Metropolis is characterized by faulted shales and sandstone resting on a hard basement of granite, gneiss and schist. The two main rivers flowing through the metropolis are the Whin and the Kansawora rivers, while the lagoons are the Essei and the Butre (Kesse, 1985).

Agriculture in the area

The economically active population is about 209,697 (51.9 percent of total population), and agriculture (farming and fishing) is engaged in by about 83,879 people (40% of the economically active population) with about 11% of the "farmers" engaged in fishing. Major crops cultivated in the metropolis are cassava, maize, plantain, cocoyam, yam, sugarcane, oil palm, citrus, sweet potato, vegetables and coconut. (MOFA, 2011)

3.1.1.2 Forest and Horticultural Crops Research Centre (FOHCREC) – *Kwaebibirem District.*

The Forest and Horticultural Crops Research Centre is located at Okumaning near Kade in the Kwaebibirem District (6º 05' N; 0º 05'W), 175 Km from Accra. The Centre is located in the moist semi - deciduous vegetation zone in the Eastern Region of Ghana.

Climate

The climate of the area is humid tropical. The monthly average temperature reaches a maximum of 28-29ºC in February and March, and a minimum of 25-26 ºC in July /August. The rainfall pattern is bimodal with peaks (150-200 mm) in May/ June and September/October. The potential evapotranspiration varies between 3 mm daily in the rainy season and 5 mm in the dry season, and may reach an annual value of 1400 mm. The soil temperature regime is isohyperthermic and the soil moisture regime is udic (Soil Survey Staff, 1998).

Geology and Soil

The soils of the area according to Adu (1992) are generally developed from rocks of the Birrimian system. The well-drained upland soils are generally classified as Acrisols in the World Reference Base for soil resources (IUSS Working Group, 2007) and as Utilsols in Soil Taxonomy (Soil Survey Staff, 1998).

Agriculture in the area

The inhabitants are mainly farmers who cultivate cash crops such as oil palm (*Elaeis guineensis*), citrus (*Citrus spp*), cocoa (*Theobroma cacao*), food crops such as rice (*Oryza sativa*), maize (*Zea mays*), cassava (*Manihot utilissima*) and plantain (*Musa sapietum*). Palm oil processing is the major occupation of significant number of the women (Adamtey, 2005).

3.2 General procedures for laboratory analyses of faecal sludge, plant tissues and composts.

3.2.1 *pH*

The pH of the sludge were measured using a pH meter (Metrohm model 691 pH meter) and procedure stipulated in APHA, AWWA, WEF(1998) was followed. The pH meter was calibrated using pH 4 and pH 7 buffers respectively. Afterwards, the electrode of the meter was dipped into the raw faecal sludge samples individually and their corresponding pH values recorded. The electrode after measuring a sample was rinsed with distilled water and shaken before dipping into another sample.

3.2.2 Electrical Conductivity (EC)

Electrical conductivity of the sludge was determined according to the procedure described by APHA, AWWA, WPCF, (1995) using a Metrohm E587 conductivity meter. The instrument was calibrated with standard KCl (0.01M solution), which has a conductivity of 1413 µS/cm at 25ºC. The electrode of the conductivity meter was dipped into each raw faecal sludge sample and the corresponding conductivity value recorded. The electrode after measuring the conductivity of each sample was rinsed with distilled water and shaken before dipping into the next sample.

3.2.3 Total Solids (TS)

Total solids were determined following methods described in IWMI (2003). An evaporating dish was cleaned and heated in an oven at a temperature of 105 ^{o}C for an hour. It was then removed, cooled to room temperature in a dessicator and

weighed. The weight of the empty dish was recorded. The sample was well shaken and a measured volume of 100 ml was taken and poured into the empty dish. The dish with the sample was transferred into the oven and dried at 105 ^{o}C to a constant weight. The dish was removed from the oven, cooled to room temperature and reweighed.

Calculation of TS:

$$\text{TS (mg/L)} = \frac{(\text{A} - \text{B}) \text{ x } 1000000}{\text{V}} \quad (1)$$

Where; A = Weight of dish + Residue in grams.

B = Weight of empty dish in grams.

V = Volume of sample taken in ml.

3.2.4 *Biochemical Oxygen Demand (BOD)*

The azide modification of the Winkler method (APHA, AWWA, WEF., 1998) was used in the determination of BOD. An aliquot of 10 ml of the sludge was taken and diluted with distilled water to 100 ml into a 250 ml Erlenmeyer flask. Eight (8) drops of Winkler I (Manganous Sulphate solution) was added to the sample in the flask and shaken followed by eight (8) drops of Winker II (Alkali-Iodide solution). The mixture was shaken for about a minute and was allowed to stand in a dark room covered with aluminium foil for at least thirty (30) minutes. Afterwards sixteen drops of concentrated H_2SO_4 was added and at this point, a golden yellow colouration was observed. The sample was then slowly titrated with sodium thiosulphate solution ($Na_2S_2O_3.5H_2O$) until a pale straw colour was reached. A few drops of starch solution were added and the titration process continued whiles swirling the Erlenmeyer flask till end point was reached. The

volume of $Na_2S_2O_3.5H_2O$ solution that was used in the titration was recorded and used to calculate the amount of dissolved oxygen (DO_1) in the sample. The experiment was carried out again in five days to obtain the dissolved oxygen after five days (DO_5).

Calculation of BOD:

$$\text{DO (mg/L)} = \frac{\text{burette reading x N x 8000}}{\text{sample volume (mL)}} \quad (2)$$

Where; N = normality of sodium thiosulphate solution

$$BOD_5 \text{ mg/L} = DO_1 - DO_5 \quad (3)$$

3.2.5 Chemical oxygen demand (COD)

The open reflux method using potassium dichromate and ferrous ammonium sulphate was used (APHA; AWWA; WPCF, 1995). A volume of 10 ml of the sludge was taken into a 250 ml Erlenmeyer flask and 3 ml of potassium dichromate solution ($K_2Cr_2O_7$) added to it followed by 3 ml of conc. H_2SO_4. The mixture was refluxed for five (5) minutes followed by an addition of 10 ml (twice of sludge volume) of distilled water and left to cool for 5 to 10 minutes. The mixture was then titrated with 0.25 M ferrous ammonium sulphate solution $\{(NH_4)_2Fe(SO_4)_2.6H_20)\}$ using ferroins (2-3 drops) as indicator till end point was reached. The volume of $(NH_4)_2Fe(SO_4)_2.6H_20)$ used was recorded.

Note: The same procedure was carried out on a blank sample (distilled water).

Calculation of COD:

$$\text{COD (mg/L)} = \frac{(A - B) \text{ x M x } 8000}{V} \quad (4)$$

Where; A = $(NH_4)_2Fe(SO_4)_2.6H_20$) used for blank.

B = $(NH_4)_2Fe(SO_4)_2.6H_20$) used for sludge.

M = Molarity of $(NH_4)_2Fe(SO_4)_2.6H_20$) used.

V = volume of sludge taken.

$$\text{Molarity of } (NH_4)_2Fe(SO_4)_2.6H_20) = \frac{\text{Vol of 0.0417M K2Cr2O7 x 0.25}}{\text{Vol of (NH4)2Fe(SO4)2.6H20) used in the titrstion}} \quad (5)$$

3.2.6 Total nitrogen (N)

The total nitrogen in the sludge was determined using the modified Kjeldahl method as described by Black (1965). Ten (10) ml of the sample was measured into a 500 ml Kjeldahl flask. In addition, 10 ml of concentrated H_2SO_4 was added and the mixture was heated on a digestion block in the presence of selenium catalyst and salt (Na_2SO_4). The resulting digested mixture was transferred into a 100 ml volumetric flask and topped up to the mark. An aliquot of 5 ml was then distilled with excess NaOH and condensed as ammonium hydroxide (NH_4OH) to liberate ammonia. The liberated ammonium was trapped with 5 ml boric acid in a conical flask and titrated against 0.01M HCl using mixed indicator (bromocresol green and methyl red) until end point was reached. At the end point, the colour changed from green to reddish pink colour. The volume of HCl used in the titration was recorded.

Calculation of total nitrogen:

$$\% \text{ N} = \frac{\text{Titre value x 14 x V x 100 x 0.01}}{\text{w x al x 1000}} \quad (6)$$

Where; V= final volume of the digestion = 100 ml.

w = dry weight of the sample in grams.

al = aliquot of the solution taken for analysis = 5 ml.

14 = Molar weight of nitrogen.

0.01 = molarity of HCl.

3.2.7 Ammonium-N (NH_4^+-N) and Nitrate-N (NO_3^--N)

A volume of 10 ml of the sludge was measured into the distillation flask and about 0.2 g of magnesium oxide (MgO) was added to the sludge in the flask. The distillation flask was then connected to the distillation apparatus and the distillation process was started. The ammonium-N in the sludge was collected with 5 ml boric acid as described above. Ammonium-N content in the distillate was determined by titrating with 0.01M HCl till colour changed from green to light pink signifying end point of the titration.

After the ammonium-N was distilled from the sludge in the above, the stopper at the side arm of the distilling flask was removed and 0.2 g of Devarda's alloy was added. The stopper was then replaced immediately into the neck of the side arm and nitrate-N was distilled into fresh boric acid in a conical flask. The NO_3^- is converted to NH_4^+ and trapped in the conical flask. This ammonium was then estimated by titrating with 0.01M HCl as described above.

Calculation of NH_4^+-N and NO_3^--N,

$$\mathrm{NH4-N} = \frac{0.01 \text{ x titre value x } 18 \text{ x V x } 1000000}{\text{al x w x } 1000} \quad (7)$$

$$\mathrm{NO3-N} = \frac{0.01 \text{ x titre value x } 18 \text{ x V x } 1000000}{\text{al x w x } 1000} \quad (8)$$

Where; V = volume of sample prepared = 40 ml.

al = aliquot of sludge taken = 10ml.

w = dry weight of the sample in grams.

3.2.8 Total Potassium (K)

Ten (10) ml of the sludge sample was measured into a 500 ml digestion flask and 10 ml of Ternary Solution was added to it. The mixture was heated on the digestion block till a yellow colouration was obtained. After it had cooled, it was transferred into a 100 ml Erlenmeyer round bottom flask and topped up to the mark with distilled water. The concentration of total potassium in the sludge was read by aspirating into Jenway flame photometer (PFP7) that was calibrated with 1000 ppm of standard solution.

Calculation of total potassium (K):

$$\%K = \frac{\text{flame photometer reading x V x 100}}{1000 \text{ x } 1000 \text{ x w}} \quad (9)$$

Where; V = final volume of digestion = 100ml.

w = dry weight of sample.

3.2.9 Total phosphorus (P)

Ten (10) ml of the sludge was measured, digested and made up to the 100 ml mark in an Erlenmeyer. Afterwards, 1 ml of the sample was taken into a 50 ml conical flask and 2 drops each of *p*-nitrophenol and ammonia were added followed by 5 ml of ascorbic acid. The colour of the mixture changed to blue and was made up to the mark with distilled water. The total phosphorus concentration was read using PHILIPS PU 8620 UV/VIS/NIR spectrophotometer. The

wavelength dial was rotated until the display showed 712 nm. The spectrophotometer was calibrated with a known standard of 25 ppm before samples were read. The sample was well shaken and a 1 ml portion of it was poured into the cuvette and read.

Calculation of total phosphorus (P):

$$\% P = \frac{\text{spectrophotometer reading x V x 100}}{\text{w x al x 1000000}} \quad (10)$$

Where; V = final volume of digestion = 100 ml.

al = aliquot of sample taken.

w = dry weight of sample taken.

3.2.10 E. coli and faecal coliform determination.

Escherichia coli and faecal coliforms in faecal sludge (FS) and co-compost samples were determined by the Direct Figure Count Method. Ten (10) gram dry weight of dried FS and co-compost were weighed into sterile 90 ml (10^{-1}) phosphate buffered saline (PBS) solution and homogenized. However, for fresh FS, because of its high moisture content, 10 ml sample was used instead. Tenfold serial dilution was performed by transferring 1 ml of the well-mixed sample in 10^{-1} into sterile test tubes numbered 1-9 containing 9 ml (PBS) solution. After the serial dilution, 1 ml aliquot from each of the dilutions were spread on Chromocult agar (Merck KGaA, 64271 Darmstadt, Germany) in petri dishes and incubated at 45˚C for 24 to 48 hours. Growth of the colonies were counted and expressed as CFU/ml.

3.2.11 Helminth eggs determination.

Helminth eggs were determined by the Schwartzbrod and Gaspard (1998) method (modified US-EPA Method). Ten (10) grams (dry weight) of the sample was taken and homogenized using a blender. The sample was then transferred into a container and 2 L of water was added and left to settle overnight. The supernatant was sucked up using a siphon and the sediments transferred into 15 ml centrifuge tubes. The container was rinsed 3 times using distilled water and added to the tubes. The sediments were then centrifuged at 1450 rpm for 3 minutes and regrouped. After regrouping, the samples were centrifuged again and the supernatant was poured off and zinc sulphate solution ($ZnSO_4$) was then added to the residue in the tube and centrifuged again at 1450 rpm for 3 minutes. The supernatant was poured into a 1 L container and topped up to the mark with distilled water. The container was left to stand overnight. Much of the supernatant was sucked up as much as possible and the residue were resuspended by shaking. The sediments were transferred into 15 ml centrifuge tubes and centrifuged at 1600 rpm for 3 minutes. The supernatant was poured off and the residue resuspended with acid/alcohol (5.16 ml H_2SO_4 + 350 ml C_2H_5OH making it up to 1 L) solution and ethyl acetate. The mixture was shaken and occasionally opened to let out gas. It was then centrifuged at 2200 rpm for 3 minutes. At this stage three layers were clearly visible and each layer was carefully taken out step by step till about 1 ml of the liquid is left in the tube. The 1 ml liquid (sediment) was poured unto a slide and observed under a light microscope. The eggs were identified based on the shapes and sizes depicted in WHO's Integrated Guide to Sanitary Parasitology (2004).

3.2.12 Organic carbon

Organic carbon was determined by principles and procedures described by Walkley and Black (1934). A 0.5 g representative sample of compost was weighed in a 250 Erlenmeyer flask. Ten (10) ml of dichromate solution followed by 20 ml of conc. H_2SO_4 was added to the sample. The flask was swirled to make sure the solution was in contact with all the particles of the compost and allowed to stand on an asbestos sheet for 30 minutes. Two hundred (200) ml of distilled water was added followed by 10 ml of orthophosphoric acid and finally 2 ml of barium diphenylamine sulphonate indicator. The mixture was then titrated with ferrous ammonium sulphate solution until the colour changed to blue then to a green end-point.

Calculations:

$$\% \text{ Carbon} = \frac{\{10.0 - (XN)\} \text{ x } 0.3 \text{ x } 1.33}{W} \qquad (11)$$

Where;

X = ml of ferrous ammonium sulphate required for titration

N = molarity of ferrous ammonium sulphate solution

W = weight of sample taken

10 = ml of dichromate solution used.

1.33 = correction factor

Calculation of percent Organic matter;

Multiply the percentage C by the factor 1.724 to convert to organic matter.

3.2.13 Bulk density

The bulk density of soil/compost is the mass per unit volume expressed as gcm^{-3}. The procedure described by Okalebo *et al.* (2002) was followed. A 5 cm diameter tin of known weight (W1) and volume (V) was filled with the compost sample. The tin was dropped about 10 cm above ground several times to ensure that the compost particles filled every available space or volume of the tin. The tin with the sample was weighed again (W2).

Calculations:

$$\text{Bulk density (g/cm3)} = \frac{(W2 - W1)}{V} \quad (12)$$

3.2.14 Water holding capacity (WHC)

Water holding capacity of compost, carbonated rice husks (CRH) and compost-CRH mixes were determined by procedures described in Vengadaramana and Jashothan (2012). A number of small holes were punctured at the base of a tin box. The box was filled with 100 g of air dried and sieved compost/CRH/compost-CRH mixed sample. Water was added to the individual samples to attain saturation. The tin was kept in a slanting position and hanged to a stand with the help of a string. Extra water came out of the perforation at the base. When water drops had stop coming out, the individual samples were removed and weighed immediately. Afterwards, the samples were kept in a hot air oven and dried at 105˚C for 48 hours. The samples were cooled in a dessicator and weighed again.

Calculations:

$$\text{Water holding capacity (per gram of compost)} = \frac{W2 - W3}{W1} \quad (13)$$

Where;

W1 = initial weight of compost (100 g)

W2 = weight of compost after water drained of

W3 = weight of compost after kept in oven at 105 ˚C for 48 h

3.2.15 Microbial respiration rates

Microbial respiration in compost is used as an indicator to determine compost maturity. The principle and procedure given by Black (1965) was used. A 1M NaOH solution poured into a beaker alongside with compost in another beaker. The compost together with the NaOH were then placed in a bigger glass bottle and covered. As carbon dioxide evolves from the compost, it was trapped in the glass bottle and was confined until it was absorbed by the alkali solution. After 24hrs, the alkali solution was removed and the unreacted portion was determined by titrating against 1M HCl. By means of subtraction, the amount of CO_2 that combined with the alkali was determined as shown below.

$$\text{Milligram of CO2 evolved per day} = \frac{(B-V)\ NE}{\text{Weight of sample}} \qquad (14)$$

Where; B= volume (millilitres) of acid needed to titrate the NaOH in the blank jar to the end point.

V= volume (millilitres) of acid that was needed to titrate the NaOH in the jars exposed to the compost.

M= Molarity of the acid used

E= Equivalent weight of carbon or carbon dioxide

To express the data in terms of carbon, E=6; to express in terms of CO_2, E = 22

PHASE I

3.3 Faecal Sludge (FS) Characterisation and Quantification.

Sampling of FS

Faecal sludge samples were collected twice a month from the new liquid waste treatment facility (Plate 3.1) in Sofokrom from May to July, 2012. Sampling was done according to the two main types/sources of the FS: public toilet and septage (water closets) that are generated within the Sekondi-Takoradi Metropolitan Area (STMA).

Plate 3.1: Collecting FS samples at the Liquid Waste Treatment facility in Sofokrom

Characterisation of FS

The two types/sources of the FS were analysed and characterized based on the parameters listed below:

Physicochemical parameters: pH, EC, TS, BOD, COD, N, NH_4-N, NO_3-N, P and K.

Microbiological parameters: *E. coli*, faecal coliforms and Helminth eggs.

The analyses of the parameters were performed as described in Section 3.2.

Quantification of FS

Secondary data on the quantities of the FS disposed off within the Metropolitan Area were obtained from the Waste Management Department of the Assembly. Primary data were also collected from the field daily using a designed logging-in sheet (see appendix 1). All data were compiled and analysed using Microsoft Excel Spreadsheet.

PHASE II

3.4 Co-composting of dewatered FS with EFB and CPH (*building co-compost windrows)*

3.4.1 Experimental Setup

The experimental setup was located at the Forest and Horticultural Crops Research Centre (FOHCREC) and lasted from September 2012 to December 2012. A concrete platform (L = 25 m and W = 3 m) was constructed at the Centre for the composting process.

3.4.2 Feedstock acquisition, preparation and characterisation

Obtaining dewatered faecal sludge

Raw human excreta (FS) was dewatered on sand drying beds at the Tema Metropolitan Assembly human waste disposal and treatment site located at Ashalley Botwe, Accra. Mixtures of sludge from public toilets and septic tanks (septage) were loaded onto the drying bed at a ratio of 2: 1 (Plate 3.2 and 3.3).

Plate 3.2: A cesspit emptier dislodging onto the drying bed.

Plate 3.3: Fresh FS on the drying bed.

Plate 3.4: Almost dried FS

Plate 3.5: Dried FS collected into sacks

It took a total of thirty (30) days for the sludge to dry to the required moisture content (Plate 3.4). The dried/dewatered FS were collected into sacks (Plate 3.5) and transported to the composting site where they were stored in a cool dry place

until the composting process took off. Samples of FS were collected and analysed (as described in Section 3.2) before dewatering. After dewatering the physico-chemical and microbial characteristics of the FS were determined.

Obtaining empty fruit bunches (EFB) and cocoa pod husks (CPH)

The EFB and CPH were obtained from the nearby oil palm and cocoa farms respectively. The EFB was chopped (cut) into pieces (Plate 3.6) of about 2 -3 cm to increase the surface area and also to allow for efficient aeration during composting. Larger sizes of the CPH were also cut into pieces (2 -3 cm) (Plate 3.7). Representative samples of EFB and CPH were analysed for their physico-chemical properties before the composting. The parameters that were considered for the characterisation were N, NH_4^+-N, NO_3^--N, P, avail-P and K as described in Section 3.2 above.

3.4.3 Building co-compost windrows

The shredded EFB and CPH were mixed thoroughly with the dewatered FS (Plate 3.8) at different combinations shown in (Table 3.1). The mixed feedstock were moistened with water to 60% and then laid in piles (windrows) in three replicates each.

Table 3.1: Different experimental combinations of co-compost feedstock

Treatment	Raw Materials	Ratio(v/v)
1	FS + EFB	1 : 1
2	FS + CPH	1 : 1
3	FS + EFB + CPH	1 : 1 : 1
4	FS + EFB + CPH	2 : 1 : 1
5	FS + EFB + CPH	2 : 2 : 1

In all, a total of fifteen (15) windrows were prepared and arranged in a completely randomized design on the composting platform. Windrows were turned manually every 3 days for the first 2 to 3 weeks and then once a week for the rest of the period. Moisture contents were adjusted to 60% during the turning.

Three Bamboo sticks of approximately equal dimensions were perforated and mounted vertically into each compost pile for daily temperature readings (Plate 3.9). The windrows were covered with thick plastics sheets during rainy days to prevent them from being soaked up with excess water.

Plate 3.6: Empty fruit bunches (EFB) being cut into smaller units at the composting site.

Plate 3.7: Fresh cocoa pod husks (CPH) being cut into smaller units at the composting site.

Plate 3.8: Mixing and building of compost windrows

Plate 3.9: Taking Temperature readings of compost heaps.

3.4.4 Co-compost sampling and sample preparation

Representative co-compost samples were collected every two (2) weeks and three (3) weeks during turning regimes for analysis of the physico-chemical and microbiological parameters, respectively. Preparation of samples for the physico-chemical analysis was done by air drying, pulverising and passing of the samples through a 2 mm sieve.

3.4.5 Determination of compost maturity indices

(i) Temperature measurement

The temperatures of the piles (windrows) were taken with a soil thermometer. Three (3) perforated bamboo pipes of approximately equal sizes were mounted in each pile for the temperature readings. The thermometer was lowered into the three pipes consecutively for each pile and the temperature readings recorded after 2-3 minutes. Daily temperatures were recorded as a mean of the three individual measurements.

(ii) pH

The pH was determined using a 1:5 (sample: water) described by USDA and USCC (2001). Five grams (5 g) of the dried sample was weighed into a 100 ml beaker and 25 ml of distilled water was added to the sample and stirred for about 10 minutes. The mixture was allowed to stand for 30 minutes. The pH was then read as described in Section 3.2.1 above.

(iii) Determination of C/N ratio

Organic carbon was determined by the dichromatometric oxidation method (Walkley and Black, 1934) described in Section 3.2.12. The Kjeldahl method

described in Section 3.2.6 was used to determine total nitrogen. The C/N ratio for each treatment was then estimated by dividing carbon by the total nitrogen.

(iv) Microbial respiration rates of co-composts

The microbial respiration rates of each co-compost treatment were measured according to the method described in Section 3.2.15

3.4.6 Feedstock and co-compost analysis

(i) Electrical conductivity (EC)

The EC was also determined by 1:10 sample to water extract method as was carried out for the pH above. The EC was determined as described in Section 3.2.2.

(ii) Total nitrogen (N)

The modified Kjeldahl method as described by Black, (1965) was used to determine total N in the feedstock and compost samples. A 0.1g of each of the samples was weighed into 500 ml Kjeldahl flask and heated with 5 ml of concentrated H_2SO_4 in the presence of selenium catalyst and salts (Na_2SO_4) . The resulting digest was distilled with excess strong alkali (NaOH) as described in Section 3.2.6

(iii) Determination of ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) in feedstock and co-compost samples

One gram (1g) of air-dried ground sample that has passed through 2.0 mm sieve was weighed into a 200 ml plastic bottle, and 40 ml of 2M KCl extracting solution was added. The bottle was covered and the content shaken for one hour.

The sample was then centrifuged and filtered through No. 5 or No. 42 Whatman filter paper.

Measurement of $NH_4^+ - N$

An aliquot of 10 ml of the co-compost extract was pipetted into the distillation flask ammonium-N (NH_4^+ –N) was determined as described in Section 3.2.7.

Measurement of $NO_3^- - N$

Nitrate- N (NO_3^--N) was also distilled, following ammonium-N (NH_4^+ –N) distillation as described in Section 3.2.7

(iv) Measurement of total phosphorus (Perchloric acid digestion)

A 0.1g of the feedstock/co-compost sample was weighed into a 125 ml Erlenmeyer flask which was previously washed with acid and distilled water. A 10 ml aliquot of Ternary solution was added and digested. After the digested solution had cooled it was filtered completely with Whatman No.42 filter paper, into a 100 ml Pyrex volumetric flask and made up to the mark with distilled water. Total P was determined as described in Section 3.2.9.

(v) Determination of available phosphorus (Bray No.1 Method)

Extraction

One gram (1g) of air-dried feedstock/ co-compost sample that had passed through a 2mm sieve was weighed into a 100ml conical flask and 7ml of extracting solution added to it. The content of the flask was placed on a shaking machine for 5 minutes and filtered through Whatman No.42 filter paper. Phosphorous was determined calorimetrically as described in Section 3.2.9.

(vi) Measurement of total potassium

A 0.1g of the feedstock/co-compost sample was weighed into a conical flask and digested with 10 ml Ternary mixture (20 ml of 60% concentrated perchloric acid, 500 ml concentrated nitric acid mixture and 50 ml H_2SO_4). The digest was allowed to cool and filtered into 100 ml volumetric flask which was top up to the mark. Because of the high concentration of K, 10 ml aliquot of the digest was taken into 100 ml volumetric flask and top up with distilled water to the mark. Total K was read as described in Section 3.2.8.

(vii) Organic carbon (TOC), (viii) Bulk density and (ix) Water holding capacity of co-compost samples were determined as described in Sections 3.2.12, 3.2.13 and 3.2.14 respectively.

(x) E. coli, feacal coliform and Helminth egg.

The FS and co-compost samples were analysed for *E. coli*, *faecal coliform* and Helminth egg following same methods described in the Sections 3.2.10 and 3.2.11 above.

3.4.7 Calculations

1. *Nutrient loss (Tiquia et al., 2002)*

$$\text{Nutrient loss (\% of initial)} = \frac{\text{A (initial)} - \text{A(final) x } 100\%}{\text{A (initial)}} \qquad (15)$$

Where, A = Nutrient concentration x mass of windrow

PHASE III

3.5 Greenhouse Experiment: Evaluating Compost and Compost Tea on Vegetative Properties of Tomato and Pepper Transplant.

The focus of this greenhouse trials were: a) to evaluate the suitability of the co-compost obtained from faecal sludge and agricultural waste as a complete or partial soilless substrate component for tomato and pepper transplant production, b) to evaluate the nitrogen fertilizer equivalency of compost tea brewed from the co-compost as a nutrient source. The greenhouse trials were conducted in a greenhouse located at University of Ghana, Forest and Horticultural Crops Research Centre (FOHCREC) – near Kade. The temperature in the greenhouse ranged between 28˚C and 44˚C.

3.5.1 Tomato Transplant:

Tomato (*Lypersicon esculentum var. M2*) seeds were purchased from Agrimat® (viability as tested = 90%) and used for the Greenhouse trials.

3.5.1.1 Media preparation and filling of seed trays

After the co-composting process had ended in Section 3.4 above, the best co-compost treatment was selected for this study. The chosen type was treatment E; FS + EFB + CPH: 2: 2: 1. This co-compost was ground and passed through a 2 mm sieve to obtain uniform particle sizes. The sieved co-compost was mixed at different combinations with carbonated rice husk (CRH) (Plate 3.10) which served as the control soilless growth medium. The CRH was obtained from FOHCREC. A 42 cell Inverted pyramid seed tray (75 cm^3 per cell) was filled with the different growing media (Plate 3.11).

Plate 3.10: Mixing of co-compost with CRH

Plate 3.11: Filling of seed trays with growing media.

3.5.1.2 Compost Tea Preparation

Compost tea (CT) was prepared using the same faecal sludge based compost as above, following the bucket- fermentation method described in Diver (2002). This method is also referred to as the European approach or European-style compost tea and dates back hundreds of years (Diver, 2002; Grobe, 2003).

The CT stock solution was prepared by steeping 2.5 kg of compost in 15 L of distilled water (or 1: 3 by volume) for 6 days. For application, the stock solution was further diluted to 1: 5 and 1: 10. The two compost tea dilutions were prepared in 20 L batches and analyzed for N, P and K content before use in the greenhouse.

3.5.1.3 Inorganic nutrient solution preparations

The sources of the N, P and K inorganic fertilizers are shown in Table 3.2 with their respective percent compositions.

Table 3.2: Sources and percent composition of the inorganic nutrients

Nutrient	Sources	Percent composition
N	Ammonium nitrate (NH_4NO_3)	34% N (Yara International, 2013)
P	Triple super phosphate (TSP)	46% P_2O_5 (Better Crops, 1998)
K	Potassium chloride (KCl)	52.45% K (FAO, 2000)

The fertilizers were dissolved in distilled water to obtain the various concentrations (amounts) of NPK per litre of solution as shown in the nutrient solution treatments below.

3.5.1.4 Experimental design and treatments

A completely randomised greenhouse experiment with 3 replications of the treatments was conducted. The media (substrate) and nutrient solution treatments used are listed below:

Media Treatments (Factor 1);

1. *100% compost.*
2. *50% compost: 50% CRH.*
3. *100% CRH.*

Nutrient solution Treatments (Factor 2):

1. *Compost tea 1; (1: 5;- compost extract: water)*
2. *Compost tea 2; (1: 10;-compost extract: water)*
3. *400mg N/L: 176 mg P/L: 332 mg K/L*
4. *200 mg N/L; 100 mg P/L; 150 mg K/L*

5. *0 mg N/L: 0 mg P/L; 0 mg K/L (water)*

The tomato seeds were sown (3 per cell) in the three media and irrigated with tap water under best greenhouse practices till the seeds germinated. Emerged seedlings were counted on 4 and 10 days after seeding (DAS) by which time all viable seeds would have germinated. Percentage emergence and mean days to emergence (MDE) were calculated by the formula below (Gerson and Honma, 1978):

$$\text{MDE} = \frac{(\text{days to emergence})(\text{number emerged each day})}{\text{total number emerged}} \quad (16)$$

$$\text{Percentage emergence (\%)} = \frac{\text{number of seeds emerged x 100}}{\text{total number of seeds sown}} \quad (17)$$

The seedlings were continually irrigated with tap water till they showed second true leaves after which they were thinned to one plant per cell. After thinning, irrigation with tap water was terminated. The seedlings were then fertigated by sub-irrigation (ebb and flow) (Plate 3. 12) with compost tea at the rates of 1: 5 and 1: 10 (compost extract: water) and inorganic fertilizer solution containing 400 mg N/L and 200 mg N/L. Both inorganic nutrient solutions contain 176 mg P/L and 332 mg K/L. Ordinary tap water served as control. Sub-irrigation with the nutrient solutions was carried out for 3 weeks after which the transplants were harvested.

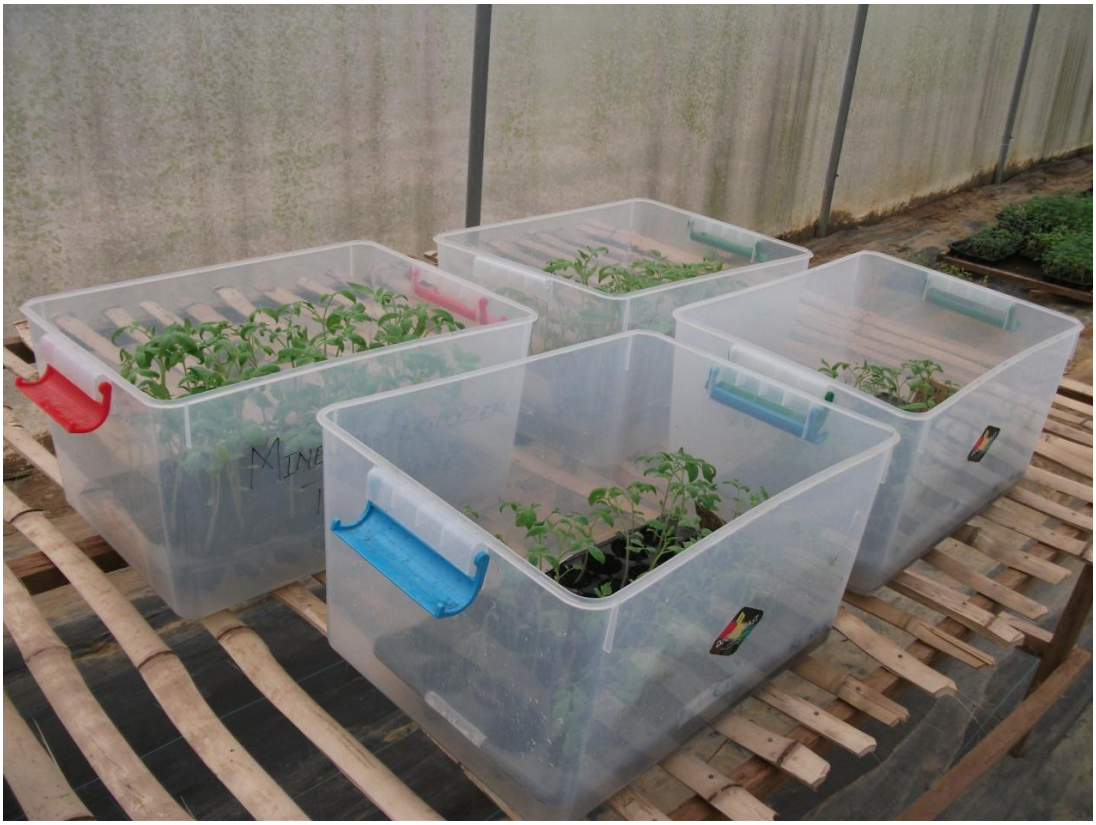

Plate 3.12: Transplants being floated in plastic tubs during a sub irrigation event.

3.5.1.5 Samplings and plant analysis

Seedlings were sampled (5 plants per treatment replicate) every week to measure some selected growth parameters listed below. Leaf chlorophyll content was measured using Apogee chlorophyll content meter (Model CCM- 200). Plant height and root length were measured with a rule in cm. Stem diameter was measured with a pair of vernier callipers, 1 cm above media surface. The plant samples were oven dried at 68˚C for 48 hours and weighed to obtain dry weights.

Growth Parameters:

1. *Plant height.*
2. *Chlorophyll content.*
3. *Number of true leaves.*
4. *Stem diameter.*
5. *and root mass.*
6. *Root length.*
7. *Root volume*

3.5.2 Pepper:

The experiment carried out in Section 3.5.1 was again repeated for pepper (*Capsicum annum var. Bird eye*) transplants but with different media and nutrient solution treatments listed below.

3.5.2.1 Experimental treatments

Media Treatments (Factor 1):

1. *100% compost.*
2. *75% compost: 25% CRH.*
3. *50% compost: 50% CRH.*
4. *25% compost: 75% CRH*
5. *100% CRH.*

Nutrient solution Treatments (Factor 2):

1. *Compost tea; (1:2;- compost extract: water)*
2. *400 mg N/L: 176 mg P/L: 332 mg K/L*

3. *200 mg N/L; 100 mg P/L; 150 mg K/L*
4. *100 mg N/L: 80 mg P/L: 80 mg K/L*
5. *0 mg N/L: 0 mg P/L; 0 mg K/L*

3.5.3 Calculations

1. *Fertilizer Equivalence (FE)*

Fertilizer equivalencies (FE) of the compost teas were obtained by comparing the total dry matter from the compost tea treatments to that of the nitrogen response curve from inorganic nitrogen fertilizer. Calculation for the corresponding nitrogen fertilizer equivalent for the compost teas was obtained from the quadratic equation ($Y = aFE^2 + bFE + c$) exhibited by the nitrogen response curves. The following formula for solving quadratic equations was used:

$$\mathrm{FE} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad (18)$$

Where a, b, and c are constants. To compare the FE, FE% was calculated by dividing FE by the actual amount of N applied in crop residues and expressed as a percentage (Mutuo *et al.*, 1999):

$$\%\ \mathrm{FE} = \frac{\mathrm{FE\ x\ 100}}{\mathrm{N\ applied}} \qquad (19)$$

PHASE IV

3.6 Ascertaining the perception of farmers and consumers on human waste (FS) composting and use in crop production.

A survey was conducted through the administration of questionnaires to ascertain the perception of vegetable farmers and consumers on human waste composting and use in crop production. The survey was carried out in the Accra metropolis. Accra was selected for the survey because, though there is some level of urban agriculture in Sekondi-Takoradi, the level is small-scaled with about a total of 25 farmers only. According to Obuobie and Sarpong (2005) this level of urban agriculture in Sekondi-Takoradi, even combined with that in Cape Coast can be described as insignificant compared to that in Accra. Accra has the biggest number of urban vegetable farmer in Ghana ranging between 800 – 1000 (Obuobie *et al*., 2006). Two different forms of questionnaires were administered; one to the farmers and the other to the consumers (see Appendix 8). Questions in the questionnaires were translated into local languages by the investigator as and when it was necessary.

3.6.1 Farmers' survey

Thirty (30) vegetable farmers were interviewed from three purposively selected vegetable growing sites namely: Dzorwulu, Ridge (GBC) and Korle bu. These sites were chosen for representativeness. Ten (10) farmers were randomly interviewed in each vegetable growing site.

3.6.2 Consumers' survey

Ten (10) consumers each were randomly interviewed from communities in North Legon, Labone and Kaneshie. These communities were selected because of the differences in socio-cultural and educational backgrounds.

3.7 Statistical Analysis

Treatment means were subjected to ANOVA using Genstat 9th edition (Release 9.2) statistical package. Data for the microbial analysis were transformed into $\log_{10}$ units and subjected to ANOVA. Data for N-mineralisation and N& P-loss were also transformed into percentages before ANOVA analysis. Treatment means which were found to be significantly different from each other at *(P < 0.05)* were separated by the Least Significant Differences (LSD) tests. Data collected from the questionnaire survey were analysed with the use of descriptive statistics such as frequencies and percentages.

CHAPTER FOUR

4.0 RESULTS

4.1 Characterisation and quantification of faecal sludge in Sekondi-Takoradi metropolitan area (STMA)

4.1.1 Characteristics of septage in STMA

As shown in Table 4.1, the physical, chemical and microbiological characteristics of septage exhibited high variations. The pH ranged between 7.6 and 8.2 with an average of 8.0 ± 0.2. The mean BOD was 1080 mg/L and this was higher than the Ghana EPA limit of 50 mg/L (GEPA, 2000) for effluent release into the Ghanaian environment. Total N, P and K ranged between 8.35 – 24.67, 1.22 – 4.48 and 1.85 – 15.38%, respectively.

Table 4.1: Characteristics of septage in STMA

Parameter	Minimum	Maximum	Mean ± SD
Ph	7.6	8.2	8.0 ± 0.2
EC (μScm^{-1})	1000	6000	2900.00 ± 1715.93
TS (mgL^{-1})	1430	5510	3245.00 ± 1809.45
BOD (mgL^{-1})	700	1300	1080.00 ± 240.14
COD (mgL^{-1})	1400	9200	4650.00 ± 3069.04
Total N (%)	8.35	24.67	16.04 ± 6.19
NH_4-N ($mgKg^{-1}$)	45.79	1258.74	648.29 ± 448.71
NO_3-N ($mgKg^{-1}$)	9.21	40.18	22.72 ± 12.02
Total P (%)	1.22	4.48	2.66 ± 1.35
Total K (%)	1.85	15.38	7.48 ± 5.04
E. coli (CFU/100ml)	2.60×10^5	5.20×10^6	$1.87 \times 10^6 \pm 1.98 \times 10^6$
faecal coliform (CFU/100ml)	2.60×10^5	6.80×10^6	$2.29 \times 10^6 \pm 2.38 \times 10^6$
Helminths (per 10g dry weight)	1.00	3.00	1.75 ± 0.96

n=6

The coliform load was very high; E. coli (1.87 x 106 ± 1.98 x 106 CFU/100 ml) and faecal colifom (2.29 x 106 ± 2.38 x 106 CFU/100 ml) levels were well above limits set by EPA (Ghana) guideline value of 0 CFU/100 ml for effluents (Hodgson and Larmie, 1999).

4.1.2 Characteristics of public toilet sludge in STMA

Table 4.2 shows the variations in characteristics of public toilet sludge from STMA. Faecal coliform contaminations were relatively higher in the public toilet sludge (4.20 x 107 ± 8.73 x 107 CFU/100 ml) than was observed for septage (2.29 x 106 ± 2.38 x 106 CFU/100 ml). The BOD of public toilet sludge (6200.00 ± 2550.62 mg/L) was also higher than the BOD of septage (1080.00 ± 240.14 mg/L), indicating that public toilet sludge was less stabilised than septage.

Table 4.2: Characteristics of public toilet sludge in STMA

Parameter	Minimum	Maximum	Mean ± SD
pH	7.4	8.4	7.9 ± 0.4
EC (μScm^{-1})	8100.00	54000.00	27350.00 ± 20937.88
TS (mgL^{-1})	7270.00	66990.00	37200.00 ± 22239.61
BOD (mgL^{-1})	3500.00	9800.00	6200.00 ± 2550.62
COD (mgL^{-1})	8300.00	56000.00	26600.00 ± 20076.10
Total N (%)	4.57	30.81	15.44 ± 9.77
NH_4-N ($mgKg^{-1}$)	188.38	1055.59	577.17 ± 293.89
NO_3-N ($mgKg^{-1}$)	2.27	49.52	17.68 ± 16.88
Total P (%)	0.30	1.85	0.92 ± 0.54
Total K (%)	0.37	11.93	5.89 ± 4.59
E. coli (CFU/100ml)	2.20 x 10^6	2.60 x 10^7	8.05 x 10^6 ± 9.18 x 10^6
faecal coliform (CFU/100ml)	3.00 x 10^6	2.20 x 10^8	4.20 x 10^7 ± 8.73 x 10^7
Helminth (per 10g dry weight)	1.00	6.00	2.75 ± 2.22

n=6

A relatively higher number of helminth eggs compared to septage were observed, the most common being Ascaris eggs. The helminth eggs recorded for public toilet sludge ranged between 1 to 6 eggs per 10 g (dry weight) of sludge whiles a range of 1 to 3 eggs per 10 g (dry weight) of sludge was recorded for septage.

4.1.3 Quantification of faecal sludge (FS)

The quantities of FS generated in the metropolis were studied for three different years and it is shown in Table 4.3.

Table 4.3: Showing the quantities of FS that were generated and disposed of in STMA.

Year	Population[1]	Total trips	Total quantity of FS disposed of
2005	335,000	1616	16,680 m^3
2008		2418	28,390 m^3
January – April, 2012	559, 548	957	11,266 m^3

[1]Source: Ghana Statistical Service- 2005 Census Reports and 2010 Population and Housing Census.

The period January – April, 2012 was studied in retrospect and the following trends were observed (Table 4.4). The average daily trips for the first quarter of 2012 i.e. January, February, March and April were 10.00, 8.62, 8.15 and 10.84 trips respectively corresponding to the following quantities; 118.04 m^3, 103.65 m^3, 88.38 m^3 and 132.88 m^3.

Table 4.4: Showing daily and weekly averages of FS disposed of in each month in 2012.

Month	Daily average Trips	Daily average quantity (m^3)	Weekly average Trips	Weekly average quantity (m^3)	Total Monthly Trips	Total Monthly quantity (m^3)
January	10.00	118.04	62.50	737.75	250	2951
February	8.62	103.65	56.00	673.75	224	2695
March	8.15	88.38	53.00	574.50	212	2298
April	10.84	132.88	67.75	830.50	271	3322

Within the month of January 2012, the highest amount of FS was generated within the Takoradi township (783 m^3) followed by Takoradi harbour (516 m^3) and then Sekondi township with a quantity of 273 m^3 (Figure 4.1). The localities that generated the least quantity of FS were Kweikuma, Sofokrom, and New Takoradi with a quantity of 9 m^3 each.

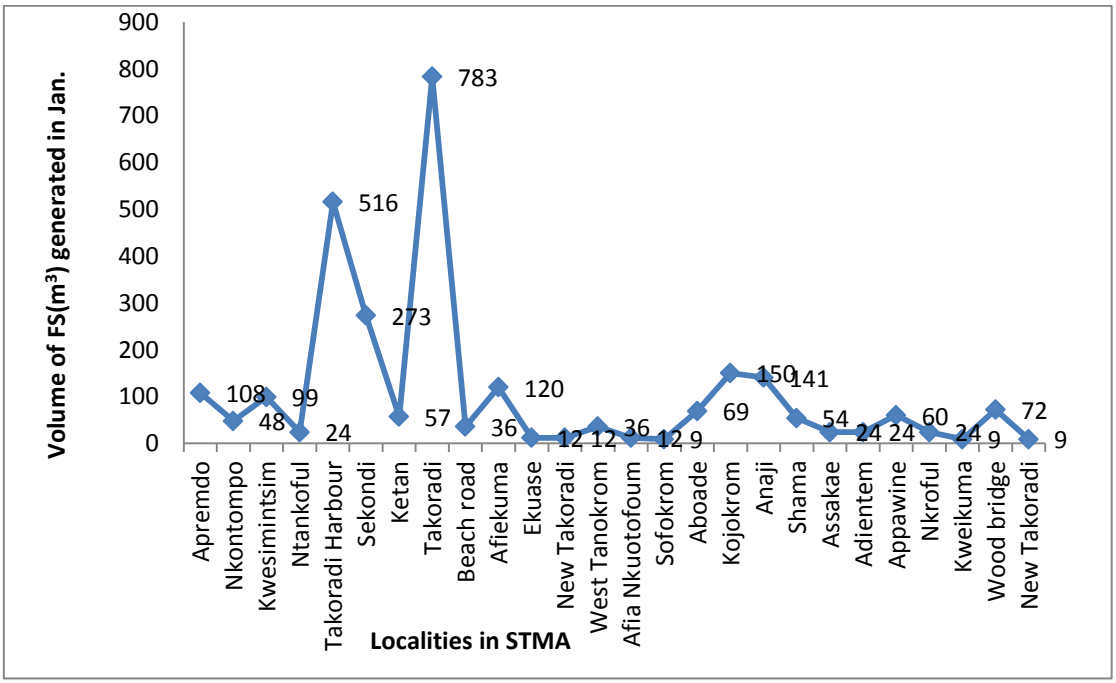

Figure 4.1: A graph showing the quantity of FS that were generated in the different localities in STMA for the month of January, 2012

4.2 Physical, biological and chemical changes during co-composting of faecal sludge with empty fruit bunches and cocoa pod husks.

4.2.1 Physical, chemical and microbial characteristics of raw FS before dewatering.

The raw FS was characterised before pre-treatment (dewatering) and results show that the pH and EC were 8.56 and 15.44 dS/cm respectively (Table 4.5a). The NPK contents were 20.89 (%), 0.14 (%) and 9.60 (%) respectively whiles the organic matter (OM) content was 27.48 (%) (Table 4.5b). The pathogen loads per 100 ml of sludge were 4.20 x 10^6 CFU for *E. coli* and 5.00 x 10^7 CFU for faecal coliforms (Table 4.5c).

Table 4.5a: Physical characteristics of FS before dewatering

Feedstock	pH	EC (dS/cm)	TS (mg/L)	BOD (mg/L)	COD (mg/L)
Raw FS	8.56 ±0.14	15.44 ± 5.84	19000 ± 7426	4900 ± 937	21750 ± 4234

FS = Faecal sludge, (x ± SD) (n=8)

Table 4.5b: Chemical characteristics of FS before dewatering

Parameter	Raw FS
C (%)	16.10±0.98
OM (%)	27.48±1.68
Total N (%)	20.89±6.22
Total P (%)	0.14±0.09
Total K (%)	9.60±4.19
NH4-N (mg/kg)	1038.07±368.67
NO3-N (mg/kg)	52.02±30.78

FS = Faecal sludge, (x ± SD) (n=8)

Table 4.5c: Microbial characteristics of FS before dewatering

Feedstock	*E. coli* (CFU/100 ml)	faecal coliform (CFU/100 ml)
Raw FS	$4.20 \times 10^6 \pm 2.95 \times 10^6$	$5.00 \times 10^7 \pm 2.58 \times 10^7$

FS = Faecal sludge, (x ± SD) (n=8)

4.2.2 Physico-chemical and microbial characteristics of compost feedstock (raw materials)

Table 4.6a shows the physico-chemical characteristics of empty fruit bunches (EFB), cocoa pod husks (CPH) and FS. The total N and P were highest (3.10% and 1.48%) in FS followed by CPH (1.64% and 0.25%) and then EFB (1.49% and 0.14%). However, total K was highest in CPH (2.21%) and least in FS (0.79%). The C/N ratios were 43.45, 25.05 and 11.09 for EFB, CPH and FS, respectively. The pH was higher (8.9) in the EFB and lowest (7.7) in the FS.

Table 4.6a: Physico-chemical characteristics of compost feedstock

Feedstock	pH (1:5)	C (%)	C/N	Total N (%)	Total P (%)	Total K (%)	NH_4^+-N (mg/kg)	NO_3^--N (mg/kg)
EFB	8.9± 0.1	64.58± 4.43	43.45± 1.37	1.49± 0.05	0.14± 0.01	1.32± 0.03	378.00± 54.00	363.60± 126.00
CPH	8.6± 0.1	41.07± 0.76	25.05± 0.96	1.64± 0.04	0.25± 0.02	2.21± 0.08	399.50± 3.00	320.40± 54.00
FS	7.7± 0.0	34.29± 1.96	11.09± 0.21	3.10± 0.23	1.48± 0.53	0.79± 0.01	2062.80± 205.20	662.40± 86.40

EFB = Empty fruit bunches, CPH = Cocoa pod husks, FS = Faecal sludge, (x ± SD) *(n=3)*.

Results of dry FS samples analysed for microbial loads are shown in Table 4.6b.

Table 4.6b: Microbial properties of FS before composting

Feedstock	*E. coli* (CFU/g)	faecal coliform (CFU/g)	Helminth eggs(per 10g dry weight)
FS	600 ± 1603	59100 ± 70926	5*

FS = Faecal sludge, * results for *n=5*, (x ± SD) (n=20).

4.2.3 Composting process and maturity determination of co-composts

4.2.3.1 Volume reduction

There was significant reduction in volume or sizes of the individual heaps as shown in (Figure 4.2). Co-compost treatments A and E achieved 50% volume reduction whiles treatments B, C and D reduced by 36%, 51% and 40%, respectively, during the 90 days.

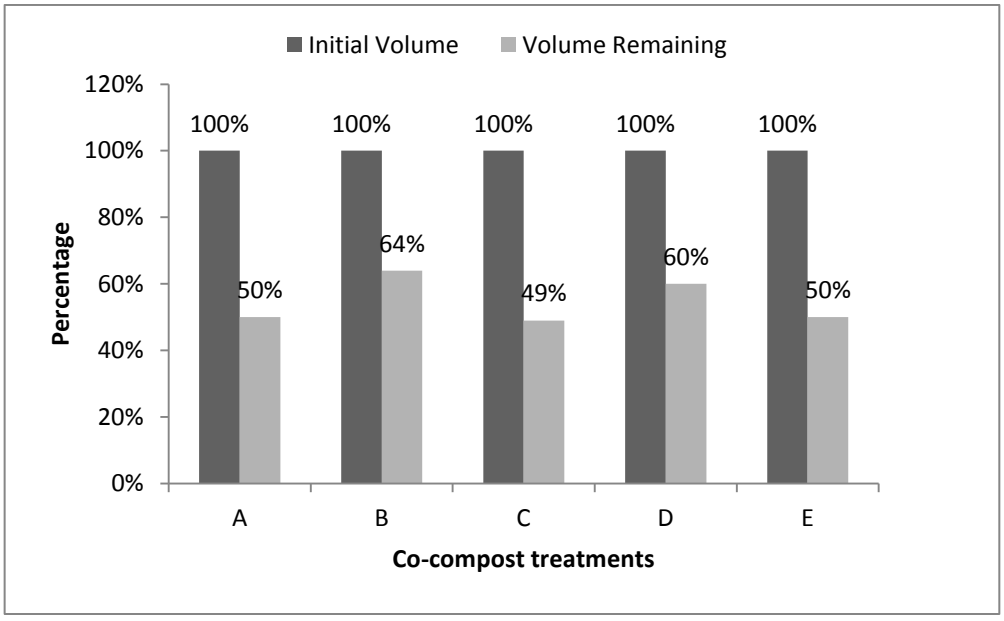

Figure 4.2: Initial and final volumes of heap remaining after 90 days of composting.

4.2.3.2 Temperature of co-composts

Throughout the composting process, the ambient temperature ranged from 23.0 to 35.5 ˚C. Figures 4.3 (a and b) show the variation in temperature in the different compost treatments (piles) over the 90 days period. Generally, the mesophilic phase of the composting process lasted between the first and second day in all the treatments. Treatments A, D and E (figure 4.3b) reached thermophilic temperatures (>50˚C) whiles treatments B and C (figure 4.3a) did not. The cooling and maturation phase then proceeded after 14 days of active co-composting till the temperature in all the treatment piles declined to ambient temperature.

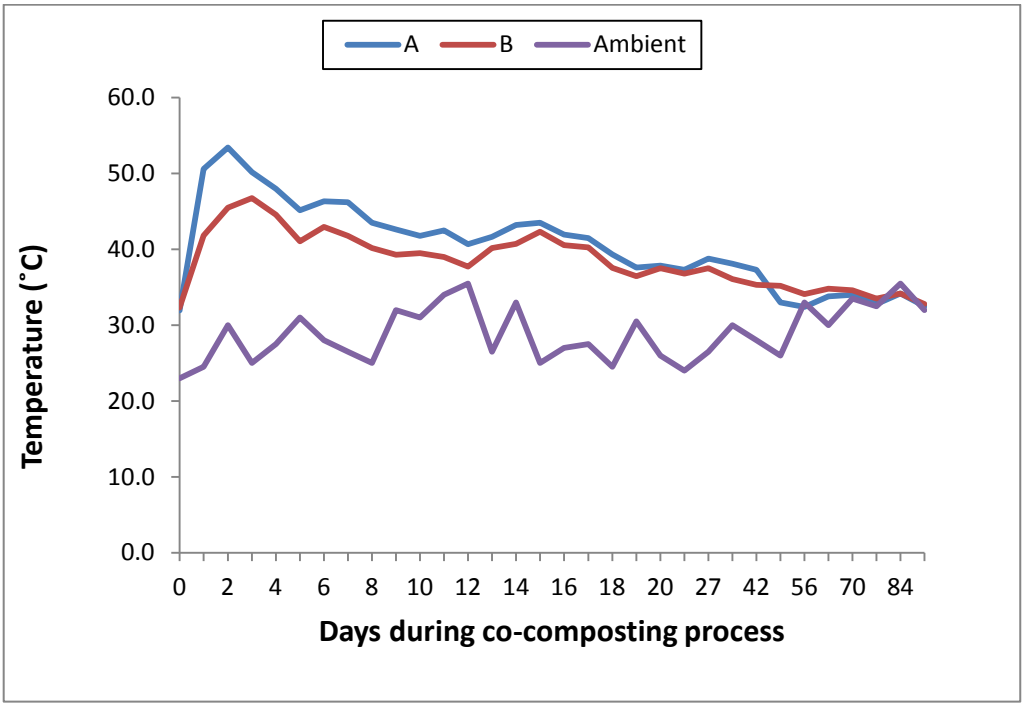

Figure 4.3a Change in ambient air temperature and temperature in co-compost piles during the co-composting process. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1)

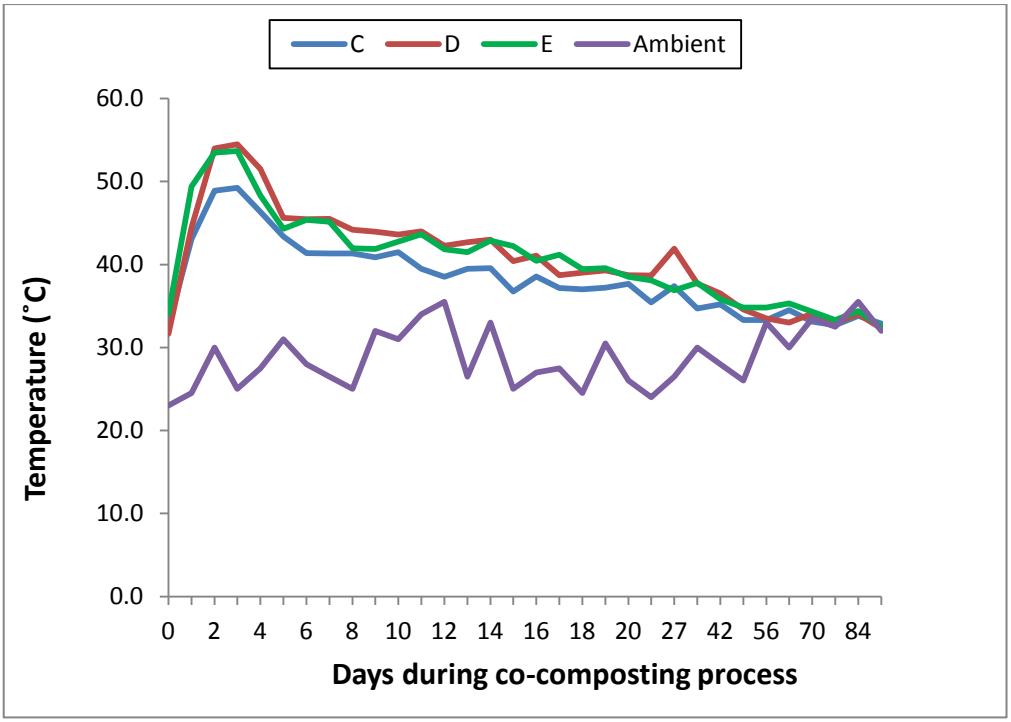

Figure 4.3b Change in ambient air temperature and temperature in co-compost piles during the co-composting process. (**C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)

4.2.3.3 pH

Figure 4.4 represents the mean weekly pH of the different co-compost treatment piles. The pH of co-compost treatments A, B, C, D and E at the initial stages were 7.6, 7. 9, 7.7, 7.8 and 7.6 respectively. The pH remained above neutral pH of 7 throughout the co-composting process. At the end of co-composting, the pH values attained were 7.3, 7.3, 8.1, 7.5 and 7.9 for treatments A, B, C, D and E, respectively.

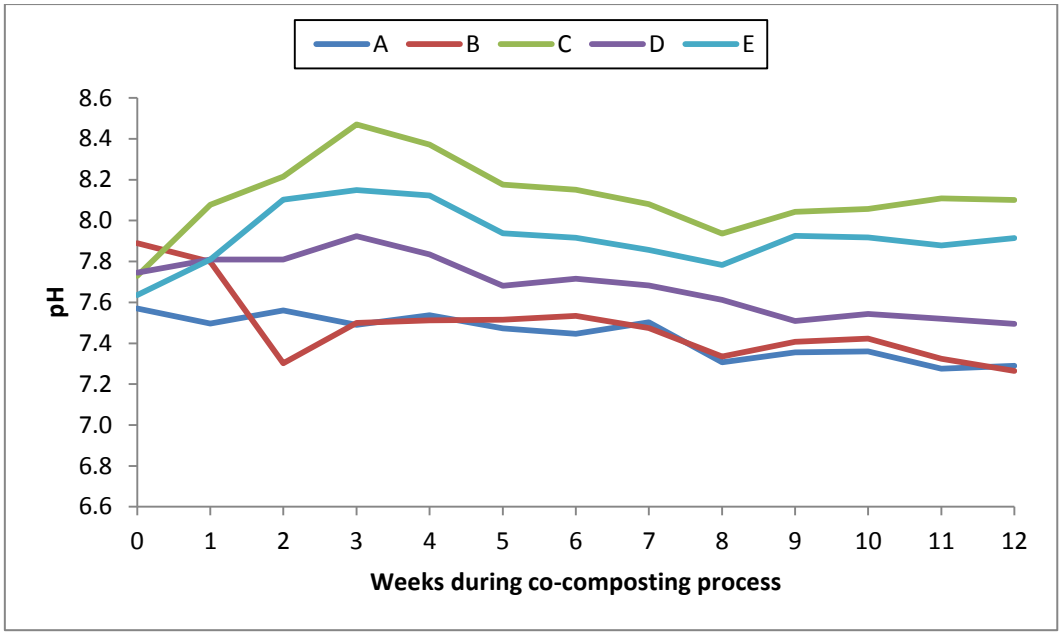

Figure 4.4 Change in pH in co-compost piles during the co-composting process. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1).

4.2.3.4 Microbial respiration rates of co-compost treatments

Figure 4.5 shows changes in carbon dioxide (CO_2) evolution as a measure of microbial respiration rate from the different compost treatments. Generally, the CO_2 evolution rates decreased with time over the 12 weeks period. For the first week, the CO_2 evolution rates were highest (8.40 mg/g compost per day) in the treatment E and lowest (2.70 mg/g compost per day) in treatment B. By the fifth week, the evolution rates of treatment B became the highest (1.70 mg/g compost per day) amongst the treatment with treatment D being the lowest (0.77 mg/g compost per day). At the end of the twelfth week, all the treatments recorded stable CO_2 evolutions which were less than 1 mg CO_2/g compost per day.

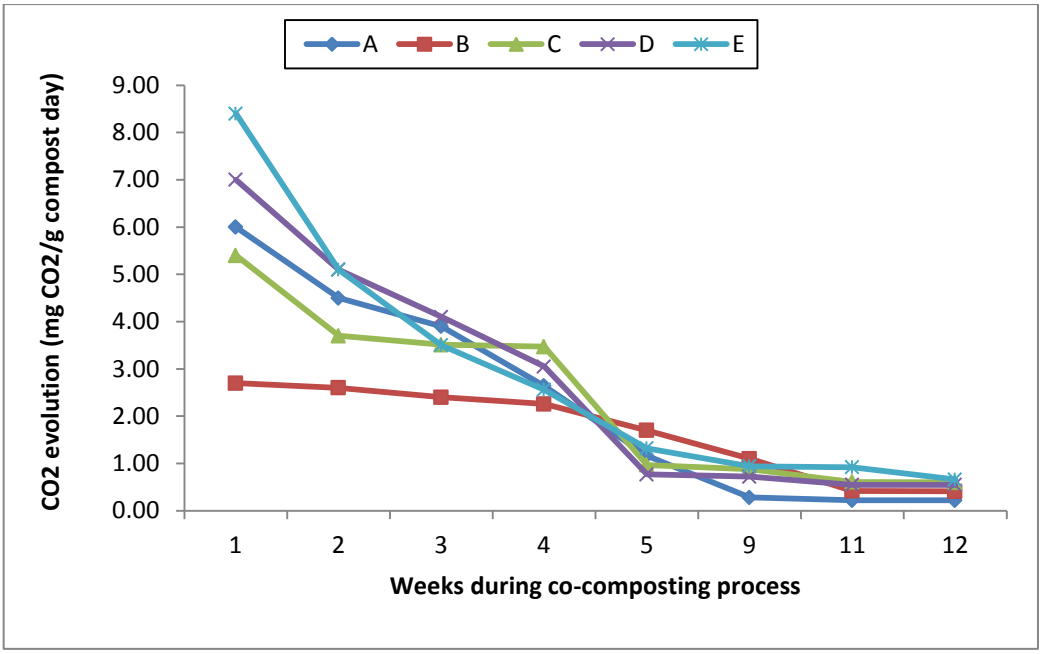

Figure 4.5 Change in CO_2 evolution during the co-composting process. . (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1).

4.3.3.5 NH4+-N and NO3--N concentrations

The ammonium- nitrogen (NH_4-N) levels generally decreased sharply from the start of co-composting till the end of the 2nd week (Figure 4.6). For treatment A, the decrease was up to the 4th week. The levels then remained low till the end of co-composting (12th week) where slight increases were recorded for all the treatments. On the other hand, the nitrate- nitrogen (NO_3^--N) levels rose gently from the start of composting to the end. The highest levels (1000.80 mg/kg) were attained at the end of co-composting by treatment B, followed by treatment A (849.60 mg/kg) (Figure 4.7). Treatment C had the lowest levels of NO_3^--N, however it was not significantly different from levels obtained in treatment D and E.

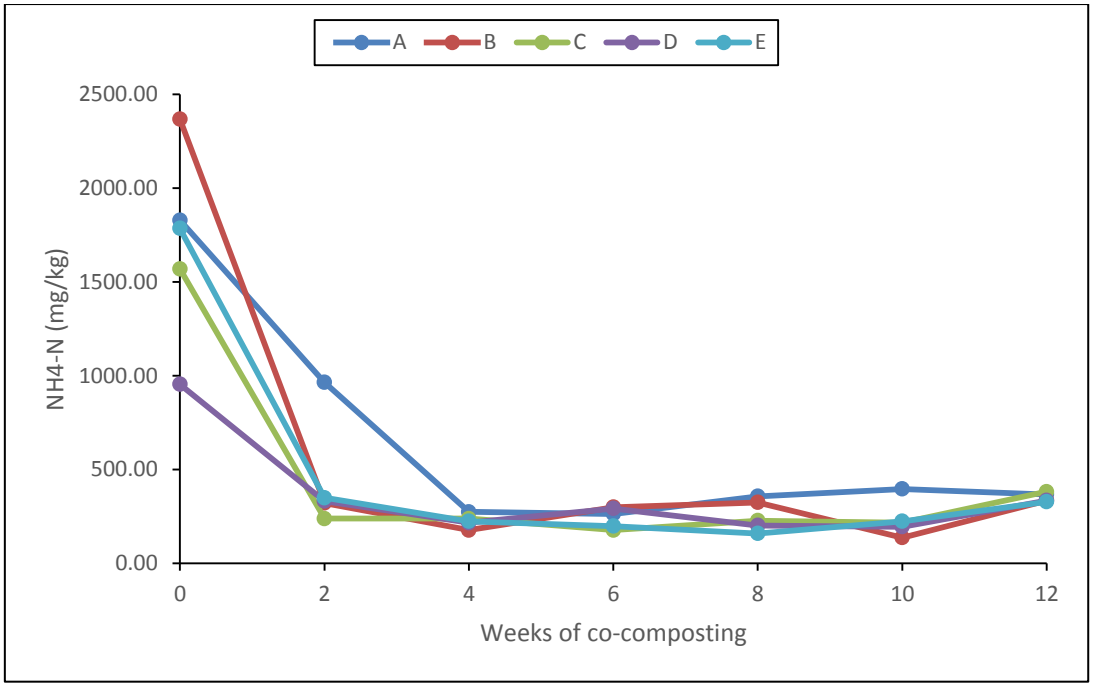

Figure 4.6 Change in ammonium- N levels during the co-composting process. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)

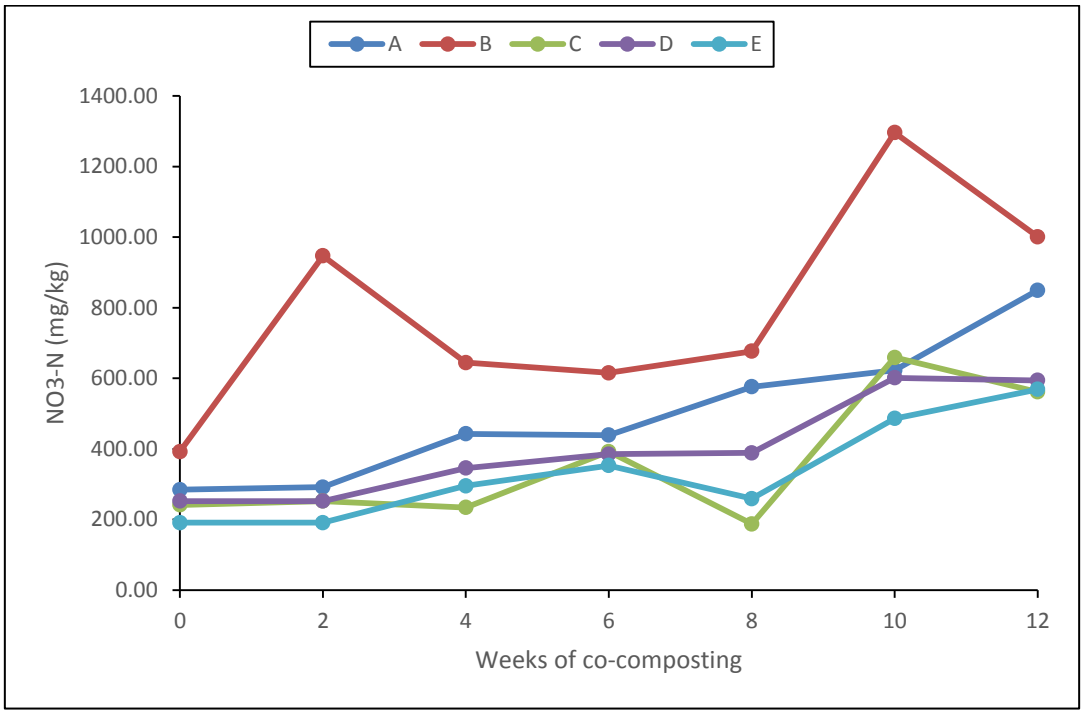

Figure 4.7 Change in nitrate- N levels during the co-composting process. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)

4.3.3.6 C/N ratio

Figure 4.8 show the C/N ratios of the various co-compost treatments. The starting ratios were 37.54, 32.15, 45.04, 60.71 and 50.32 for A, B, C, D and E, respectively. Generally, the C/N ratios decreased drastically within the first 2 – 4 weeks of composting for all the treatments and remained low till the end of composting which was accompanied by slight increases in the C/N ratios. From the beginning of the 4th week, decreases in total organic carbon were associated with the increases in total nitrogen content for all the treatments leading to a much lower C/N ratios between the 4th and 10th week. The final ratios were 20.28, 12.07, 19.36, 17.84 and 19.71 for A, B, C, D and E, respectively.

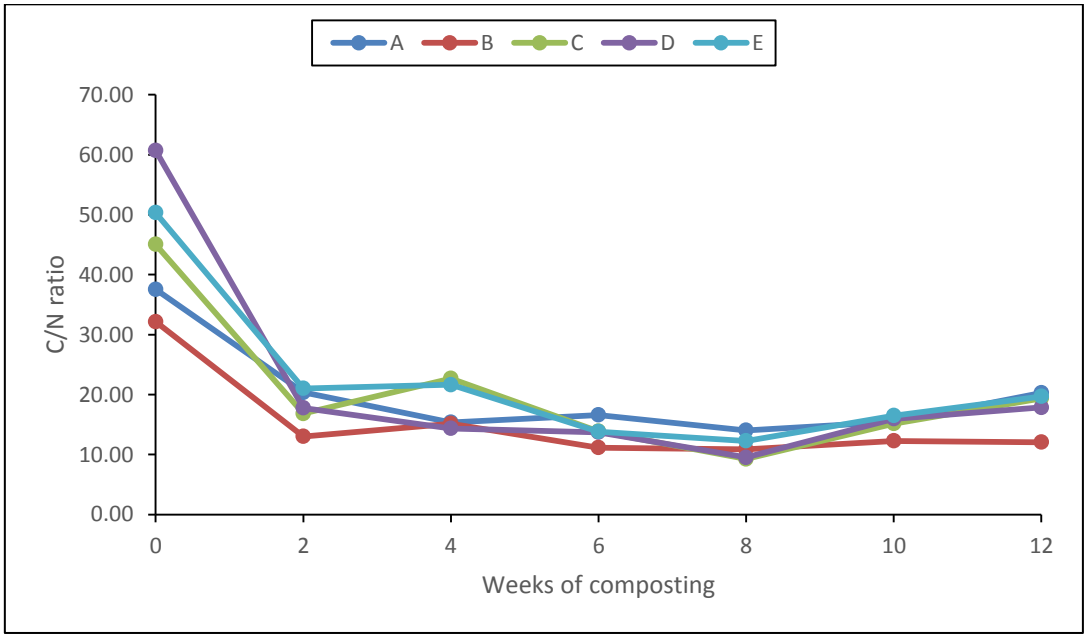

Figure 4.8 Change in C/N ratios during the co-composting process. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)

4.2.4 Effects of feedstock ratios on the physico-chemical and microbial dynamics of co-composts.

4.2.4.1 physico-chemical characteristics of co-composts

The physico-chemical characteristics of feedstock ratios at the start of composting are shown in Table 4.7. At the end of the composting process, the effect of the treatment ratios was examined on the final compost quality (Table 4.8) in terms of nutrient content, stability (low carbon content), EC and pH.

Table 4.7: Some physico-chemical characteristics of co-compost treatments at start of composting

Treat-ment	EC (µS/cm)	C/N	Total N (%)	NH_4^+-N ($mgkg^{-1}$)	NO_3^--N ($mgkg^{-1}$)	Total P (%)	Avail-P (%)	Total K (%)
A	2150	38.20	2.23	1828.80	284.40	2.603	0.271	1.250
B	2875	32.20	3.05	2368.80	392.40	3.103	0.318	1.900
C	2275	45.20	1.77	1569.60	241.20	2.369	0.250	1.600
D	1750	61.00	1.53	954.00	252.00	2.353	0.134	1.450
E	2525	51.40	2.02	1785.60	190.80	2.353	0.228	1.500
LSD	551.4	10.370	0.378	604.200	66.790	0.5377	0.0476	0.2074

(**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1) ($p<0.05$) (n=3).

In the matured co-compost, Total N was highest in treatment E (1.76%) but was not significantly different from treatments B (1.75%) (Table 4.8). These two treatments had the highest total N content followed by treatment D (1.43%). Treatment C (1.05%) had the lowest N, but it was not significantly different from treatment A (1.15%). Total P did not vary significantly between treatments B (0.690%), C (0.580%) and D (0.672). Also it did not vary between treatments A

(0.844%) and E (0.851). However the highest P was recorded by treatment E and the lowest by treatment C. Total K was highest in treatment E (0.945%) and lowest in treatment A (0.675%). There were however no significant differences between treatments B (0.875%) and C (0.925%); C and E; B and D (0.790%); and finally between A and D. Electrical conductivity (EC) was significantly higher in treatment B than the rest of the treatments. There were however no significant differences between treatments A, C, D and E.

Table 4.8: Some physico-chemical characteristics of matured co-composts

Treat-ment	EC (µS/cm)	C/N	Total N (%)	NH_4^+-N ($mgkg^{-1}$)	NO_3^--N ($mgkg^{-1}$)	Total P (%)	Avail-P (%)	Total K (%)
A	1975	20.32	1.15	367.20	849.60	0.844	0.197	0.675
B	2725	12.15	1.75	334.80	1000.80	0.690	0.340	0.875
C	2175	19.73	1.05	381.60	561.60	0.580	0.137	0.925
D	1925	17.88	1.43	334.80	594.00	0.672	0.162	0.790
E	2025	19.70	1.76	327.60	568.80	0.851	0.149	0.945
LSD	417.3	4.204	0.167	30.090	185.360	0.1214	0.0347	0.1347

(**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1) ($p<0.05$) (n=3).

The pH ranged between 7.3 in treatment B and 8.1 in treatment C (Figure 4.4). There were no significant differences in pH between treatments A and B; B and D and finally C and E. On the other hand there were differences between A and C; B and C; and D and E. The C/N ratios were significantly reduced after the 12 weeks of composting.

4.2.4.2 Pathogen dynamics

The changes in levels of *E. coli* and faecal coliforms are represented by the Figures 4.9 and 4.10 respectively. The E. *coli* levels in log units were not significantly different (at $P < 0.05$) between co-compost treatments C and D at the start of co-composting. However, these levels were significantly higher than levels reported for treatments A, B and E at the start of composting. The levels reduced from 2.90, 3.79, 4.20, 4.20 and 3.45 log units for co-compost treatments A, B, C, D and E to nil (0.00) respectively at the end of composting. The faecal coliform levels also reduced from 4.73, 4.69, 4.49, 4.62 and 4.95 to 3.89, 2.82, 2.58, 2.33 and 2.19 for treatments A, B, C, D and E respectively. Though treatment E had the lowest level of faecal coliforms, it was not significantly different from treatments B, C and D.

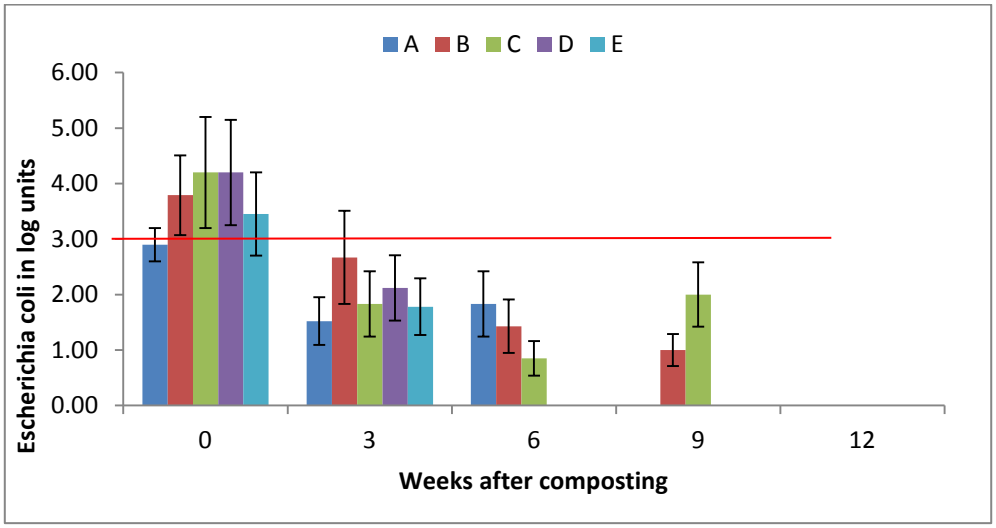

Figure 4.9 Changes in *Escherichia coli* population (x ± se) in compost piles during composting process. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1) — USEPA part 503 class A standard (<1 x 10^3CFU/g) of E. *coli* in compost.

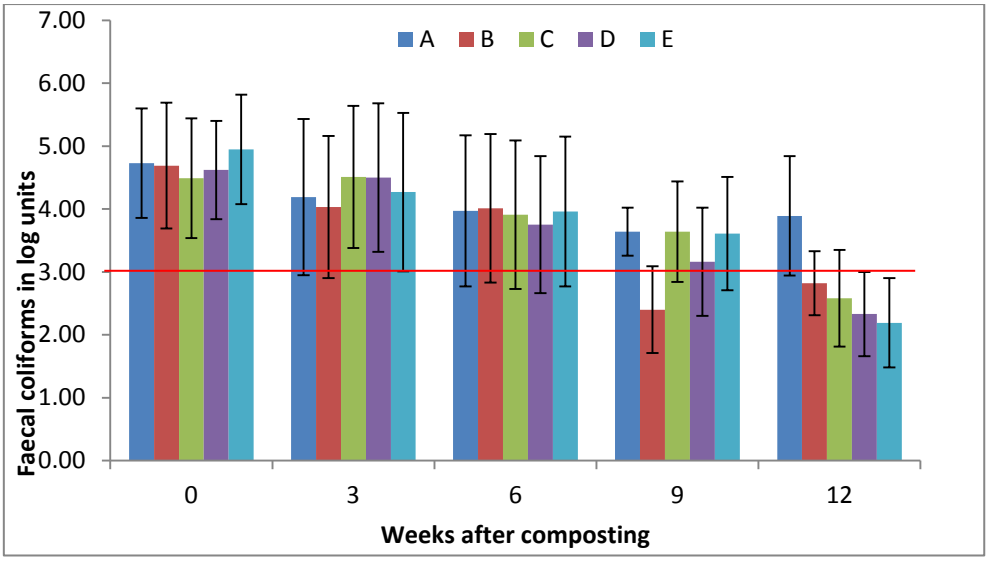

Figure 4.10 Changes in faecal coliform populations (x ± se) in co-compost piles during composting process. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)— USEPA part 503 class A standard (<1 x 10^3CFU/g) of faecal coliforms in compost.

Helminth eggs were not found in any of the co-compost treatments at the end of the composting process.

4.2.4.3 N-mineralization

Figures 4.11a and 4.11b show the amounts of available- N (NH_4^+-N and NO_3^--N) at the start and end of composting, respectively. At the start of composting (Figure 4.11a), the available-N was predominantly in the form of NH_4-N. Treatment C had the highest percentage of 8.87 and D had the least of 6.24%. The NH_4-N levels differed significantly between treatment D (6.24%) and E (8.84%). The levels were not significantly different between treatments A (8.20%), B (7.77%) and C (8.87%) at *($P < 0.05$).*

The matured co-composts had significant levels of both NH_4^+-N and NO_3^--N but the NO_3^--N levels were relatively higher than the NH_4^+-N (Figure 4.11b). NH_4^+-N was significantly highest in treatment C (3.63%) followed by treatment A

(3.19%) and D (2.34%). There was no difference between treatments B (1.91%) and E (1.86%) at *(P < 0.05)*. NO_3^--N was significantly highest in treatment A (7.39%) and lowest in treatment E (3.23%). However there were no significant differences between treatment D (4.15%) and E (3.23%) and then between treatment B (5.72%) and C (5.35%).

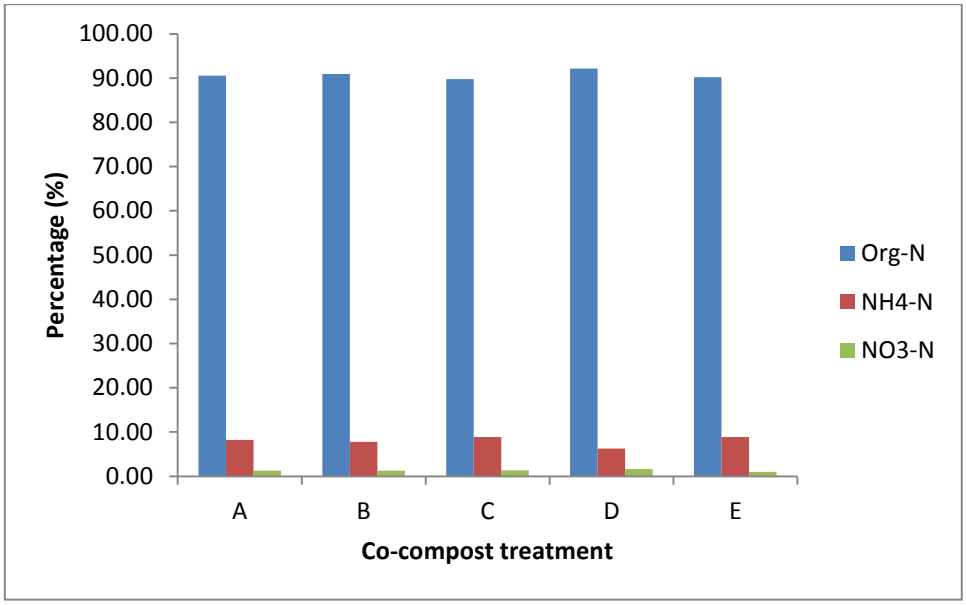

Figure 4.11a: N- mineralisation before co-composting (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)

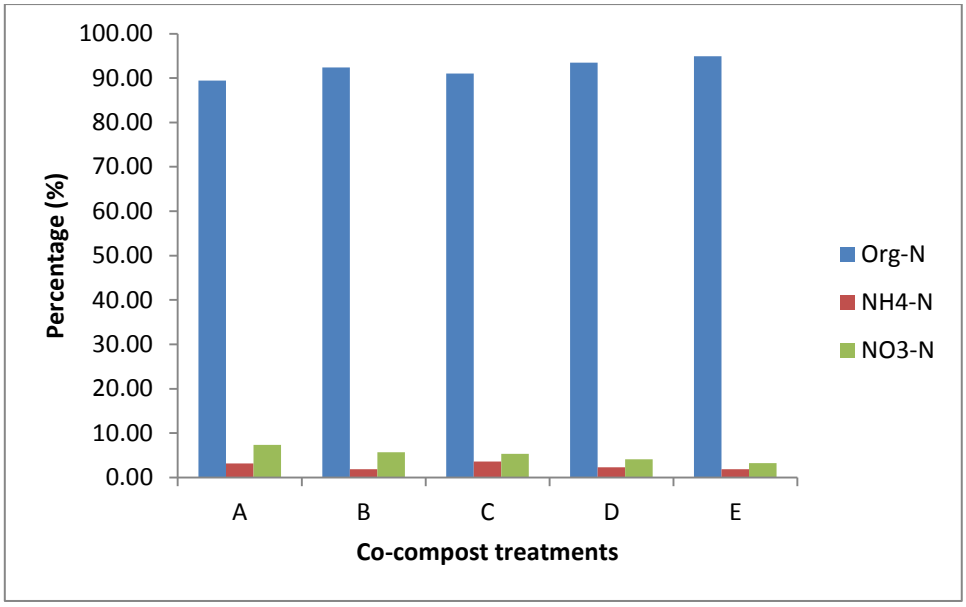

Figure 4.11b: N- mineralisation after co-composting (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)

4.2.4.4 N and P-loss

Nitrogen (N) and phosphorus (P) losses were significant for all the treatments at *(P< 0.05)*. Treatment A lost the most N (73%) whiles treatment D (44%) lost the least (Figure 4.12). There were however no significant differences in N-loss between treatments A (73%) and C (71%) and then between treatments B (63%) and C (71%). Phosphorus loss was generally high (> 80%) in all the co-compost treatments (Figure 4.12). The P-loss was highest in treatment C (88%) though it was not significantly different from treatment B (86%). Treatments D (82%) and E (82%), though not significantly different, achieved the least loss in P.

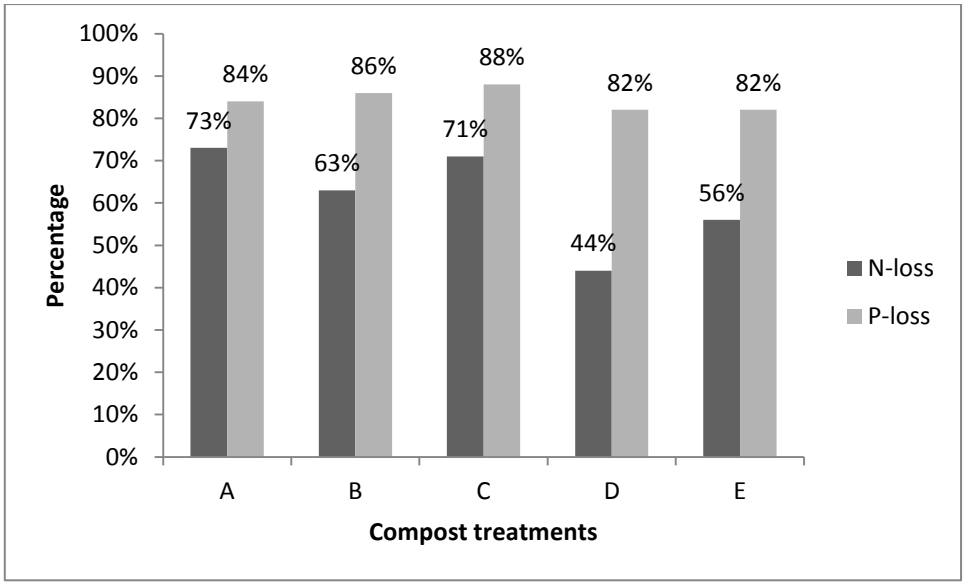

Figure 4.12: N and P-loss in matured co-composts. (**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1)

4.2.5 Selecting a co-compost type as potting/growing media for vegetable transplant production

The selection was based on performance ratings of the co-compost treatments where: 1 = excellent, 2 = very good, 3 = good, 4 = fair and 5 = poor. Faecal sludge with EFB and CPH co-compost at a ratio of 2: 2: 1 (treatment E) was found to be the best co-compost for use as a potting medium for vegetable transplants because of its high nutrient (NPK) and least pathogen content (Table 4.9).

Table 4.9 Criteria for selecting co-compost as potting media based on interested parameters

Co-compost Treatments	Pathogen reduction	N & P loss	N-mineralization	Total NPK	Total	Quality ranking
A	5	5	1	4	15	4th
B	4	3	2	2	11	3rd
C	3	4	3	5	15	4th
D	2	1	4	3	10	2nd
E	1	2	5	1	9	1st

(**A**= FS+EFB; 1:1, **B**= FS+CPH; 1:1, **C**= FS+EFB+CPH; 1:1:1, **D**= FS+EFB+CPH; 2:1:1, **E**= FS+EFB+CPH; 2:2:1).

4.3 Greenhouse experiment: Evaluating the effect of compost and compost tea on some vegetative properties of tomato and pepper transplant

4.3.1 Tomato (Lycopersicon esculentum var. M2) transplant production.

4.3.1.1 Physical and chemical properties of growing media (substrate) types

Physical properties of the growing media were significantly affected by the addition of compost to the media (Table 4.10). Electrical conductivity (EC) increased with increasing compost application rate/ concentration. The highest EC (2.10 dS/cm) was observed in the "compost only" growing medium whiles the lowest of 0.01 dS/cm was observed in the "CRH only". The pH was significantly higher (7.8) in the compost- CRH mix (1: 1) than that of the "compost only" (7.5) or "CRH only" (7.3) growing medium. The lowest pH was observed for "CRH only". The bulk density, similar to the EC also increased with

increasing compost concentration in the media. It was significantly highest in "compost only" (0.73 g/cm^3) and lowest in "CRH only" (0.31 g/cm^3). Water holding capacity (WHC) was significantly higher in the "CRH only" medium (3.10 per g) than the compost amended media. "Compost only" recorded the lowest WHC of 1.16 per gram of substrate.

Table 4.10: Some physical characteristics of compost only, compost- CRH mix and CRH only

Media (substrate)	pH (1:5)	EC (1:10)(dS/cm)	Bulk density (g/cm^3)	Water holding capacity (per gram)
Compost only	7.5	2.10	0.73	1.16
Compost: CRH mix (1:1)	7.8	1.60	0.55	1.74
CRH only	7.3	0.01	0.31	3.10
LSD *(P<0.05)(n=5)*	0.03	0.076	0.015	0.127

CRH= carbonated rice husks

The total N, P, K content, though higher in "compost only" media were not significantly different between the "compost only" media and the compost – CRH mix (1:1) media (Table 4.11). The ammonium – nitrogen (NH_4-N) concentrations were 205, 223 and 158 mg/kg for "compost only", compost – CRH mix (1:1) and "CRH only", respectively though these were not significantly different between the three different media. Nitrate – nitrogen (NO_3-N) was however significantly higher in "compost only" (1156 mg/kg) than in compost – CRH mix (1:1) (423 mg/kg). Water available P (Avail – P) was significantly highest in compost - CRH mix (1:1) (0.146 %) followed by "compost only" with 0.116 % and "CRH only" with 0.003 %.

Table 4.11: Chemical characteristics of compost only, compost- CRH mix and CRH only

Media (Substrate)	Total N (%)	NH_4^+-N ($mgkg^{-1}$)	NO_3^--N ($mgkg^{-1}$)	Total P (%)	Avail-P (%)	Total K (%)	C/N
Compost only	1.79	205.00	1156.00	0.540	0.116	1.050	19.75
Compost: CRH mix (1:1)	1.65	223.00	423.00	0.438	0.146	0.920	13.34
CRH only	1.13	158.00	187.00	0.062	0.003	0.455	10.99
LSD*(P<0.05)(n=3)*	0.281	96.100	142.100	0.1568	0.0106	0.0526	3.824

CRH= carbonated rice husks

4.3.1.2 Physico-chemical characteristics of organic and inorganic nutrient solutions.

The pH of the compost teas (CT-1 and CT-2) were both 8.1 irrespective of the dilution rates (Table 4.12). Similarly, the pH of In-fert-1 and In-fert-2 was also not significantly different, they were both 5.6. However, the pH values of CT-1 and CT-2 were significantly higher than those of In-fert-1 and In-fert-2. On the other hand, the EC of the compost teas decreased with increasing dilution rate from 0.56 dS/cm for CT-1 to 0.10 dS/cm for CT-2. Whereas that of In-fert-1 and In-fert-2 also decreased with decreased concentration of nitrogen (from 0.90 dS/cm for In-fert-1 to 0.20 dS/cm for In-fert-2).

Table 4.12: Physico-chemical characteristics of organic and inorganic nutrient solutions

Nutrient Solutions	pH	EC (dS/cm)	Total N (mg/L)	NH_4^+-N (mg/L)	NO_3^--N (mg/L)	Total P (mg/L)	Avail P (mg/L)	Total K (mg/L)
CT-1	8.1	0.56	74.83	41.29	41.41	1085.00	51.48	7420.00
CT-2	8.1	0.10	72.79	29.96	41.69	560.00	51.38	3340.00
In-fert-1	5.6	0.90	400.00	200.00	200.00	176.00	176.00	332.00
In-fert-2	5.6	0.20	200.00	100.00	100.00	176.00	176.00	332.00
LSD	0.16	0.104	N/A	N/A	N/A	N/A	N/A	N/A

CT-1= Compost tea 1 (1: 5, compost extract: water), CT-2= Compost tea 2 (1: 10, compost extract: water), In-fert-1= inorganic fertilizer N solution (400 mg N/L) and In-fert-2= inorganic fertilizer N solution (200 mg N/L). N/A = not applicable.

4.3.1.3 The effect of growing medium (substrate) type on seed emergence and early vegetative properties of tomato

Germinated tomato seeds emerged fastest in "CRH only" followed by "compost only" and compost- CRH mix (1:1) media as shown by mean days to emergence (MDE) values of 5.55, 6.56 and 6.57, respectively (Table 4.13). There was however no significant difference in MDE between "compost only" and compost-CRH mix (1:1). Percentage of seedlings emerged was also higher in "CRH only" (84.01%) though not significantly different from the compost-CRH mix (1:1) (78.73%). However, percentage emerged was significantly higher in "CRH only" than in the "compost only" (68.69%).

Early growth and development of transplants were significantly affected by the type of media (Table 4.14). Transplants were tallest in "compost only" (7.38 cm) compared to "CRH only" (5.70 cm) which had the shortest. But the plant height was not significantly different between "compost only" and compost- CRH mix (1:1) (6.84 cm). Stems were thickest in the compost- CRH mix (1:1) (0.19 mm)

compared to the others which were 0.16 and 0.13 mm for "compost only" and "CRH only", respectively.

Table 4.13: Effect of growing medium on germination and emergence of tomato transplants.

Media (Substrate)	Percentage emergence (%)	Mean days to emergence (MDE)
Compost only	68.69	6.56
Compost: CRH mix (1:1)	78.73	6.57
CRH only	84.01	5.55
LSD *(P<0.05)(n=5)*	10.903	0.587

CRH= carbonated rice husks

Table 4.14: Early vegetative properties of tomato transplants before treatment (sub-irrigation).

Media (Substrate)	Plant height (cm)	Stem diameter (mm)	Root length (cm)	No. of leaves	Shoot DM (mg/plant)	Root DM (mg/plant)	Shoot/ Root ratio
Compost only	7.38	0.16	2.28	1.92	12.00	3.00	4.04
Compost: CRH mix (1:1)	6.84	0.19	2.78	1.88	11.00	3.00	3.67
CRH only	5.70	0.13	3.36	0.89	7.86	3.00	2.73
LSD *(P<0.05)(n=5)*	1.187	0.029	0.570	0.370	0.667	0.629	0.623

CRH= carbonated rice husks

4.3.1.4 Effect of growing medium (factor 1) on vegetative properties of tomato transplants after three weeks of treatment

Results from the experiment show that increasing compost concentration in the substrate resulted in increased growth of tomato transplants (Table 4.15). Transplants in "compost only" had the highest plant height and shoot/ root ratio with 27.14 cm and 6.16, respectively. Transplants in compost-CRH mix (1:1) had the highest shoot DM (446.70 mg/plant), root DM (101.90 mg/plant) and leaf chlorophyll content (11.52 CCI). At the end of treatment, plant height, stem diameter, total dry matter (shoot and root), chlorophyll content and root volume were significantly higher in both "compost only" and compost-CRH mix (1:1) media than in "CRH only". Stem diameter, plant height, root length and volume, and number of leaves were however not significantly different between the two media types (compost only and compost-CRH mix 1:1). See Appendix 2 for complete results.

Table 4.15: Effect of growing media on vegetative properties of tomato in the greenhouse after 3 weeks of treatment.

Media Treatments	Plant height (cm)	Stem diameter (mm)	Shoot DM (mg/plant)	Root DM (mg/plant)	Chlorophyll content (CCI)	Shoot/ root ratio
Compost only	27.14	0.39	441.30	74.30	9.63	6.16
Compost: CRH mix (1:1)	26.70	0.40	446.70	101.90	11.52	4.54
CRH only	14.17	0.29	118.00	34.70	6.27	3.32
LSD *(p<0.05)(n=3)*	0.984	0.012	28.480	8.170	0.676	0.625

CRH= carbonated rice husks.

4.3.1.5 Effect of nutrient solution (factor 2) on vegetative properties of tomato transplant after three weeks of treatment.

The different nutrient solutions significantly affected growth and development of the transplants in the greenhouse. Generally transplant heights were highest in the inorganic nutrient solutions; In-fert-1 (29.24 cm) and In-fert-2 (28.47 cm) than in the organic nutrient solutions; CT-1 (19.87 cm) and CT-2 (17.22 cm) and in the W (18.56 cm) (Table 4.16). Plant height, stem diameter and total dry matter were significantly higher in both inorganic solutions (In-fert-1 and In-fert-2) than in the organic nutrient solutions (CT-1 and CT-2) and control (water). However there were no significant differences in the measured growth parameters between In-fert-1 and In-fert-2 except in root dry matter (DM), where it was significantly higher (102.80 mg/plant) in In-fert-2 than in In-fert-1 (86.10 mg/plants). Similarly shoot dry matter, number of true leaves, stem diameter and plant height were higher in the CT-1 than in CT-2 but there were no significant differences in chlorophyll content, root dry matter, root volume and shoot/ root ratio between these two organic solutions. Interestingly, the control (water) solution recorded higher plant height (18.56 cm), and root DM (66.40 mg/plant) than transplants in the CT-2 which had height of 17.22 cm and root DM of 44.40 mg/plant. Whereas CT-2 nutrient solution recorded higher shoot/ root ratio (4.24) than in the control (3.33). See Appendix 3 for complete results.

Table 4.16: Effect of nutrient solution on vegetative properties of tomato transplants after three weeks of treatment.

Nutrient Solutions	Plant Height (cm)	Stem Diameter (mm)	Shoot DM (mg/plant)	Root DM (mg/plant)	Chlorophyll content (CCI)	Shoot/ root ratio
CT-1	19.87	0.33	279.40	51.70	6.30	4.84
CT-2	17.22	0.31	213.30	44.40	5.97	4.24
In-fert-1	29.24	0.42	490.00	86.10	14.17	5.70
In-fert-2	28.47	0.43	506.10	102.80	13.21	5.24
W	18.56	0.32	221.10	66.40	6.05	3.33
LSD *(p<0.05)(n=3)*	1.271	0.015	36.770	10.550	0.873	0.807

CT-1= Compost tea 1 (1: 5, compost extract: water), CT-2= Compost tea 2 (1: 10, compost extract: water), In-fert-1= inorganic fertilizer N solution (400 mg N/L), In-fert-2= inorganic fertilizer N solution (200 mg N/L) and W= water (control).

4.3.1.6 Interactions between growing medium and nutrient solution type on vegetative properties of tomato after three weeks of treatment

Increasing concentrations of compost in the medium (from 0% to 100%) and organic nutrient solution (CT-2 to CT-1) resulted in significant increase in shoot dry matter and shoot/ root ratio. Stem diameter, root length, leaf chlorophyll content, root dry matter and root volume reduced with increasing compost concentration but were hardly significant (Table 4.17). Stem diameter was significantly higher in compost-CRH mix (1:1) but there was no significant difference between CT-1 (0.38 mm) and CT-2 (0.37 mm). Similarly, root dry

matter, number of leaves and plant height were highest in both "compost only" and compost-CRH mix (1:1) but there were no significant difference between the two types of media.

Interactions between media and inorganic nutrient solutions show that increasing medium compost concentration (0% to 100%) and inorganic nitrogen (N) from 200 to 400 mg/L did not necessarily result in increased growth of tomato transplants (Table 4.17). Total dry matter (shoot and root) were significantly reduced at the highest compost and inorganic N concentrations. Highest shoot dry matter was obtained in compost-CRH mix (1:1) but there was no significant difference between In-fert-1 (728.30 mg/plant) and In-fert-2 (711.70 mg/plant). Similarly highest root dry matter was obtained in compost-CRH mix; however it was significantly higher in In-fert-2 (153.30 mg/plant) than in In-fert-1 (121.70 mg/plant). Increasing concentration of N from 200 to 400 mg N/L did not significantly affect plant height within each medium type; also plant height was not different between "compost only" and compost-CRH mix (1:1) for both inorganic nutrient solutions. Leaf chlorophyll content was significantly higher in compost-CRH mix (1:1) but there was no significant difference between In-fert-1 (16.85 CCI) and In-fert-2 (16.89 CCI).

In the control, number of leaves and shoot/root ratio did not significantly differ among the medium types. However, plant height, stem diameter and shoot dry matter increased significantly with increased compost addition to the substrate. There were no significant differences in root volume, root dry matter; root length and leaf chlorophyll content between compost only and compost-CRH mix though both were significantly higher than CRH only.

Comparing growth response of tomato to both media and nutrient solutions, Plant height, stem diameter were significantly higher in compost-CRH mix and In-fert-2 than the rest of the other treatment except compost-CRH mix and In-fert-1 which was not significantly different from compost-CRH mix and In-fert-2. Root length was highest in compost-CRH mix (1:1) and CT-2 but was not significantly different from compost-CRH mix and W. See Appendix 4 for more details.

Table 4.17: Interaction effects between media type and nutrient solution type on vegetative properties of tomato transplants at the end of treatment.

	Irrigation nutrient solutions				
Media (Substrate)	CT-1	CT-2	In-fert-1	In-fert-2	W
Plant Height (cm)					
Compost only	25.55	22.35	31.62	30.67	25.50
Compost- CRH mix (1:1)	24.70	20.40	32.92	33.33	22.17
CRH only	9.35	8.90	23.18	21.42	8.00
LSD *(P < 0.05)(n =3)*			2.201		
Stem diameter (mm)					
Compost only	0.38	0.35	0.44	0.41	0.37
Compost- CRH mix (1:1)	0.38	0.37	0.44	0.45	0.35
CRH only	0.22	0.22	0.38	0.43	0.22
LSD *(P < 0.05)(n =3)*			0.013		
Chlorophyll content (CCI)					
Compost only	7.24	7.07	14.42	12.44	6.97
Compost- CRH mix (1:1)	8.17	7.25	16.85	16.89	8.45
CRH only	3.50	3.58	11.23	10.30	2.73
LSD *(P < 0.05)(n =3)*			1.512		
Shoot dry matter (mg/plant)					
Compost only	455.00	368.30	503.30	515.00	365.00
Compost- CRH mix (1:1)	358.30	253.30	728.30	711.70	281.70
CRH only	25.00	18.30	238.30	291.70	16.70
LSD *(P < 0.05)(n =3)*			63.690		
Root dry matter (mg/plant)					
Compost only	71.70	65.00	66.70	71.70	96.7
Compost- CRH mix (1:1)	75.00	61.70	121.70	153.30	97.7
CRH only	8.30	6.70	70.00	83.30	5.00
LSD *(P < 0.05)(n =3)*			18.260		

CT-1= Compost tea 1 (1: 5, compost extract: water), CT-2= Compost tea 2 (1: 10, compost extract: water), In-fert-1= inorganic fertilizer N solution (400 mg N/L), In-fert-2= inorganic fertilizer N solution (200 mg N/L) and W= water (control).

4.3.1.7 Nitrogen fertilizer equivalents of compost teas (CT-1 and CT-2).

Total dry matter (shoot + root DM) yields for the inorganic fertilizer N treatments were significantly *($p<0.05$)* higher than those of the compost tea treatments. The total DM yields obtained were 608.9 and 576.1 mg/plant for 200 and 400 mg N/L respectively. CT-1 and CT-2 had 331.1 and 257.7 mg/plant, respectively. As can be seen in Figure 4.13, total DM of compost teas total DM fell below or fell lower than the N response curve. Hence, the fertilizer equivalencies for the compost teas could not be estimated from the N response curve.

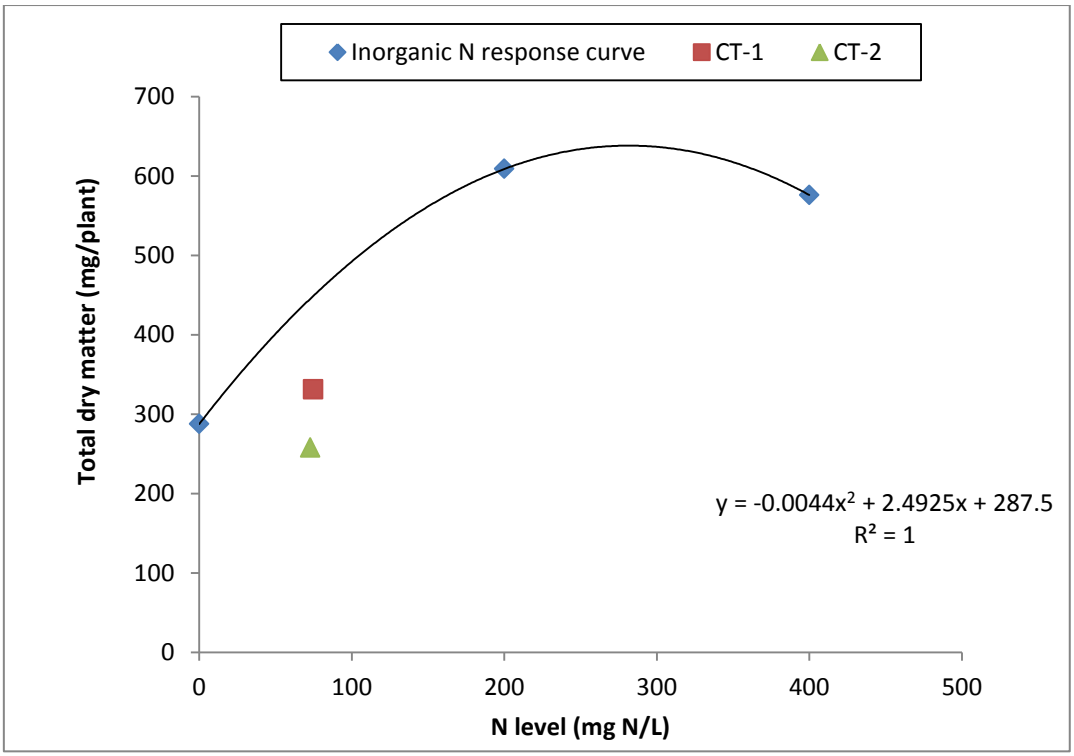

Figure 4.13: The biomass yield response to levels of nitrogen (N).

4.3.2 Pepper (*Capsicum annum var. Bird eye*) transplant production

4.3.2.1 Physical and chemical characteristics of growing media (substrate) types

Physical properties of the growing media were significantly affected by the addition of compost to the media (Table 4.18). Electrical conductivity (EC) increased with increasing compost application rate. The highest EC (2.10 dS/cm) was observed in the 100% compost growing medium whiles the lowest of 0.01 dS/cm was observed in the 100% CRH medium. The pH was significantly higher in the 50% compost (7.8) than in that of the other media treatments. The lowest pH was observed for 100% CRH (7.3). The bulk density, similar to EC also increased with increasing compost application rate in the growing medium. It was significantly highest in 100% compost (0.73 g/cm^3) and lowest in 100% CRH (0.31 g/cm^3). Water holding capacity (WHC) was significantly higher in the 100% CRH medium (3.10 per g) than in the compost amended media. The 100% Compost medium had the lowest WHC of 1.16 per gram of substrate.

Table 4.18: Some physical characteristics of "compost only", compost- CRH mixes and "CRH only".

Media (substrate)	pH (1:5)	EC (1:10) (dS/cm)	Bulk density (g/cm^3)	Water holding capacity (per gram)
100% Compost: 0% CRH	7.5	2.10	0.73	1.16
75% Compost: 25% CRH	7.7	1.93	0.66	1.43
50% Compost: 50% CRH	7.8	1.60	0.55	1.74
25% Compost: 75% CRH	7.8	1.20	0.45	1.97
0% Compost: 100% CRH	7.3	0.01	0.31	3.10
LSD *(P<0.05)(n=5)*	0.03	0.076	0.015	0.127

CRH= carbonated rice husks

Table 4.19 shows the NPK content in the different growing media. There were no significant differences in total N content between 50% compost (1.65%), 75% (1.67%) compost and 100% compost (1.79%) amended media. Total and available phosphorus (P) were higher in the 75% compost amended media whiles the total potassium was highest in the 100% compost (1.050%) amended media and lowest in the 100% CRH (0.455%) growing media.

Table 4.19: Some chemical characteristics of "compost only", compost- CRH mixes and "CRH only".

Media (Substrate)	Total N (%)	NH_4-N ($mgkg^{-1}$)	NO_3-N ($mgkg^{-1}$)	Total P (%)	Avail-P (%)	Total K (%)	C/N
100% Compost: 0% CRH	1.79	205.20	1155.60	0.540	0.116	1.050	19.75
75% Compost: 25% CRH	1.67	316.80	590.40	0.550	0.132	1.035	17.98
50% Compost: 50% CRH	1.65	223.20	423.30	0.438	0.146	0.920	13.34
25% Compost:75% CRH	1.23	180.00	441.00	0.335	0.093	0.815	13.61
0%Compost:100% CRH	1.13	158.40	187.20	0.062	0.003	0.455	10.99
LSD(P<0.05)(n=5)	0.281	96.100	142.100	0.1568	0.0106	0.0526	3.824

CRH= Carbonated Rice Husks

4.3.2.2 Physico-chemical characteristics of organic and inorganic nutrient solutions

Table 4.20 shows some physico- chemical characteristics of the compost teas (CT) and the inorganic fertilizer N solutions. The pH of In-fert-2 (5.1) and In-fert-3 (5.1) were not significantly different, however the pH of CT (8.1) was significantly higher than that of all the inorganic fertilizer solutions. On the other hand, the EC of CT (0.56 dS/cm) was significantly higher than that of In-fert-2 (0.30 dS/cm) and In-fert-3 (0.01 dS/cm) but lower than that of In-fert- 1 (0.90 dS/cm).

Table 4.20: Physico-chemical characteristics of organic and inorganic N source solutions

Nutrient Solutions	pH	EC (dS/cm)	Total N (mg/L)	NH_4^+-N (mg/L)	NO_3^--N (mg/L)	Total P (mg/L)	Avail P (mg/L)	Total K (mg/L)
CT	8.1	0.56	89.36	54.93	64.71	1525.00	75.14	11130.00
In-fert-1	5.6	0.90	400.00	200.00	200.00	176.00	176.00	150.00
In-fert-2	5.1	0.30	200.00	100.00	100.00	100.00	100.00	150.00
In-fert-3	5.1	0.01	100.00	50.00	50.00	80.00	80.00	80.00
LSD *(P< 0.05)* *(n=6)*	0.13	0.082	N/A	N/A	N/A	N/A	N/A	N/A

CT= Compost tea (1: 2, compost extract: water), In-fert-1= inorganic fertilizer N solution (400 mg N/L), In-fert-2= inorganic fertilizer solution (200 mg N/L) and In-fert-3= inorganic fertilizer N solution (100 mg N/L). N/A = not applicable.

4.3.2.3 Effect of growing medium (factor1) on vegetative properties of pepper transplants after three weeks of treatment.

Plant height, stem diameter and number of leaves increased with increasing compost concentration in the media (Table 4.21). Total DM yield was affected by the media treatments. Shoot DM generally increased with increasing compost amendment. However, 50% compost had the highest shoot DM (657.30 mg/plant). Similarly, root DM also increased with increasing compost amendment but there was no significant difference between 75% compost (190.00 mg/plant) and 100% compost (189.30 mg/plant). The rest of the results are shown in Appendix 5.

Table 4.21: Effect of growing medium on vegetative properties of pepper transplant in the greenhouse after 3 weeks of treatment.

Media Treatments	Plant Height (cm)	Stem Diameter (mm)	Shoot DM (mg/plant)	Root DM (mg/plant)	Chlorophyll content (CCI)	Shoot/ root ratio
100% Compost : 0% CRH	22.99	0.28	650.70	189.30	11.04	3.29
75% Compost : 25% CRH	24.39	0.28	610.70	190.00	11.40	3.24
50% Compost : 50% CRH	24.18	0.29	657.30	166.00	11.15	4.25
25% Compost : 75% CRH	19.61	0.23	436.00	134.70	9.58	3.37
0% Compost : 100% CRH	9.94	0.14	129.60	42.30	9.54	3.18
LSD *(p<0.01)(n=3)*	0.639	0.010	46.090	17.900	0.581	0.412

CRH= carbonated rice husks.

4.3.2.4 Effect of nutrient solution (factor 2) on vegetative *properties of pepper transplants after three weeks of treatment*

Plant height increased with increasing N source in the inorganic fertilizer solutions however, plant height was shorter (19.88 cm) in the compost tea (CT) treatment than in the inorganic treatments (Table 4.22). Stem diameter was generally thickest in the inorganic fertilizer solutions than in the CT treatments. Root length was significantly highest in CT treatment than in the inorganic treatments. However, chlorophyll content was lowest in the CT treatment than the other treatments. Full details of the results are shown in Appendix 6.

Table 4.22: Effect of nutrient solution on vegetative properties of tomato transplants after three weeks of treatment.

Nutrient Solutions	Plant Height (cm)	Stem Diameter (mm)	Shoot DM (mg/plant)	Root DM (mg/plant)	Chlorophyll content (CCI)	Shoot/ root ratio
CT	19.88	0.23	449.30	172.00	8.09	2.81
In-fert-1	23.38	0.28	616.70	126.00	11.50	5.15
In-fert-2	22.72	0.29	693.30	166.00	9.84	4.40
In-fert-3	21.03	0.24	472.00	153.30	13.06	3.11
W	15.10	0.19	213.00	104.30	10.24	1.85
LSD *(p<0.01)(n=3)*	0.639	0.010	46.090	17.900	0.581	0.412

CT= Compost tea 1 (1: 2, compost extract: water), In-fert-1= inorganic fertilizer N solution (400 mg N/L), In-fert-2= inorganic fertilizer N solution (200 mg N/L), In-fert-3= inorganic fertilizer N solution (100 mg N/L) and W= water (control).

4.3.2.5 Interactions between growing medium and nutrient solution type on vegetative properties of pepper transplants after three weeks of treatment

Data in Table 4.23 show that, increasing the application rates of compost in the growing media coupled with increasing N concentration in the inorganic nutrient solutions did not necessarily result in a positive response from the pepper transplants in terms of growth. The same could be said for the interaction between the growing media and the compost tea (CT) treatment; best results in terms of the vegetative growth parameters were obtain for the combination between CT and 50% - 75% compost amended media. Interactions between the growing media and the inorganic fertilizer N solutions revealed that the highest total biomass yield was obtained for the 100% compost growing media and In-fert-2 (200 mg N/L) combination. See appendix 7 for the complete results

Table 4.23: Interaction effects between media type and nutrient solution type on vegetative properties of pepper transplants at the end of treatment.

	Irrigation nutrient solutions				
Media (Substrate)	CT	In-fert-1	In-fert-2	In-fert-3	W
Plant Height (cm)					
100% Compost: 0% CRH	24.23	26.95	27.32	20.52	15.93
75% Compost: 25% CRH	27.02	25.45	24.22	27.33	17.93
50% Compost: 50% CRH	24.04	23.48	26.57	25.03	21.77
25% Compost: 75% CRH	15.63	22.18	24.53	20.18	15.55
0% Compost: 100% CRH	8.45	13.83	10.98	12.12	4.33
LSD *(P < 0.01)(n =3)*			1.428		
Stem diameter (mm)					
100% Compost: 0% CRH	0.26	0.35	0.36	0.24	0.20
75% Compost: 25% CRH	0.27	0.30	0.28	0.31	0.21
50% Compost: 50% CRH	0.29	0.30	0.30	0.28	0.29
25% Compost: 75% CRH	0.22	0.25	0.30	0.23	0.18
0% Compost: 100% CRH	0.10	0.19	0.19	0.17	0.04
LSD *(P < 0.01)(n =3)*			0.022		
Shoot dry matter (mg/plant)					
100% Compost: 0% CRH	633.30	883.30	1070.00	436.70	230.00
75% Compost: 25% CRH	620.00	726.70	696.70	750.00	260.00
50% Compost: 50% CRH	686.70	726.70	810.00	656.70	406.70
25% Compost: 75% CRH	396.70	513.30	720.00	390.00	160.00
0% Compost: 100% CRH	160.00	233.30	170.00	126.70	8.20
LSD *(P < 0.01)(n =3)*			103.060		
Root dry matter (mg/plant)					
100% Compost: 0% CRH	206.70	213.30	296.70	140.00	110.00
75% Compost: 25% CRH	233.30	170.00	166.70	276.70	133.30
50% Compost: 50% CRH	220.00	110.00	150.00	180.00	190.00
25% Compost: 75% CRH	220.00	93.3	180.00	126.70	80.00
0% Compost: 100% CRH	76.70	46.70	36.70	43.30	8.10
LSD *(P < 0.01)(n =3)*			40.020		

CT = Compost tea 1 (1: 2, compost extract: water), In-fert-1= inorganic fertilizer N solution (400 mg N/L), In-fert-2= inorganic fertilizer solution (200 mg N/L), In-fert-3= inorganic fertiliser solution (100 mg N/L) and W= water (control).

4.3.2.6 Nitrogen fertilizer equivalent of compost tea (CT)

Results obtained showed that the total DM yields were 625.30, 859.30 and 743.40 mg/plant for inorganic N fertilizer solutions; 100, 200 and 400 mg N/L respectively. Total DM yield obtained from CT treatment was 671.3 mg/plant and as shown in Figure 4.14, it is closer to or comparable to the DM yields obtained

for 100 mg N/L inorganic N fertilizer solution. The FE was thus estimated from the N response curve and gave a value of 108% for the compost tea (CT).

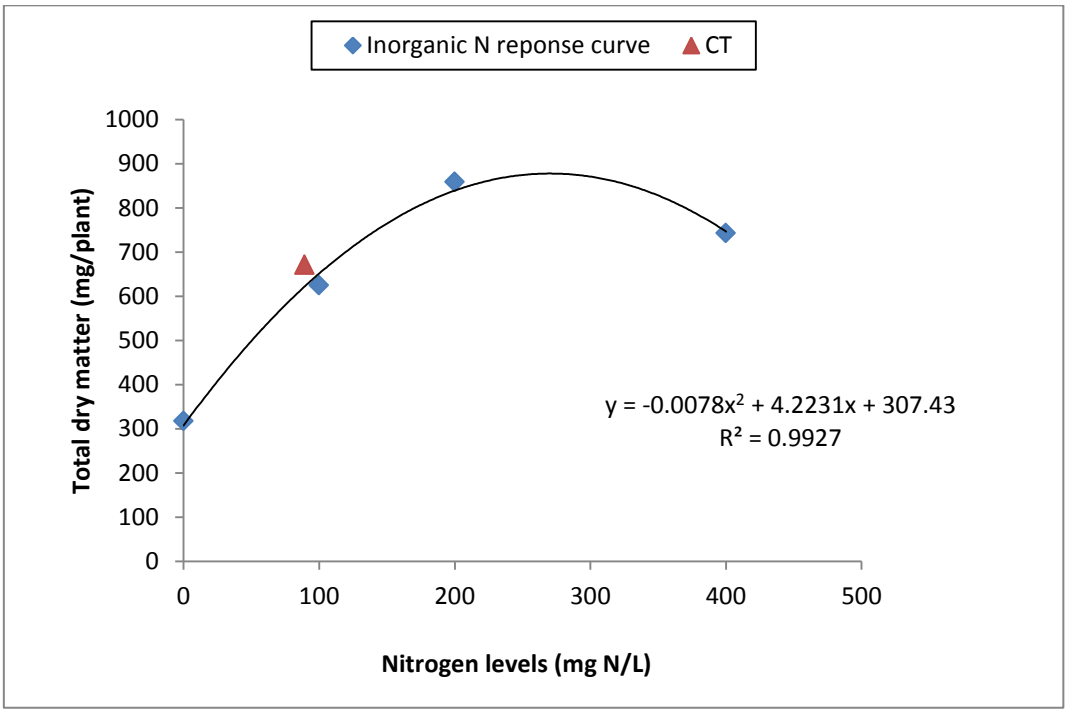

Figure 4.14: The Biomass yield response to levels of nitrogen (N).

4.4 Perception of farmers and consumers on human waste (FS) composting and use in crop production.

4.4.1 Perception of farmers

Out of the thirty (30) farmers interviewed, only 5 (17%) of them knew about composting and out of those 5 farmers, only 2 (40%) had actually composted before. Thus about 83% of vegetable farmers in Accra do not know about composting. More so, 33% of the farmers responded to having knowledge on human waste use in crop production, but had no knowledge of how it is composted. Whiles 67% of farmers interviewed had no knowledge what so ever on human waste composting and use. Out of the 33% farmers who responded to having knowledge about human waste use, 90% of them responded yes to go into

human waste composting and subsequently apply it to their crops provided training could be offered to them.

4.4.2 Perception of consumers

Results of the study show that, all (100%) the consumers interviewed purchase their vegetables from the market and none directly from the farm. Ninety percent (90%) of them do not ask what type of fertilizer is used to cultivate the vegetables. Out of the 10% who ask, the willingness of 67% of them to buy vegetables was affected by the type of fertilizer used.

Only 17% responded to knowing about composting and use in vegetable production, though 30% of them would patronise vegetables grown with compost. When asked about human waste composting, only 7% of the consumers knew human waste can be composted whiles 93% did not know. However, 23% of them agreed human waste should be composted whiles 47% of them disagreed. The remaining 30% said they did not know if human waste should be composted or not.

About 84% of the consumers interviewed had no idea farmers use composted human waste but 20% of them agreed composting of human waste makes it safe for use. At the end, 40% of the consumers would actually patronise vegetables cultivated with composted human waste under the condition that it is better than the chemical fertilizers and that they would have to wash the vegetables well before they consume them.

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Characterisation and quantification of faecal sludge (FS) in Sekondi-Takoradi metropolitan area (STMA)

5.1.1 Characteristics of faecal sludge (FS) in STMA

The characteristics of septage and public toilet sludge in STMA showed very high variations and differences suggesting that the type of on-site sanitation system (OSS) and storage duration may have influenced the characteristics of the sludge in terms of BOD, COD, *E. coli* and helminth eggs. This confirms reports from earlier studies by Montangero and Strauss (2002) as well as Kone and Strauss (2004) that, FS characteristics vary widely within and among cities, based on the types of on-site sanitation installations in use and on the emptying practice.

The septage had lower BOD and was more stabilised as compared to the public toilet sludge. This supports earlier studies by Kuffour *et al.* (2013) that more than 50% of the BOD load entering the septic tank is removed by anaerobic digestion during storage. Furthermore, intrusion of water from underground discharge also reduces the septage BOD further and causing a reduction in concentration of some of the biosolids (Kuffour *et al.*, 2013). A relatively higher number of helminth eggs were found in the public toilet sludge than in the septage, a percentage of 57% higher. Out of the total helminth eggs identified, 57% and 82% found in the septage and public toilet sludge, respectively, were *Ascaris lumbricoides* eggs. This could be due to the differences in the age of the sludge that might have generated heat to inactivate some of the helminth eggs during

storage. In a previous study by Kone *et al.* (2007), they reported that, there is no apparent connection between the type of FS source (public toilet sludge or septage) and degree of contamination with helminth eggs. However, the results obtained in this present study could be explained by the higher use frequency of public toilets by the inhabitants of STMA than water closets. This is evidenced by the higher quantities of public toilet sludge generated in the STMA observed by the researcher. This confirms earlier reports by CHF International (2011) that, among households in the entire STMA area, only 17% have access to a water closet while 49% use public toilets.

The predominance of *Ascaris* in the FS and the environment can be explained by its higher egg production and capacity to survive. This confirms earlier reports by Kone *et al*. (2007). Indeed, the female *Ascaris lumbricoides* worms produce 200,000 eggs compared to others (Feachem *et al.*, 1983). For faecal coliforms, the source of sludge could play a role in the level of contamination. The longer periods of storage and evolution of certain gases such as methane (CH4) during anaerobic digestion in septic tanks may have been responsible for a lot of coliform die – out in septage. This might explain why there were lower levels of *E. coli* and faecal coliforms observed in septage than the public toilet sludge.

5.1.2 Comparison of faecal sludge in STMA with other cities

Table 5.1 shows some characteristics of FS (septage and public toilet sludge) in STMA which was characterized in the present study, compared with previous studies on FS in Accra (Ghana) and some cities in other developing countries around the world by Kone and Strauss (2004). In Accra, the BOD of septage was 840 mg/L whiles those reported from Bangkok and Alcorta were between 600 –

5500 mg/L and 750 – 2600 mg/L respectively. These BOD values are closer to the minimum BOD value (700 mg/L) reported in the present study for STMA. This confirms that the BOD of septage is similar among different cities and could be due to the similarities in means and types of sludge disposal (on-site sanitation systems) technologies employed in these cities. Similarly, the BOD of public toilet sludge in STMA is similar to that reported in Accra (7600 mg/L) confirming earlier studies by (Kone and Strauss, 2004). Chemical oxygen demand (COD) values recorded for public toilet sludge in Accra (4900 mg/L) is closer to the maximum limit (8300 -56000 mg/L) reported for STMA.

The NH_4-N concentration of STMA septage was twice the value reported for Accra, though it was within the range reported for Bangkok (Kone and Strauss, 2004). This indicates that there are similarities between the septages. However the lower NH_4^+-N values in Accra and elsewhere could be due to either a lower microbial decomposition (ammonification) rate or a higher volatilization (ammonia gas release) rate. The latter is usually accompanied by foul smells or odour. Total solids (TS) concentration was also lower for both public toilet sludge and septage in STMA compared to values reported in Accra (Kone and Strauss, 2004). This could be due to the infiltration of groundwater into the underground storage vaults used for FS in the STMA thereby diluting the solid contents. This phenomenon is very pronounced during both major and minor raining seasons leading to the rapid filing up of the vaults. This is confirmed by the Waste Management Department of STMA which records increased trips or increased volumes of FS disposed of during rainy seasons.

Table 5.1: The comparison between FS in STMA with FS from cities in other countries.

Parameter	[1]Sekondi-Takoradi (Ghana)	[1]Sekondi-Takoradi (Ghana)	Accra (Ghana)	Accra (Ghana)	Ouagadougou (Burkina-Faso)	Bangkok (Thailand)	Alcorta (Argentina)
Type of FS	*Public toilet sludge*	*Septage*	*Public toilet sludge*	*Septage*	*Septage*	*Septage mean (range)*	*Septage mean (range)*
COD (mg/L)	8300-56000	1400-9200	49000	7800	13500	15700 (1200-76000)	4200
BOD (mg/L)	3500-9800	700-1300	7600	840	2240	2300 (600-5500)	750-2600
TS (mg/L)	37200	3245	52500	12000	19000	15350 (2200-67200)	(6000-35000 SS)
TVS (% of TS)	**	**	68	59	47	73	50 (VSS)
TKN (mg/L)	154400	160400	**	**	2100	1100 (300-5000)	190
NH4-N (mg/L)	577	648	3300	330	**	415 (120-1200)	150

*Source: Kone and Strauss (2004), ** Not determined. [1]present study conducted in STMA by researcher.*

Total solids values for STMA falls within the range of TS reported for Bangkok and Alcorta. Therefore it can be said that the characteristics of FS in this present study are similar to those from other developing countries.

5.1.3 Quantification of faecal sludge

Following the data collected in STMA, using the year 2005 as a base year, it can be projected that by the end of 2008, there was an increment of 33.17% in the number of tanker trips corresponding to 41.25% increment in the total quantify of FS generated and disposed of. By the end of the first quarter of the year 2012, the total number of trips was estimated to increase to 57.78% corresponding to an estimated increment of 62.99% in the total quantity of FS generated and disposed of. It may therefore be suggested that relevant stakeholders develop FS

management/treatment technologies capable of expansion to meet the rapidly increasing quantities in the Metropolitan Area.

Further analysis and review of data showed that in the Month of January 2012, the highest peak (783 m^3) representing FS quantities was generated within the Takoradi Township, followed by Takoradi harbour and Sekondi Township with quantities of 516m^3 and 273 m^3 respectively. These trends can be attributed to the various socio- economic activities that take place at those places to attract a lot of people. The Takoradi Township (described as the commercial capital of the metropolis) for instance has the largest markets (foodstuffs market, lorry stations etc), offices, schools etc. Hence on daily basis, influx of people from all over the other localities visit the area for one business or the other causing large volumes of FS to be generated from that locality. Similarly, Sekondi Township which can be described as the administrative capital of the metropolis has most of the Government institutions such as the Regional coordinating council, the Metropolitan Assembly, a Magistrate Court and many others attracting lots of people to the township on daily basis. This could explain why there was high FS generation in this locality. The Takoradi harbour is also one of the busiest localities within the STMA. It is believed that most of the FS generated from this locality comes from the vessels that come to dock and offload goods.

The least quantities of FS that were generated from localities such as Kweikuma, Sofokrom and New Takoradi do not necessarily mean people do not live in those areas. It could be due to the assumption that most people from those areas spend on the average 4 - 12 hours in a day away from home to work, school, church and market located mostly in Sekondi and Takoradi Townships. It is possible the inhabitants rarely visit the on-site sanitation systems at home. Another disturbing

reason, which was gathered through personal communication with an inhabitant, was that most of the times water supply is not regular therefore people in those affected localities resort to defecating in black polythene bags and dispose them off as municipal solid waste.

5.2 Physical, biological and chemical changes during co-composting of faecal sludge (FS) with empty fruit bunches (EFB) and cocoa pod husks (CPH).

5.2.1 Composting process and maturity determination of co-composts

At the end of the 90 days co-composting process, there was significant reduction in heap volumes for all treatments. The volume reduction recorded was between 36 and 51%. Treatments A and E which were (FS + EFB; 1:1) and (FS + EFB + CPH; 2:2:1) respectively achieved 50% volume reduction whiles treatments B (FS+CPH; 1:1) and D (FS + EFB + CPH; 2: 1: 1) achieved 36% and 40%, respectively. This could be attributed to differences in feedstock, in terms of easily biodegradable materials and lignin contents found especially in the EFB. The lower volume reduction observed for treatment B could be due to the very fine nature of CPH which led to the pile becoming compacted. This may have prevented the diffusion of air through the pile for the microbes to respire. These findings or losses confirm the normal range of 35 to 50% reported by Eghball *et al*. (1997). However treatment C (FS + EFB + CPH; 1: 1: 1) recorded higher volume reduction than the normal range. This also confirms earlier observations made by Dao (1999) when he composted animal manure.

Temperature of the co-compost treatments was generally above 45˚C but could not exceed 55˚C. These temperatures were lower than the maximum temperature

(62˚C) reported by Adamtey (2005) and higher than the 45˚C observed by Kala *et al.* (2012). These differences could be due to the type of composting process or the type of feedstock and ratios used. Only co-compost treatments A, D and E reached the thermophilic stage (50˚C) whiles treatments B and C did not. The fact that B and C did not reach the thermophilic stage could be attributed to the dissipation of heat due to small volume of the piles. This confirms earlier reports by Kala *et al.* (2012) when he composted oil palm waste with sewage sludge. In the case of treatment B, the cocoa pod husks (CPH) particles easily became very fine thereby making the pile easily compacted. It was also found out that, generally empty fruit bunch (EFB) mixtures resulted in a more rapid rise in temperature. This finding agrees with finding of Thambirajah (1988) and Kala *et al.*, (2009) that, EFB mixtures during composting resulted in a more rapid rise in temperature compared to trunk and frond mixtures.

The initial pH of the co-compost treatments ranged between 7.6 – 7.9. Though these were not in the optimum range of 5.6-6.1 reported for composting (Bertoldi *et al*., 1983; Miller, 1992; Polprasert, 1996), this could probably be due to original high pH of the compost feedstock. The pH of treatments A, C, D and E behaved in similar patterns during the composting process; their pH increased when the temperature increased during the initial stages. This may be due to the loss of ammonium through volatilization as a result of high temperatures. This agrees with observations by Baharuddin *et al.* (2009) when he co-composted EFB with partially treated POME. However for treatment B which did not contain any EFB, the pH declined during the initial stages. This might be due to the action of the microorganisms on the most labile organic matter fraction (e.g. carbohydrates), leading to the release of carbon dioxide and organic acids (Bernal *et al.*, 1998a).

Though throughout the composting process, the pH did not fall below 7, the pH of the process still fell within the optimum pH range of 6.5 to 8.5 for composting reported by other authors (Jeris and Regan, 1973; Willson, 1993). At the end of co-composting, the pH of the co-compost treatments A (7.3), B (7.3) and D (7.5) were lower than the pH at the start. This observation may be due to the formation of organic acids (e.g. humic acids) towards the end of composting. Treatments A, B, D and E were within the recommended level (5.5-8.0) by CEC (1986) for compost. Whiles the pH of treatment C (8.10) confirms the maximum pH reported by Baharuddin *et al.* (2009).

Carbon dioxide evolution provides a measure of microbial activity (respiration). The decrease in CO_2 evolution rates over 12 weeks period shows that it was due to the decrease in microbial activities as a result of a decrease in the amount of biodegradable substrate available. However, the differences in CO_2 rates observed for the different treatments show that the rates may have been affected by the differences in the easily biodegradable materials and the feedstock ratios. Treatment B had the lowest CO_2 evolution rates between weeks 1 – 4. And this may be due to the lower carbon sources in treatment B as indicated by the lowest C/N ratio (32.15). A low respiration activity indicates that the available carbon has essentially been utilised. This could account for why the rates for all the treatments in Figure 4.5 decreased with time. This confirms reports from previous studies by Ayuso (1996) that microbial activities to a large extent depend on the nature of the organic matter added to soil or the compost mixtures. Also, the presence of EFB in other treatments (A, C, D and E) may have made the treatment mixtures more porous to O_2 because of its fibrous nature hence allowing for efficient supply of O_2 and the maximisation of respiratory activities. The final

CO_2 evolution rates observed for all the treatments were less than 1 mg CO_2/g compost per day. This value is lower than what was reported by Adamtey (2005) indicating that the composts were stable and matured.

After co-composting, the initial C/N ratios of the treatments reduced from 38.20, 32.20, 45.20, 61.00 and 51.40 to 20.32, 12.15, 19.73, 17.88 and 19.70 for treatments A, B, C, D and E, respectively. This indicates that the carbon sources in the materials were drastically reduced by microbial activity on the cellulosic substrate and nitrogen. Final C/N ratios of treatments B, C, D, E confirms reports by Heerden *et al.* (2002) that a value of C/N ratio less than 20 could be considered as a satisfactory maturation level of compost. Treatment B also agrees with Jimenez and Perez (1992) that the ratio of 15 or less is more preferable. Treatments in this study had C/N ratios of less than 20 except treatment A which was slightly above 20. This might be due to the nitrogen sources not being sufficient for the microbes to fully degrade the carbon sources. More so, during the co-composting process, increases in total nitrogen content believed to be in the form of microbial protein and humic substances were observed for all treatments leading to the drastic reduction in C/N ratios. Similar observations were also made by Saber *et al.* (2011); Buerno *et al.* (2008) and Tsai (1994).

The rate of ammonium (NH_4-N) production decreased rapidly with time within the first four weeks of composting for all the co-compost treatments and then remained relatively stable till the end of composting. The rate of NH_4^+-N production could be affected by the type of composting (windrow or vessel) or the type of feedstock (high in protein or carbon source). This is in agreement with Laos *et al.* (2002), Levanon and Pluda (2002) and Banegas *et al.* (2007) who

noted that NH_4^+-N concentrations decreased towards stable values at the end of the thermophilic stage of composting.

Generally, all the treatments in this study exhibited an increasing trend in NO_3^-- N concentration throughout the 12 weeks. Formation of NO_3^--N and NO_2^--N accompanies the decrease in NH_4^+-N concentrations in the later period of composting process (Sun, 2006). According to Kala *et al.* (2009), it is at the maturation phase, where temperature decreases to mesophilic and subsequently, ambient levels, that nitrification reactions, in which ammonia (a by-product from waste stabilization) is biologically oxidized to become nitrite (NO_2^--N) and finally nitrate (NO_3^--N) take place. This might explain the uniform low increases in NO_3-N for Treatments A and B and then Treatment C and E between Weeks 0 – 6. This also confirms previous studies by Parkinson *et al*., (2004) and Huang *et al.*, (2004).

5.2.2 Effect of feedstock ratio on the physico-chemical and microbial dynamics of co-composts.

Total N was significantly high *($p<0.05$)* in co-compost treatments E (FS+ EFB + CPH, 2: 2:1) and B (FS +CPH, 1: 1), followed by co-compost treatment D (FS+ EFB+ CPH, 2:1:1) at the end of co-composting. This might be due to the high N content and high FS percentage of the feedstock. These treatments had higher percentages of the FS, indicating that the increase in FS component during composting of agricultural residues (EFB and CPH) might result in a higher N content of the final co-composts. This confirms earlier reports by Kala *et al.* (2009). In the present study, total N content varying from 1.05 to 1.76% was

obtained. This confirms earlier reports by Kulhman (1989) that the total N content of compost are from 0.5 to 2.7%.

Similarly, total P at the end of composting was not significantly different *($p<0.05$)* between co-compost treatments E and A. Both treatments had significantly higher total P content followed by treatment B and D suggesting again that, this might be due to the higher P content of the FS compared to the EFB and CPH at the start of composting. Similar observations were again reported by Kala *et al.* (2009). Phosphorus is the main component in the production of nucleic acids, nucleotides, co-enzymes, phospholipids and phytic acids and plays a major role in ATP buildup in plants (Taiz and Zeiger, 1991). According to Morgan (1998), insufficient P concentration in plants could lead to stunted growth and stem and leaves turning to purple. Total K in this study ranged between 0.675 to 0.945%. This was however higher than the recommended level (0.3%) by CEC (1986) in compost. The total K level was lowest in treatment A and highest in treatment C indicating that the major sources of K in the co-compost may have been CPH followed by EFB. The electrical conductivity (EC) did not seem to be affected by feedstock ratios in this study.

The effect of different feedstock ratios in generating thermophilic conditions to sanitize co-composts was evaluated. According to Singh *et al.* (2011), the primary process criteria used for ensuring the microbiological safety of composts have been narrowly defined as time – temperature conditions. For complete sanitation of composts, the USEPA standard demands temperature of > 55˚C for 2 weeks with 5 turns (USEPA, 1993).These sanitation periods are in accordance with most international standards (Hogg *et al.*, 2002a; Noble and Roberts, 2004). In the present study, the temperatures of all co-compost treatments were below

the 55˚C minimum. These were lower than the required temperature reported by USEPA (1993). However, maximum temperatures attained in treatments A, D and E exceeded 50˚C within the first 7 days (1st week) of composting. The level of *E. coli* in all the treatments declined by the 3rd week of composting below the current composting standard which require an *E. coli* load below 1 x 10^3 CFU/g (Hogg *et al*., 2002b; USEPA, 1993). By the end of the 6th week, *E. coli* load in D and E were well below detectable limits. At the end of composting, *E. coli* were completely deactivated in all the treatments indicating that complete deactivation occurred during the cooler curing phase and not during the active thermophilic stages. This confirms earlier reports by Droffner and Brinton (1995) that *Salmonell*a and *E. coli* were found to survive for 59 days at about 60˚C, although pathogens were destroyed during the cooler curing process in the industrial compost. Results from this study suggest that high temperatures might not be the only factor responsible for *E. coli* deactivation. This phenomenon is in agreement with Golueke (1991) and Dumontet *et al.* (1999) that other factors such as pH, presence of metabolic and antagonistic compounds produced by indigenous microflora, accumulation of toxic NH_3 and microbiological competition for nutrients are also involved in the deactivation.

It is however not clear from this study which of the measured parameters or factor or set of factors might have led to the inactivation of *E. coli* as none of the factors tested showed any significant correlation with the *E. coli* counts. The *E.coli* deactivation in this study might however be due to microbiological competition for nutrients and space. This further confirms the findings of Droffner and Brinton (1995) that the mechanism for removal of these

microorganisms during aerobic composting is complex and not simply the result of a thermal physical environment or solely dependent on temperature and time.

However for the faecal coliforms, reductions in numbers below the international standard 1 x 103 CFU/g was only observed for treatment D and E. More so, these treatments recorded the highest temperature ranges during the composting process. This indicates that the different feedstock ratios (treatments) may have affected temperature generation which later affected faecal coliform reductions. Treatments A and B experienced increased levels of faecal colifoms at the end of composting. This could be due to insufficiently high temperatures generated over the period. These results agree with observations made by Turner (2002) that if incomplete inactivation has taken place due to insufficiently high temperature, recovery and growth of the damaged population may be possible.

No helminth eggs were detected in any of the treatments at the end of co-composting process. This could be due to the high temperature (> 45˚C) patterns observed for the different co-compost treatments in this study. Similar observations were made by Kone *et al.* (2007) when he composted faecal sludge with municipal solid waste. According to Kone *et al.* (2007), exposure to temperature over 45˚C for at least 5 days is known to inactivate *Ascaris* eggs, which are very predominant in faecal sludge and the environment.

N-mineralization is of extreme importance because it converts organic N into ammonium (NH_4^+) and nitrates (NO_3^-), the forms that plants take. In this study, N-mineralisation at the end of co-composting was very low (< 11%) making organic N the major nitrogen constituents in the various treatments. This could be attributed to the physico- chemical properties of the starting materials (feedstock) such as the carbon (C) and nitrogen (N) content. Subair *et al.* (1999) found out

that in an experiment with manure, the percentage of organic N mineralised negatively correlated with the amount of carbon, the initial C/N ratio and the loss of carbon during the process. In other studies, it was also found that, organic materials with carbon/ organic N ratio of 15 or more will immobilize N whiles those with carbon/organic N of less than 15 will have greater mineralization rates (Kirchmann, 1985; Mary and Recous, 1994). It was however observed in this study that, Treatments A, C, D and E all had carbon/ organic N ratios of more than 15 and so might explain why N was immobilised or predominantly in the organic form. However, for treatment B which had carbon/ organic N ratio of 13.04 (less than the 15 stated above), N-mineralisation was still low. This could be attributed to the relatively lower microbial activity and conversion rates (from organic to inorganic) measured in the low CO_2 evolution rates of Treatment B.

Nitrogen losses during composting depends on the materials (feedstock) used and on the pH values of the mixtures (Sanchez-Monedero *et al.*, 2001). It may also vary depending on several environmental factors such as aeration, moisture content and temperature (Bishop and Godfrey, 1983). In this study, high N-losses in the range of 44- 73% were observed. This falls within a similar range of 21 - 77% reported by Martins and Dewes (1992) and Rao Bhamidimarri and Pandey (1996). These losses were accompanied by drastic decreases in NH_4^+-N concentration during the first two weeks of composting and might have been due to the high temperature (> 40˚C) and pH (>7.00) generated within that phase. Similar observations were reported by Witter and Lopez-Real (1988) and Bishop and Godfrey (1983). de Bartoldi *et al*. (1980, 1985) reported that the initial C/N ratio of the material also affects loss of N during composting. This was confirmed

by observations in Treatment A, C, D and E where, higher C/N ratios resulted in lower N losses.

Phosphorus losses in this study were surprisingly higher (82 - 88%) than the N losses. The feedstock ratio did not seem to have any significant effect on P loss in this study as was seen for N loss. The losses were probably due to the higher solubility and volatility of phosphoric compounds in the compost materials which might have led to higher leaching and volatilization of P. Even though during the composting process, the leachate were collected and returned back to the respective piles, it did not minimize P loss. In addition, the composting process met with the minor raining season and this may have sped up the leaching process. This however confirms reports by Eghball *et al*., (1997) that, Leaching can also be an important factor in N and other nutrient losses from compost, depending on rainfall conditions. These therefore suggest that, co-composting of feedstock as such should not be carried out under shelter in wet climates or during rainy seasons.

5.3 Greenhouse experiment: Evaluating the effect of compost and compost tea on some vegetative properties of tomato and pepper transplant

5.3.1 Tomato (*Lypersicon esculentum var. M2*) Transplant Production

Physical characteristics such as bulk density and water holding capacity (WHC) of a substrate (medium) can affect emergence and seedling growth. Transplants germinated and emerged faster in carbonated rice husk (CRH) only media, indicating a loose porous medium is preferred for seed germination. This agrees with earlier findings of Ball (1985). In addition, “CRH only” which had the

lowest bulk density, EC and the highest WHC measured may have provided the most favourable air and water infiltration for the tomato seeds. This is also in line with earlier reports by Roe *et al.* (1997). "Compost only" medium recorded the lowest seed germination and emergence in this study. This might be as a result of the relatively high electrical conductivity (EC) (2.10 dS/cm) measured in the medium. This confirms reports by Wong and Chu (1985) that, chemical constituents and properties of compost extracts, such as NH_3, salts, ethylene oxide, heavy metals and pH affected seed germination and root elongation. The pH of the media may not have effected seed germination and emergence in this experiment.

Early vegetative growth and development of the tomato transplants after emergence was observed to be higher in the compost amended media than in the "CRH only" medium. This might be due attributed to the higher NPK content of "compost only" media and Compost-CRH mix (1:1). According to Roe *et al.* (1997) plants that have adequate nutrition and water generally tend to have a higher shoot-to-root ratio than plants that are deficient in either. In this study, the lowest shoot-to-root ratio of transplants was recorded for "CRH only" media whiles relatively higher ratios were recorded for the compost amended media, indicating that conditions in terms of water and nutrient availability for growth of transplants was favourable in the compost amended media. This therefore confirms earlier reports by Roe *et al.*, (1997) stated above. However, between the two compost amended media, i.e. compost – CRH mix (1:1) and "compost only", there was an interesting interaction between the physical characteristics of the media and their nutrient supplying capabilities on the early vegetative growth of the tomato transplant. The transplants were tallest in the "compost only" but had

very slender stems compared to those in the compost- CRH mix (1:1) which had thicker stems as shown in Plate 5.1. This may be due to the higher NH_4-N (223.00 mg/kg) and avail-P (0.146%) in the compost- CRH mix (1:1) mix than in the "compost only" medium

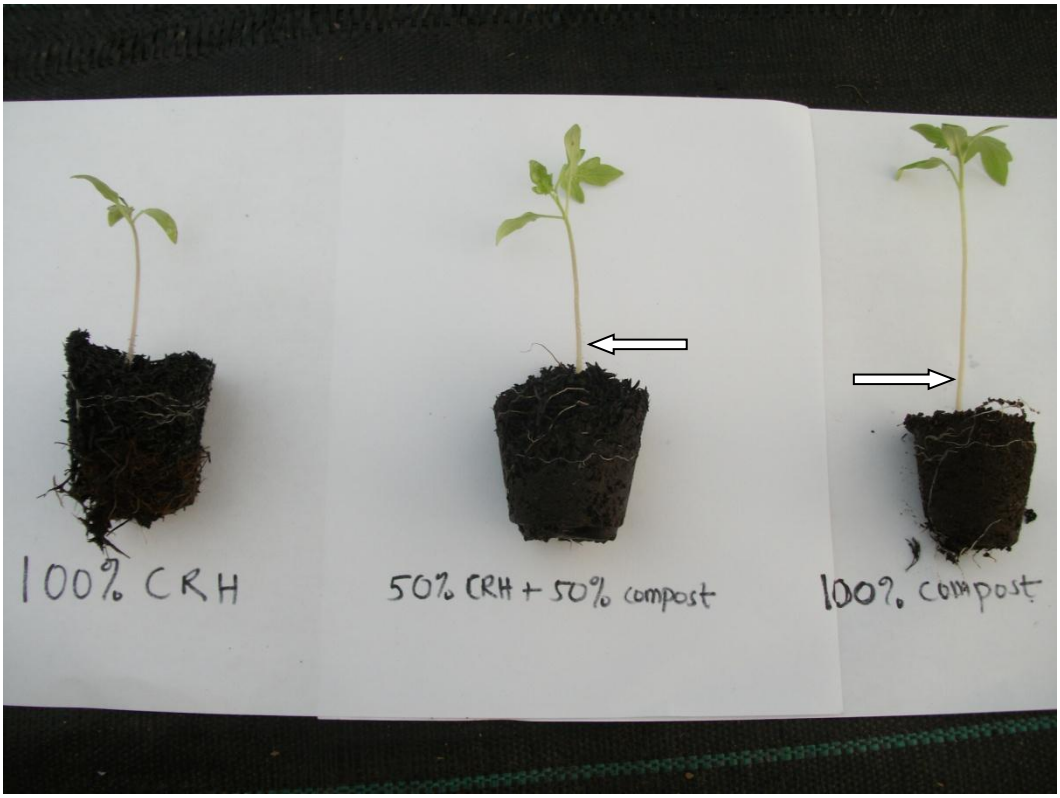

Plate 5.1: Early vegetative growth of tomato transplants in different growing media. (*Insert: showing thickness of stems*)

However, most of the other growth parameters measured had no significant difference between these two media. Stem diameter and root systems, according to Arenas (1999) are variables deemed most important by Florida Transplant Growers. Therefore, for this study and in terms of transplant quality, tomato transplants cultivated in the compost-CRH mix (1:1) could be said to be the best in terms of what transplant growers might be looking for.

After 3 weeks of treatment application, transplants in the compost amended media showed superior qualities to transplants in "CRH only". Plant height was higher (27.14 cm) in "Compost only" and lowest (14.17 cm) in "CRH only". Stem diameter of 0.40 mm, shoot DM of 446.7 mg/plant and root DM of 101.90 mg/plant were the highest recorded by compost-CRH mix (1:1) and the lowest stem diameter (0.29 mm), shoot DM (118.00 mg/plant) and root DM (34.70 mg/plant) was recorded for "CRH only". This might be due to the relatively higher total and available NPK contents in the compost compared to CRH (Table 4.11). This is similar to reports by Diaz- Perez *et al*., (2006). However between the compost-CRH mix(1:1) and "compost only" media, there were not much significant differences between the measured growth parameters except in the case of leaf chlorophyll content and root DM which were significantly higher in the compost- CRH mix (1:1). This may be due to the higher NH_4-N (223.00 mg/kg) and avail-P (0.146%) in the compost-CRH mix (1:1) than the NH_4-N (205.00 mg/kg) and avail-P (0.116%) in the "Compost only". Or it may also have been due to the relatively lower bulk density of the compost-CRH mix (1:1) than the "compost only", which might have enhanced the development and spread of the root system to take up much water and nutrients. This media may have resulted in better plant anchorage and more chlorophyll content in the leaves.

The direct cause of improved plant growth following compost extract (compost tea) application is often not clear (Shrestha *et al.,* 2012). According to Scheuerell and Mahaffee (2002), the mineral nutrients extracted from compost can improve soil fertility directly. Other claims include a role for the extracted microbiota in improved mineralisation of soil organic matter and solubilisation of soil minerals, chelation of ions (Janzen *et al.,* 1995), suppression/ biocontrol of certain plant

root and foliar diseases (Haggag and Saber, 2007; Bernal-Vicente *et al.*, 2008), and microbial production of plant growth promoting hormones such as auxins (Garcia *et al.*, 2002), or cytokinin-like substances (Arthur *et al.*, 2001).

In this study, compost tea CT-1 performed significantly better ($p < 0.05$) in terms of measured growth parameters than in CT-2. Data in Table 4.16 indicates that increased growth response in tomato transplant might be due to nutritional effect, attributed to a higher compost extract concentration in CT-1 compared to CT-2. Similar results were also observed by Shrestha *et al.*, (2012), where it was noted that growth benefit of CT was not directly biological in nature. It was further observed that the high dose of compost extract may have had a positive impact on plant growth. However, response to CT-2 was in most cases not significantly different ($p < 0.05$) from that of the control. In general, the CT treatments (CT-1 and CT-2) affected the root development of tomato transplants negatively compared to the control.

Both inorganic nutrient solutions (In-fert-1 and In-fert-2) had positive impact on tomato transplant growth than was observed in the CT treatments and control, indicating that relatively higher N levels/ concentrations were preferred by the tomato transplants. However, there were no significant differences ($p < 0.05$) in transplant response to the two treatments except for root DM, which was significantly higher in In-fert-2. This shows that increasing the N concentration beyond 200 mg N/L did not result in significant transplant growth or response, indicating that In-fert-2 (200mg N/L) was more preferable. Similar results were also obtained by Kang and van Iersel (2004), where increasing concentration of N beyond 210 mg N/L did not further increase growth of *Salvia splendens.*

Transplant growth was significantly *(p<0.05)* affected by interactions between the growth medium and nutrient solution applied. Biomass production is a major quality index for horticultural transplants (Gazal *et al.*, 2004). In this study, the observed increase in DM yields (biomass) and other growth parameters of tomato transplants due to nutrient solution indicated that growth could increase beyond the level that was supported by the unfertilized medium (control). Interactions between compost teas (CT-1 and CT-2) and growing medium showed that, maximum biomass was observed for CT-1 and 100% compost. This could be attributed to the higher nutrient contents in both media and nutrient solution. A different observation was however made for the interactions between the inorganic nutrient solutions and the growing medium. Biomass was significantly *(p<0.05)* reduced beyond 50% in compost (compost-CRH mix; 1:1) amended medium and 200 mg N/L nutrient solution. The reduced growth in biomass could be due to the relatively higher EC levels in both the "Compost only" (2.10 dS/cm) and In-fert-1 (0.90 dS/cm) nutrient solution. Electrical conductivity levels approaching 3.0 dS/cm are considered higher than desirable (Davidson *et al.*, 2000). Similar results were also reported by Lumis *et al.* (2000). The interaction between growing medium and inorganic nutrient solution gave superior transplant qualities compared to that of the medium and compost teas, however compost tea (CT-1) may be used by growers who are restricted from using inorganic fertilizer by the norms of organic farming.

The fertilizer equivalent of the two compost teas (CT-1 and CT-2) used in fertigating tomato transplants in this study could not be estimated from the inorganic N response curve. This was because the total DM from CT-1 and CT-2 were lower than the inorganic response curve. The differences in dry matter yield

obtained from the compost teas and inorganic N fertilizer solution treatments may be due to the lower nitrogen content of the compost teas hence their inability to supply nutrients in right quantities required by the tomato transplants.

5.3.2 Pepper (Capsicum annum var. Bird eye) transplant production

Plant height, stem diameter and number of leaves of pepper transplants increased with increasing compost concentration in the media. This could be attributed to the increasing concentration of N supplied to the transplants by the compost in the media. This confirms earlier reports by Diaz-Perez *et al*. (2006) that this growth enhancement of pepper transplant was partly due to the mineral nutrients contained in the compost. In addition, it could also be due to the physical characteristics of the media such as the EC and bulk density, which also increased with increasing compost in the medium (Table 4.18). This shows that relatively higher EC may be preferable for pepper transplants compared to the tomato transplants above. Maximum height and chlorophyll content was observed in 75% compost whiles maximum stem diameter and number of leaves was observed for 50% compost. However, there were no significant differences in these measured parameters between the two media types in this study. Similarly, shoot DM was highest in 50% compost but not significantly different between 75 and 100% compost. Whiles root DM was highest in 75% compost but not significantly different from 100% compost. These results indicate that, increasing the compost concentration in media may have positively affected root DM but may or may not have affect shoot DM positively beyond 50% compost concentration. From this present study, the optimum range of compost amendment rate for pepper transplant could be said to be between 50 – 100%.

However, during the course of the experiment, some individual transplants in the 75% compost medium developed some instant yellowing of leaves and stems. These were isolated cases which could not be explained because the other transplants in the same medium and cell tray had bright green leaves and showed no sign of disease. This caused reduced growth and it might be responsible for the relatively lower shoot DM recorded for 75% compost.

Enhanced plant height, stem diameter, leaf area, leaf number, total chlorophyll and fresh and dry shoot mass have been attributed to nitrogen application (Melton and Dufault, 1991a). In this study, plant height, stem diameter, shoot and root DM increased with increasing N of the inorganic fertilizer solution. However, stem diameter, shoot and root DM decreased at the maximum N concentration (400 mg N/L) implying that beyond 200 mg N/L, further increase in N concentration could be toxic or detrimental to the transplants. Similar results were observed by Liu *et al.* (2012), where treatments resulting in maximum dry weights (DW) for sub irrigated plants were 200 mg N/L for kale, lettuce, pepper and tomatoes. The results of this study may suggest that pepper prefers relatively high fertilizer levels, but N concentrations > 200 mg N/ L do not further increase plant growth.

The compost tea (CT) treatments had relatively smaller plant height, stem diameter and shoot DM but were mostly not significantly different from In-fert- 3 (100 mg N/ L) inorganic treatment. However, root DM in CT was higher than all the inorganic fertilizer treatments though was not significantly higher than In-fert-2 (200 mg N/L) inorganic treatment. This implies that, in the present study growth parameters observed for CT treatments are comparable to those observed for In-fert-3 (100 mg N/L) inorganic fertilizer treatments.

Interactions between media type and nutrient solution type on pepper transplants was significant at *($p<0.01$).* Interestingly, interactions between media and inorganic fertilizer solutions show that maximum shoot and root DM was observed for 100% compost and In-fert-2 (200 mg N/L). This could be attributed to the high nutrient concentration and the high EC in the compost media and nutrient solution. Though it may be probable from the present study that pepper could be more tolerable to high EC or actually may prefer higher EC than tomato, it might also be possible that increasing N concentration in the nutrient solution beyond 200 mg N/L could increase the EC to excessive limits thereby reducing growth in pepper.

For CT treatments, results of the interaction show that CT and 50% compost produced the highest DM yield, though the transplants were relatively shorter compared to transplants in the CT and 75% compost. This implies that despite the nutrient content, the EC of the media and the CT may have been also preferable to the pepper. The combined EC (2.14 dS/cm) of the CT and 50% compost media is similar to the combined EC (2.40 dS/cm) of In-fert-2 (200 mg N/L) and the 100% compost media.

The fertilizer equivalent value of 108% obtained for CT implies that, CT prepared in this study performed better than 100 mg N/L inorganic N fertilizer solution. This can be attributed to the possible high concentrations of microbes contained in the CT. The microbes may have conditioned the root medium and promoted the decomposition and mineralisation of organically bound nutrients in the growing media as was reported by Janzen *et al.* (1995).

5.4 Perception of farmers and consumers on human waste (FS) composting and use in crop production

It was found in this study that, age, level of education, cultural or religious views of farmers may not have been influencing factors affecting farmers' perception on human waste composting. The farmers concern and reasons about human waste composting and use in crop production were likely to be more technical than cultural or religious beliefs. This confirms earlier reports by Danso *et al.* (2002) who assessed the perception and acceptability of co-compost in Ghana. These farmers were more concerned about how the composting of human waste and subsequent application to crop would affect yields more than they were concerned about the health hazards and cultural/religious beliefs. This may explain why 90% out of the farmers (33%) who have heard about human waste use would actually go into composting provided training could be offered to them.

However for the consumers, the study revealed that all the 30 consumers buy their vegetables from the market and none from the farm directly. The study further showed that 90% of them do not ask what type of fertilizer is used to cultivate the crops. This could mean that for the majority of vegetable consumers in Accra, the factors that affect their choice of vegetables are more of a sensory nature (characteristics) relating to, appearance, freshness, odour and other important factors such as pricing, than of non-sensory characteristics. This is confirmed by earlier studies by Sheperd and Farleigh, (1989); Wandel and Bugge (1997); Land (1998); Grankvist and Biel (2001) and Torjusen *et al*. (2001) that, consumers consider the sensed characteristics of food to be the most important factors in their food choice.

From the study, only 7% of the consumers knew human waste can be composted whiles 93% did not know. However, 23% of them agreed human waste should be composted whiles 47% of them disagreed. The remaining 30% said they did not know if human waste should be composted or not. This results obtained indicates that the general trends in consumers choices were changing and that the consumers could be shifting from the sensory characteristics to more of the non-sensory characteristics. This observation falls in line with observation by Magnusson (2004) that, consumers are becoming increasingly interested in non-sensory characteristics. Among the most notable are the absence of food additives, preservatives and residues (Wilkens and Hillers, 1994), nutritional value (Jolly, 1991) and how the food was produced (Land, 1998). This could probably explain why 20% of the consumers interviewed agreed composting of human waste makes it safe for use. More so, why 40% of the consumers would actually patronise vegetables cultivated with composted human waste under the condition that it was better than the chemical fertilizers and that they would have to wash the vegetables well before they could consume them.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Faecal sludge (FS) in Sekondi – Takoradi consisting of septage and public toilet sludge were characterised and quantified. It was found out that the characteristics of septage and public toilet sludge in Sekondi – Takoradi are comparable with septage and public toilet sludge in other cities around the world. It was also found that FS can be composted with empty fruit bunches (EFB) and cocoa pod husks (CPH) in 90 days.

The different co-compost feedstock ratios affected pathogen reduction, N-mineralisation, N – loss and total NPK content. Feedstock treatment ratio of (FS + EFB + CPH; 2: 2: 1) was found to be highest in nutrient content and lowest in pathogen content. This particular co-compost type was found suitable as a partial or complete potting medium for tomato (*Lypersicon esculentum var. M2*) and pepper (*Capsicum annum var. Bird eye*) transplant production in greenhouse. It can also be concluded that compost tea can serve as a good N- source for the production of vegetables. Compost tea (compost extract: water; 1: 2) was found to be comparable or equivalent to 100 mg N/L inorganic fertilizer solution for greenhouse pepper transplant production.

About 33% of vegetable farmers in Accra would compost human waste (FS) and subsequently use it for crop production provided training could be offered to them. Similarly, 40% of consumers would consume vegetable cultivated with composted human waste. Though only 20% of them agree that composting of human waste makes it safe for use.

6.2 RECOMMENDATIONS

During co-composting of FS with EFB and CPH, high losses of N and P, more especially P loss through run-off and leaching were observed. It is therefore recommended for future research that, in order to understand the extent of P loss through run- off and leaching, additional studies on nutrient fate and transport will be required.

Further studies should also be conducted to evaluate the effect of co-composting FS with EFB and CPH on the survival of *Phytophthora palmivora* and *P. megakarya* found on CPH.

Further studies are required to investigate the possibility of enriching compost teas with inorganic fertilizers and its effect on vegetable crop production.

The perception study on human waste composting and use in crop production should be extended to other crop farmers.

REFERENCES

Adamafio, N.A. (2013). Theobromine Toxicity and Remediation of cocoa by – products: An overview. *Journal of Biological Sciences*. ISSN 1727-3048.

Adamtey, N. (2005). Evaluation of agricultural and agro-industrial residues for composting for agricultural use in Ghana: A case study in the Kwaebibirim District. *A dissertation submitted to the School of Research and Graduate Studies, Environmental Science Program. University of Ghana, Legon*.

Adamtey, N. (2010). Nitrogen Enrichment of compost and co-compost in maize production and its effects on the soil environment. *A PHD thesis submitted to the School of Graduate Studies*. University of Ghana.

Adu, S. V. (1992). Soils of the Kumasi region, Ashanti Region, Ghana. Memoir No. 8. Ghana Soil Research Institute. 141 pp.

Alexander, R. (2000). Compost marketing trends in the U.S. *Biocycle*, 41 (7), 64–66.

Amarchey, C.A. (2005). Farmer response to urban pressures on land, the Tamale experience. *Urban Agriculture Magazine* 15:39-40

Angelidake, I. and Ahring, B. K. (1997*).* Codigestion of olive oil mill wastewater with manure, household waste or sewage sludge. *Biodegradatio*n 8: 221-226.

APHA, AWWA, WEF. (1998). Standard methods for examination of water and wastewater; 20th edition, Washington D.C. pp. 5 - 6.

APHA, AWWA, WPCF. (1995). Standard methods for examination of waste water, 19th edition, New York.

Araujo, A.S.F., Santos, V.B., and Monteiro, R.T.R. (2008). Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piaui state, Brazil. *European Journal Soil Biology*, 44, pp. 25 - 30.

Arenas, M. (1999). Coconut (*Cocus nucifera*) pith or coir as an alternative media for tomato transplant production. MS Thesis, Univ. Of Florida, 1999. LD1780 1999 .A681.

Arthur, G.D., Jäger, A. K. and Van Staden, J. (2001). The release of cytokinin-like compounds from *Gingko biloba* leaf material during composting. *Environmental and Experimental Botany.* 45: 55-61.

Atiyeh, R.M., Edwards, C.A., Subler, S. and Metzger, J.D. (2001). Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth. *Bioresource Technology*. 78: 11- 20.

Ayuso, M., Pascual, J.A., Garcia, C., and Hernandez, T. (1996). Evaluation of urban waste for agricultural use. *Soil Science and Plant Nutrition*. Vol 42, 1: 105-111.

Baffour-Asare, E. (2009). Co-composting of dewatered sewage sludge (Biosolids) and sawdust for agricultural use as an organic fertilizer: A case study of the KNUST sewage treatment plant. A dissertation submitted to the Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology.

Baharuddin, A. S., Wakisaka, M., Shirai, Y., Abd-Aziz, S., Abdul Rahman, N. A. and Hassan, M. A. (2009). Co-composting of Empty Fruits Bunches and Partially Treated Palm oil Mill Effluents in Pilot Scale. *International Journal of Agricultural Research* 4 (2): 69 -78.

Ball Redbook. 14th ed. (1985). Reston Publishing Co. Reston, Va.

Banegas, V., Moreno, J.L. Moreno, J.I. Garcı´a, C. Leon, G. and Herna´ndez, T. (2007). Composting anaerobic and aerobic sewage sludges using two proportions of sawdust. *Waste Management*. 27: 1317–1327.

Baran, A., Cayci, G., Kütük, C., and Hartmann, R., (2001). Composted grape marc as growing medium for hypostases (*Hypostases phyllostagya*). *Bioresource Technology*. 78: 103-106.

Bationo, A., Lompo, F. and Koala, S. (1998). Research on nutrient flows and balances in West Africa: state-of-the-art. *Agriculture, Ecosystems & Environment*. 71 (1-3), 19-35.

Bazrafshan, E., Zazouli, M. A., Bazrafshan, J. and Bandpei, A. M. (2006). Evaluation of microbiological and chemical parameters during wastewater sludge and sawdust co-composting. *Journal of Applied Sciences and Environmental Management.* Vol. 10(2) 115 – 119.

Beeson, R.C., Jr. (1996). Composted yard waste as a component of container substrates. *Journal of Environmental Horticulture*, 14: 115 - 121.

Belevi, H., Leitzinger, C., Binder, C., Montangero, A., Strauss, M., Zurbrügg, C. (2000). Material flow Analysis. A Planning Tool for Organic Waste management in Kumasi, Ghana. Healthy Cities Conference, to be held in Accra, Ghana, in 2001 (submitted).

Beltoldi, M., Vallini, C. and Pera, A. (1983). The Biology of composting. A review, Waste Management and Research, 1:157-176.

Berger, E.Y. (1960). Intestinal absorption and excretion. In: Comar C. L. and Bronner F. (eds). *Mineral Metabolism*, pp. 249-286. Academic Press, New York.

Bernal, M. P., Paredes, C., Sánchez-Monedero, M. A. and Cegarra, J. (1998a). Maturity and stability parameters of composts prepared with a wide range of organic wastes. *Bioresources Technology* 63:91-99. Elsevier Science Ltd. Printed in Great Britain.

Bernal-Vicente, A., Ros, M., Tittarelli, F., Intrigliolo, F. and Pascual, J.A. (2008). Citrus compost and its water extract for cultivation of melon plants in greenhouse nurseries. Evaluation of nutriactive and biocontrol effects. *Bioresource Technology* 99: 8722-8728.

Bess, V. H. (2000). Understanding Compost Tea. *BioCycle*, 41(10): 71 -73.

Bess, V. H., Manes, R. B. S. and Snodgrass, J. L. (2002). *E. coli* survival in compost tea using different nutrient substrates. Proceedings 2002 International Symposium Composting and Compost Utilization. May 6-8, Columbus, Ohio.

Better Crops (1998). Production and use of potassium. Vol. 82, No. 3.

Bishop, P.L., and Godfrey, C., 1983. Nitrogen variations during sludge composting. *BioCycle* 24: 34 - 39.

Black, .C.A. (ed) (1965). Methods of soils analysis. *Agronomy* No.9. Part 2 American Society of Agronomy, Madison, Wisconsin.

Boot, N.L.D and Scott, R. E. (2008). Faecal sludge management in Accra, Ghana; Strengthening links in the chain. *33rd WEDC International Conference,* Accra, Ghana.

Brinton, W. and Droffner, M. (1995). The control of plant pathogenic fungi by use of compost teas. *Biodynamics* 197:12–15.

Brinton, W. F. (2000): Compost Quality Standards and Guidelines. Woods End Research Laboratory, Inc.

Brinton, W., Storms, P., Evans, E. and Hills, J. (2004). Compost teas: microbial hygiene and quality in relation to method of preparation. *Biodynamics* summer: 1–9.

Buerno, P., Tapias, R., López, F. and Díaz, M. (2008). Optimizing composting parameters for nitrogen conservation in composting. *Bioresource Technology., 99(11): 5069–5077.*

Bugbee, G.J. (2002). Growth of ornamental plants in container media amended with biosolids compost. *Compost Science and Utilization,* 10, 92-98

Bugbee, G.J., Frink C.R. and Migneault, D. (1991). Growth of perennials and leaching of heavy metals amended with a municipal leaf sewage sludge and street sand compost. *Journal of Environmental Horticulture*, 9: 47 – 50.

Bustamante, M.A., Paredes, C., Moral, R., Agulló, E., Pérez-Murcia, M.D. and Abad, M. (2008). Composts from distillery wastes as peat substitutes for transplant production. *Resource Conservation and Recycling*. 52: 792-799.

Castaldi, P., Garau, G., and Melis, P. (2004). Influence of compost from sea weeds on heavy metal dynamics in the soil-plant system. *Fresenius Environmental Bulletin*, 13, pp. 1322-1328.

Central Intelligence Agency (CIA), The World Fact Book, March (2005).

Chan, P.L.S. and Griffiths, D.A. (1988). The vermicomposting of pre-treated pig manure. *Biological Wastes*, 24, 57–69.

Chaney, R.L. 1982. Fate of toxic substances in sludge applied to cropland. *In* Proceeding International Symposium. Land Application of Sludge. Oct. 1315, Tokyo, Japan.

Chaney, R.L., Munns, J.B. and Cathy. H.M. (1980). Effectiveness of digested sewage sludge compost in studying nutrients for soilless media. *Journal of the American Society for Horticultural Science*. 105:485-492.

Chaney, R.L., Sterrett, S.B. Morella, M.C. and Lloyd. C.A. (1982). Effect of sludge quality and rate, soil pH, and time on heavy metal residues in leafy vegetables. *In* Proc. 5th Annual Madison Wastes Conf. 22-24.

Chen, Y. and Inbar, Y. (1993). Chemical and spectroscopic analysis of organic matter transformations during composting in relation to compost maturity. In: H.A.J. Hotlink and H.M. Keener, Editors, Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects, Renaissance, Washington, OH, pp. 551–600.

CHF International (2011). Sekondi –Takoradi Poverty Map: A guide to poverty reduction in Sekondi –Takoradi. CHF International Ghana. www.chfinternationalghana.org

Cofie, O. O., Drechsel, P., Agbottah, S. and van Veenhuizen, R. (2008). Resource recovery from urban waste: Options and challenges for community-based composting in sub-Saharan Africa. *Desalination 251 (2010)* 256–261.

Cofie, O. O., Kranjac-Berisavljevic, G. and Drechsel, P. (2004). The use of human waste for peri -urban agriculture in Northern Ghana. *Renewable Agriculture and Food Systems.* 20 (2), 73-80.

Cofie, O., Gordana Kranjac-Berisavljevic, O. and Drechsel, P. (2005). The use of human waste for peri -urban agriculture in Northern Ghana. *Renewable Agriculture and Food Systems*. 20 (2), 73-80.

Cofie, O., Kone, D., Rothenberger, S., Moser, S. and Zubruegg, C. (2009). Co-composting of faecal sludge and organic solid waste for agriculture: process dynamics. *Water Research (Oxford),* Vol. 43 No. 18 pp. 4665-4675.

Cooperband, L. R. (2000). Composting: art and science of organic waste conversion to a valuable soil resource, *Laboratory Medicine* 31 283–289.

Cornell University (2010). Composting trends and technologies, compost.css.cornell.edu

Cornish, G A. and Lawrence. P. (2001). Informal irrigation in peri-urban areas: A summary of findings and recommendations, DFID's Water KAR Project R7132, Report OD 144, HR Wallingford, Wallingford, UK, 54 pp.

Council Directive. 1986. CEC—Council of the European Communities. Council directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture.

Cronin, M.J., Yohalem, D.S., Harris, R.F. and Andrews, J.H. (1996). Putative mechanism and dynamics of inhibition of the apple scab pathogen *Venturia inaequalis* by compost extracts. *Soil Biology and Biochemistry* 28: 1241-1249.

Crowe, M., Nolan, K., Collins, C., Carty, G., Donlon, B., Kristoffersen, M., Brogger, M., Carlsbaek, M., Hummelshoj, R.M. and Thomsen, C.L. (2002). Part 3: Technology and market issues. Copenhagen: EEA

Danso, G., Fialor, S. C. and Dreschel, P. (2002). Farmers' perception and willingness to pay for urban waste compost in Ghana. Waste Management and Environment. WIT Press, Ashurt Lodge, Souththampton, S040 7AA, U/C.

Dao, T.H. 1999. Co-amendments to modify phosphorus extractability and nitrogen/phosphorus ratio in feedlot manure and composted manure. *Journal of Environmental Quality*. 28:1114–1121.

Davelaar, L. (2012). Can human waste hold the key to increasing agricultural productivity in sub-saharan Africa? Retrieved 12 August, 2012 from *www*.westafrica.iwmi.org/**new**s--events.aspx

Davidson, H., Mecklenburg, R. and Peterson, C. (2000). Nursery Management: Administration and Culture. Prentice Hall, Upper Saddle River, NJ.

de Bartoldi, M., Citernesi, U., Gricelli, M., (1980). Bulking agents in sludge composting. *Compost Science and Land Utilization* 21 (1): 32 - 35.

de Bertoldi, M., Vallini, G. and Pera, A. (1983). *The biology of composting: A review,* Waste Management and Research 1(2) 157-176.

de Bertoldi, M., Vallini, G., Pera, A. (1985). Technological aspects of composting including modeling and microbiology. In: Gasser, J.K.R (Ed.), Composting of Agricultural and Other Wastes. Elsevier Applied Science Publishers, New York, USA, pp. 27 – 41.

Dearbon, Y. (2011). Compost Tea: Literature review on production, application and plant disease management. A document prepared for San Francisco Department of Environment Toxic Reduction Program: IPM Task Order # 3- 18.

Diaz – Ravina, M., Acea, M.J. and Carballas, T. (1989). Microbiological characterization of four composted urban refuses. *Biological Wastes* 30:89 -100.

Diaz, L. F. and Savage, G. M. (2007). Bioremediation. in: L. F. Diaz, M. de Bertoldi, B. W. and S. E. (Eds.), Compost Science and Technology, Elsevier, Amsterdam, pp. 159-176.

Diaz-Perez, J.C., Granberry, D.M. and Germishuizen, P. (2006). Transplant growth and stand establishment of Bell pepper (*Capsicum annuum* L.) plants as affected by compost-amended substrate. ISHS Acta Horticulturae 782: IV International symposium on seed, transplants and stand establishment of horticultural crops; Translating seed and seedling physiology into technology.

Diver, S. (2002) Notes on Compost Teas: A Supplement to the ATTRA Publication: Compost Teas for Plant Disease Control. Appropriate

Technology Transfer for Rural Areas (ATTRA) Available: http://www.attra.ncat.org

Drangert, J.O. (1998). Fighting the urine blindness to provide more sanitation options. *Water South Africa* 24(2):157–164l.

Drechsel, P. S., Graefe, M., Sonou, and Cofie, O.O. (2006a). Informal Irrigation in Urban West Africa: An Overview. IWMI Research Report (in press).

Dresboll, D. B. (2004). Optimisation of growing media for organic greenhouse production. A dissertation submitted to the royal Veterinary and Agricultural University in Partial fulfilment of the requirements of the degree of Doctor of Philosophy.

Droffner, M.L, Brinton, W. F. and Evans, E. (1995). Evidence for the Prominence of Well Characterized Mesophyllic Bacteria in Thermophilic (50-70oC) Composting Environments. *Biomass Bioenergy* 8: 191-195.

Droffner, M.L. and Brinton, W.F. (1995). Survival of E. coli and Salmonella populations in aerobic thermophilic composts as measured with DNA gene probes. *International Journal of Hygiene and Environmental Medicine.* 197(5): 387 – 397.

Dumontet, S., Dinel, H. and Baloda, S.B. (1999) Pathogen reduction in sewage sludge by composting and other biological treatments: A review. *Biological Agriculture and Horticulture* 16, 409-430.

EA (Environment Agency). (2001). *Technical Guidance on Composting Operations (Draft),* Environment Agency UK, Bristol.

EAWAG-SANDEC (2006). Urban Excreta Management - Situation, Challenges, and Promising Solutions. 1st International Faecal Sludge Management Policy Symposium and Workshop. 9-12 May 2006 Dakar, Senegal.

Eghball, B., Power, J.F., Gilley, J.E. and Doran, J.W. (1997). Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. *Journal of Environmental Quality*. 26, 189–193.

Eklind, Y. and Kirchmann, H. (2000a). Composting and storage of organic household waste with different litter amendments. I: carbon turnover. *Bioresource Technology*, 74(2):115-124.

Eklind, Y. and Kirchmann, H. (2000b). Composting and storage of organic household waste with different litter amendments. II: nitrogen turnover and losses. *Bioresource Technology*, 74(2):125-133.

Eklind, Y., Ramert, B. and Wivstad, M., (2001). Evaluation of growing media containing farmyard manure compost, household waste compost or chicken manure for the propagation of lettuce (*Lactuca sativa* L.) transplants. *Biological Agriculture and Horticulture.* 19: 157-181.

Elbersen H.W., van Dam J.E.G and. Bakker R.R (2005). Oil Palm By-Products as a Biomass Source: Availability and Sustainability. 14th European Biomass Conference, 17-21 October, Paris, France.

Environmental Protection Agency, Ghana (GEPA). (2000). General Environmental Quality Standards (Ghana). Regulations 2000. Pp 8-13

Epstein, E. (1997). The science of composting, Technomic Publishing, Lancaster, Pennsylvania, USA.

Epstein, E. and Parr, J. F. (1977). Utilization of composted municipal wastes, Proc. National Conference on Composting of Municipal Residues and Sludges, Information Transfer, Inc., Rockville, MD, p. 49.

Evanylo, G. (2006). Compost Maturity and Indicators of Quality: Laboratory Analyses and On-Farm Tests. http://www.mawaterquality.org/industry_change/compostschool ICompost%20quality_Evanylo.pdf

Falahi-Ardakani, A., Bouwkamp, J.C. Gouin F.R. and Chaney. R.L. (1987a). Growth response and mineral uptake of vegetable transplants growing in composted sewage sludge amended medium. Part I. Nutrient supplying power of the medium as measured by tissue analysis. *Journal Environmental Horticulture* 5: 107-111.

Falahi-Ardakani, A., Gouin, F.R. Bouwkamp, J.C. and Chaney. R.L. (1987b). Growth response and mineral uptake of vegetable transplants growing in composted sewage sludge amended medium. Part II. As influenced by the time of application of N and K. *Journal Environmental Horticulture.* 5:112115.

Falahi-Ardakani, A., Gouin, F.R. Bouwkamp, J.C. and Chaney. R.L. (1988). Growth response and mineral uptake of lettuce and tomato transplants grown in Media amended with composted sewage sludge. *Journal Environmental Horticulture* 6(4): 130 -132.

FAO. (2000). Fertilizers and their use: A pocket guide for extension officers (4^{th} ed). Food and Agriculture organisation of the United Nations international fertilizer industry association, Rome.

Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. (1983). Sanitation and Disease Health Aspects of Excreta and Wastewater Management. Wiley, Chichester.

Fermor, T. R., Wood, D. A. and Lynch, J. M. (1989). Microbiological processes in compost, International Symposium on Compost Production and Use, San Michele All'Adige, Italy, pp. 282–300.

Figueira, A., Janick, J. and BeMiller, J. N. (1993). New products from Theobroma cacao: Seed pop and pop gum. P. 475-478. In: J. Janick and J. E. Simon (Eds), New Crops. Wiley, New York.

Finstein, M. S., Miller, F. C. and Strom, P. F. (1986). Waste treatment composting as a controlled system, *Biotechnology* 8: 396–398.

Fitzpatrick, G.E. 2001. Compost utilization in horticultural cropping systems, P.J. Stofella and B.A. Kahn (Eds.), CRC Press, Boca Raton, FL.

Francou, C., Poitrenaud, M. and Houot, S. (2005). Stabilization of Organic Matter during Composting: Influence of Process and Feedstocks. *Compost Science & Utilization* 13(1), 72-83.

Freeman, T.M. and Cawthon, D.L. (1999). Use of composted dairy cattle solid biomass, poultry litter and municipal biosolids as greenhouse growth media. *Compost Science and Utilization*. 7, 66 - 71.

Gajalakshmi, S. and Abbasi, S. A. (2008). Solid waste management by composting: State of the art, Critical Reviews in *Environmental Science and Technology* 38(5) 311-400.

Gao, X. Zh., Shen, T., Zheng, Y., Sun, X., Huang, S., Ren, Q., Zhang, X., Tian, Y. and Luan, G. (2002). Practical manure handbook. (In Chinese). Chinese Agricultural Publishing House. Beijing, China.

Garcia C., Hernandez, T. and Costa, F. (1992). Characterization of humic acids from uncomposted and composted sewage sludge by degradative and non-degradative techniques. *Bioresource Technology*. 41, pp. 53–57.

Garcia, M. I., Cruz Sosa, F., Saavedra, A. L. and Hernandez, M. S. (2002) Extraction of auxin-like substances from compost. *Crop Research* 24: 323-327.

Garcia-Gomez, A., Bernal, M.P., and Roig, A. (2002). Growth of ornamental plants in two composts prepared from agro industrial wastes. *Bioresource Technology*. 83, 81-87.

Gazal, R.M., Blanche, C.A. and Carandang, W.M. (2004). Root growth potential and seedling morphological attributes narra *(Pterocarpus indicus Willd)* transplants. *Forest ecology and Management*, 195(2): 259 – 266.

Gerson, R. and Honma, S. (1978). Emergence response of pepper at low soil temperature. *Euphytica* 27: 151 – 156.

Ghana Statistical Service (2005). 2005 Census Reports.

Ghana Statistical Service (2010). 2010 Population and Housing Census.

Golueke, C.G. (1991) When is compost "safe"? In *The art and science of composting* pp. 220-229. Pennsylvania, USA: The JG Press, Inc. Emmaus.

Gotaas, H.R. (1976). Composting – Sanitary Disposal and Reclamation of Organic Waste (six ed.). *WHO* – Switzerland.

Gouin, F.R. (1982). Using composted wastes for growing horticultural crops. *Biocycle, Journal of Waste Recycling.* 23(1):45-47.

Grankvist, G. and Biel, A. (2001). The importance of beliefs and purchase criteria in the choice of eco-labelled food products. *Journal of Environmental Psychology,* 21, 405 – 410.

Grebus, M.E., Watson, M.E. and Hoitnick, H.A.J. (1994). Biological, chemical and physical properties of composted yard trimmings as indicators of maturity and plant disease suppression, *Compost Science and Utilization* 2 , pp. 57–71.

Green, R. E., Cornell, S. J., Scharlemann, J. P. W. and Balmford, A. (2005). Farming and the fate of wild nature. *Science* 307:550-555.

Grigatti, M., Giorgioni, M.E., and Ciavatta, C. (2007). Compost-based growing media: Influence on growth and nutrient use of bedding plants. *Bioresource Technology* 98, 3526-3534.

Grobe, K. (2003). California landscape contractor calls it compost tea time. *BioCycle* 44:26–27.

Gruda, N. and Schnitzler, W. H. (2004). Suitability of wood fiber substrate production of vegetable transplants - I. Physical properties of wood fiber substrates. *Scientia Horticulturae* 100, 309-322.

Guyton, A.C. (1992). Human physiology and mechanisms of disease. W. B. Saunders Co, Philadelphia, USA.

Haas, D. and Défago, G. (2005). Biological Control of Soil-Borne Pathogens by Fluorescent Pseudomonads-*Nature Review Microbiology.* 3 (4): 307 – 19.

Haderlein, A., Legros, R. and Ramsay, B. (2006). Pyrene mineralization capacity increases with compost maturity. *Biodegradation 17(4), 293-302.*

Haggag, W.M. and Saber, M.S.M. (2007). Suppression of early blight on tomato and purple blight on onion by foliar sprays of aerated and non-aerated compost teas. *International Journal of Food, Agriculture and Environment* 5: 302-309.

Handelsman, J. and Stabb, E. (1996). Biocontrol of Soilborne Plant Pathogens; *Plant Cell*, Vol. 8, p 1855-1869.

Harman, G. E. (2006). Overview of Mechanisms and Uses of *Trichoderma* spp. *Phythopathology*. Vol. 96, No. 2, 190-194.

Harrison, E.Z., Olmstead, D. and Bonhotal, J. (2003). What's behind a compost label or seal? *Biocycle*, 44 (9), 28–30.

Hartz, T.K. and Giannini, C. (1998). Duration of composting of yard wastes affects both physical characteristics of compost and plant growth. *HortScience*, 33: 1192 - 1196.

Haug, R.T. (1993). The Practical Handbook of Compost Engineering. Lewis Publishers, Boca Raton, Florida, USA.

Heerden, I.V., Cronje, C., Swart, S.H. and Kotze, J.M. (2002). Microbial, chemical and physical aspects of citrus waste composting. *Bioresource. Technology*, 81: 71 -76.

HMJ consulting limited. (2008). *Nova Scotia Environment Compost Maturity Study.* Final report.

Hodgson, I and Larmie, S. A. (1999). Sewage, Septage and Faecal sludge management in Tamale municipality of Ghana. *Journal of Applied Science and Technology (JAST),* Vol. 4, Nos. 1 and 2, pp. 67 -71.

Hogarh, J.N., Fobil, J.N., Ofosu-Budu, K.G., Carboo, D., Ankrah, N. A. and Nyarko, A. (2008). Assessment of Heavy Metal Contamination and

Macro-nutrient Content of Composts for Environmental Pollution Control in Ghana. *Global Journal of Environmental Research* 2 (3): 133-139.

Hogg, D., Barth, J. and Faviono, E. (2002a). Comparison of Compost Standards within the EU, North America, and Australasia. Main Report. The Waste and Resources Action Programme, Banbury, UK.

Hogg, D., Barth, J. and Favoino, E. (2002b). Review of Compost Standards in the UK. Supplement to Main Report: Comparison of Compost Standards within the EU. North America and Australasia. The Waste and Resources Action Programme, Banbury, UK.

Hoitink, H. A. J., Boehm, M. J. and Hadar. Y. (1993). Mechanisms of suppression of soil borne plant pathogens in compost-amended substrates, p. 601-621. In H. A. J. Hoitink and H. M. Keener (eds.), Science and Engineering of Composting. Renaissance Publications, Worthington, OH.

Hsiang, T., and Tian, L. (2007). Compost Tea for Control of Dollar Spot- Department of Environmental Biology, University of Guelph- GTI Annual Research Report.

Hsu, J.H. and Lo, S. L. (1999). Chemical and spectroscopic analysis of organic matter transformations during composting of pig manure. *Environmental Pollution.* 104, pp. 189–196.

Huang, G.F., Wong, J.W.C. Wu, Q.T. and Nagar, B.B. (2004). Effect of C/N on composting of pig manure with sawdust. *Waste Management* 24: 805–813.

Hummel, R.L., Johnson, C.R., Riley, R., and Smith, S. (2001), Comb. Proc. *International Plant Propagators Society*, 51, 295.

Iglesias, J. E., Perez, G. V. and Fernandez, F. H. M. (1989). The agronomic value of the sewage sludge of Tenerife composting. *Agricultural Wastes* 17, 119–130.

Ingallinella, A. M., Sanguinetti, G., Koottatep, T., Montangero, A. and Straus, M. (2002). The challenge of faecal sludge management in urban areas-Strategies, regulations and treatment options. *Water Science and Technology*. Vol. 46 no. 10 pp 285-294.

Ingham, E. R. (2005). The Compost Tea Brewing Manual, 5th Ed. Soil Foodweb Incorporated, 728 SW Wake Robin Ave. Corvallis, Oregon 97333.

Ingram, D.T. and Miller, P.D. (2007). Factors Affecting Compost Tea as a Potential Source of *Escherichia coli* and *Salmonella* on Fresh Produce *Journal Food Protection*, Vol. 70, No. 4 Food Safety Implications of a Popular Farming Practice: Compost Tea.

Ipek, U., Obek, E., Akca, L., Arslan, E. I., Hasar, H., Dogru, M. and Baykara, O. (2002). Determination of degradation of radioactivity and its kinetics in aerobic composting, *Bioresource Technology* 84 283–286.

IUSS Working Group. (2007). World references base for soil resources 2006, First update 2007. World soil Resource Report No. 103. FAO, Rome.

IWMI, Accra. (2003). Co-composting of Faecal Sludge and Solid Waste for Urban and Peri-urban Agriculture in Kumasi, Ghana. IWMI/SANDEC/KNUST collaborative project. Final report submitted to the French Foreign Ministry.

IWMI, Accra. (2009). Wastewater Irrigation and Public Health: From Research to Impact- A roadmap for Ghana. *Prepared for Google.org*.

Janzen, R.A., Cook, F.D., McGill, W.B. (1995). Compost extract added to microcosms may simulate community-level controls on soil microorganisms involved in element cycling. *Soil Biology Biochemistry* 27: 181-188.

Jenkins, J. (1999). The Humanure Handbook: A guide to composting Human Manure. 2nd ed. 143 Forest Lane, Grove City, PA 16127. Jeong, Y. and Kim, J. (2001). A new method for conservation of Nitrogen in aerobic composting process. *Bioresource Technology*, 79: 129-133.

Jeris, J.S. and Regan, R.W. (1973). Controlling environmental parameters for optimum composting (Part 111). *Compost Science*. 14(3):16-22.

Jespersen, L.M. and Willumsen, J. (1993). Production of compost in a heat composting plant and test of compost mixtures as a growing media for greenhouse cultures. *Acta Horticulturae,* 342, 127 - 142.

Jimenez, E. and Perez, E. (1992). Determination of maturity indices for refuse compost. *Agriculture, Ecosystems and Environment.* 38: 331 343.

Jiménez, E. I. and Garcia, V. P. (1989). Evaluation of city refuse compost maturity: a review. *Biological Wastes*, 27(2): 115-142.

Jolly, D. (1991). Differences between buyers and nonbuyers of organic produce and willingness to pay organic price premiums. *Journal of Agribusiness,* 9 97-111.

Jönsson, H., and Vinnerås, B. (2004). Adapting the nutrient content of urine and faeces in different countries using FAO and Swedish Data. Peer reviewed paper in the proceedings of the 2nd International Symposium

on ecological sanitation, incorporating the 1st IWA specialist group conference on sustainable sanitation, Division 44, Environment and Infrastructure sector project ecosan; 7th–11th April, 2003, Lübeck, Germany. Published by GTZ, Postfach 5180, 65726 Eschborn, Germany. http://www.gtz.de.

Jönsson, H., Baky, A., Jeppsoon, U., Hellström, D., and Kärrman, E. (2005). Composition of urine, faeces, greywater and biowaste for utilization in the URWARE model. Urban water *Report of the MISTRA Programme*, *Report 2005:6*, Chalmers University of Technology, Gothenburg, Sweden. Available at: www.urbanwater.org.

Jönsson, H., Vinnerås, B., Höglund C. and Stenström, T-A. (1999). Source separation of urine. *Wasser and Boden* 51 (11), 21-25.

Kala, D. R., Rosenani, A. B., Fauziah, C. I. and Thohirah, L. A. (2009). Composting Oil Palm wastes and Sewage Sludge for use in Potting Media of Ornamental Plants. *Malaysian Journal of Soil Science* Vol. 13: 77- 91.

Kala, D. R., Rosenani, A. B., Thohirah, L. A. Fauziah, I. and Ahmad, S. H. (2012). Oil palm waste – Sewage sludge compost as a Peat substitute in a soilless potting medium for Chrysanthemum. *Global Journal of Science Frontier Research Agriculture and Biology* Volume 12. Issue 2. Version 1.

Kang, J and van Iersel, M. W. (2004). Nutrient solution concentration affects Shoot: root ratio, Leaf Area ratio, and growth of subirrigated Salvia *(Salvia splendens)*. *HortScience* 39(1): 49-54.

Kesse, G. O. (1985). The mineral and rock resources of Ghana. Balkema, Rotterdam 610 pp.

Kirchmann, H. (1985) Losses, plant uptake and utilization of manure nitrogen during a production cycle. *Acta Agriculture Scandinavia* 24 (Suppl.): 57.

Kone, D. (2004). Personal discussion. Faecal sludge treatment for developing countries, *EAWAG-SANDEC*, Switzerland.

Kone, D. and Strauss, M. (2004). Low-cost Options for Treating Faecal Sludges (FS) in Developing Countries – Challenges and Performance. A paper presented to the 9th International IWA Specialist Group Conference on Wetlands Systems for Water Pollution Control and to the 6th International IWA Specialist Group Conference on Waste Stabilisation Ponds, Avignon, France, 27 Sept. – 1 Oct., 2004.

Kone, D., Cofie, O., Zurbrugg, C., Gallizzi, K., Moser, D., Drescher, S. and Strauss, M. (2007). Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates. *Water Research*. Vol 41, Issue 19. Pp 4397- 4402.

Kudom, A.A., Mensah, B.A. and Agyemang, T.K. (2012). Characterisation of mosquito larval habitats and assessment of insecticide-resistance status of *Anopheles gambiae senso lato* in urban areas in south western Ghana. *Journal of Vector Ecology*. Volume 37, (1) pp. 77-82.

Kuffour, A. R., Awuah, E., Sarpong, D., Anyemedu, F.O.K and Kone, D. (2013). Effects of Different solid loading rates of faecal sludge on the Dewatering performance of unplanted filter bed. *Civil and Environmental Research.* Vol. 3, No. 4

Kulhman, L.R., Dale, B. Groenhof, A.C. and Young, T.F.E. (1989). *Windrow Composting of sewage sludge and other wastes.*

Kuo, S., Ortiz-Escobar, M. E., Hue, N.V. and Hummel, R.L. (2004). Composting and compost utilization for agronomic and container crops. *Recent Research in Developmental and Environmental Biology*, 1: 451–513.

Land, B (1998). Consumers' dietary patterns and desires for change. Working paper no 31/ March 1998. Centre for Market surveillance, Research and strategies for the food sector, Arhaus School of business, Arhaus, Denmark, ISSN 09072101.

Laos, F., Mazzarino, M.J. Walter, I. Roselli, L. Satti, P. and Moyano, S. (2002). Composting of fish offal and biosolids in northwestern Patagonia. *Bioresource Technology*. 81, 179–186.

Leitzinger, C. (2000). Co-Composting: Could it be a Viable Option for Kumasi, Ghana, from a Material Flow Viewpoint? Diploma thesis, Swiss Federal Institute of Technology (ETH), Zurich. In German.

Lentner, C., Lentner, C. and Wink, A. (1981). Units of Measurement, Body Fluids, Composition of the Body, Nutrition. Geigy Scientific Tables. CIBA-GEIGY Ltd Basle Switzerland ISBN 0-914168-50-9.

Levanon, D. and Pluda, D. (2002). Chemical, physical and biological criteria for maturity in composts for organic farming. *Compost Science and Utilization.* 10 (4), 339–346.

Liu, J., Leatherwood, W.R. and Mattson, N.S. (2012). Irrigation method and fertilizer concentration differentially alter growth of vegetable transplants. *Hort. Technology* Vol. 22 No. 1, 56 – 63.

Lumis, G., Purvis, P. and Taurins, L. (2000). Flood irrigation of container-grown Euonymus and Thuja as affected by fertilizer rate and substrate. *Journal of Environmental Horticulture.* 18 (1): 13 – 17.

Magnusson, M. (2004). Consumers' perception of organic and genetically modified foods. Comprehensive summaries of Uppsala dissertations from the faculty of social studies 137.

Martins, O. and Dewes, T. (1992). Loss of nitrogenous compounds during composting of animal wastes. *Bioresource Technology* 42, 103 – 111.

Mary, B. and Recous, S. (1994). Measurement of Nitrogen Mineralization and Immobilization Flues In: Soil as a Means of Predicting Net Mineralization. *European Journal of Agronomy* 3: 1-10.

Melton, R.R. and Dufault, R.J. (1991a). Nitrogen, phosphorus and potassium fertility regimes affect tomato transplant growth. *HortScience* 26, 141 – 142.

Mena, E., Garrido, A., Hernandez, T. and Garcia, C. (2003). Bioremediation of sewage sludge by composting, Communications in Soil *Science and Plant Analysis* 34(7-8) 957-971.

Miller, F. M. (1992). Composting as a process based on the control of ecologically selective factors .In: Metting Jr., F.B. (ed). Soil microbial Ecology. Marcel Dekker, New York, U.S.A, pp.515-544.

MOFA. (2011). Sekondi-Takoradi Metropolitan Area. Retrieved 08 June, 2012, from *mofa.gov.gh/site/?page_id=1787.*

Moliter, H.D. (1990). The European perspective with emphasis on subirrigation and recirculation of water and nutrients. *Acta Horticulturae,* 272, 165 - 173.

Montangero, A. and Strauss, M. (2002). Faecal sludge treatment. A report of Swiss Federal institute for Environmental Science and Technology, IHE Delft. 2002 pp. 9 – 10.

Morgan, D. (1998). What is Plant Nutrition? Dyna-Gru Corporation, pp. 1-5.

Mougeot, L.J.A. (2000). Urban agriculture: definition, presence, potentials and risks. In Growing Cities, Growing Food: Urban Agriculture on the Policy Agenda, ed. N. Bakker, M. Dubbeling, S. Gündel, U. Sabel-Koschella and H. de Zeeuw. Deutsche Stiftung für Internationale Entwicklung (DSE). Feldafing, Germany: Zentralstelle für Ernährung und Landwirtschaft, pp. 1-42.

Mutuo, P. K., Marandu, A.E., Rabeson R. Mwale, M. Snapp, S. and Palm, C.A. (1999). Nitrogen fertilizer equivalencies based on organic input quality and optimum combinations of organic and inorganic N sources: Network trial results from East and Southern Africa. In SWNM Report on the combating Nutrient Depletion – East Africa Highlands consortium.

Naidu, Y., Meon, S., Kadir, J. and Siddiqui, Y. (2010). Microbial Starter for the Enhancement of Biological Activity of compost tea. *International Journal Agriculture and Biology*, 12: 51–56.

Noble, R. and Roberts, S. (2004). Eradication of plant pathogens and nematodes during composting: a review. *Plant Pathology* 53 (5), 548–568.

Ntiamoah, A. and Afrane, G. (2008). Environmental impacts of cocoa production and processing in Ghana: Life cycle assessment approach. *Journal of Cleaner Production* 16, 1735-1740.

Obeng, L. A. and Wright, F. W. (1987). The co-composting of Domestic solid and human wastes. World Bank Technical Paper Number 57.

Obuobie, E. and Sarpong, E. (2005). General overview of urban and peri-urban agriculture in cape coast and Takoradi municipalities. Urban and per-urban agriculture (UPA) studies. IWMI West Africa (Ghana). Available at publications.iwmi.org/pdf/H037654.pdf

Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O.O., Raschid-Sally, L. and P. Drechsel. (2006). Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks. IWMI-RUAF-CPWF, Accra, Ghana: IWMI, 150 pp.

Ofosu-Budu, K. G., Quaye, A. and Danso, S.K.A. (2001). Personal communication. Evaluation of compost maturity in Ghana. UGARS, Kade.

Okalebo, J. R., Gathua, K.W. and Woomer, P.J. (2002). Laboratory methods of soil and plant analysis- A working manual 2nd edition. TSBF-CIAT and SACRED Africa, Nairobi, Kenya.

Olugbenga, S. B., Mohd, A. A. and Tan, T. S. (2011). Utilization of Cocoa Pod Husk for the Removal of Remazol Black B Reactive Dye from Aqueous Solutions: Kinetic, Equilibrium and Thermodynamic Studies. *Trends in Applied Sciences Research*, 6: 794-812.

Ostos, J.C., Lopez-Garrido, R., Murillo, J.M., Lopez, R. (2008). Substitution of peat for municipal solid waste and sewage sludge-based composts in nursery growing media: Effects on growth and nutrition of the native shrub Pistacia lentiscus L. *Bioresource Technology*. 99, 1793-1800.

Papafotiou, M., Phsyhalou, M., Kargas, G., Chatzipavlidis, I., and Chronopoulos, J. (2004). Olive-mill wastes compost as growing medium component for the production of poinsettia. *Scientia Horticulturae.* 102, 167-175.

Parkinson, R., Gibbs, P. Burchett S. and Misselbrook, T. (2004). Effect of turning regime and seasonal weather conditions on nitrogen and phosphorous losses during aerobic composting of cattle manure. *Bioresource Technology.* 91: 171–178.

Pedra, F., Polo, A, Ribeiro, A., and Domingus, H. (2007). Effects of municipal solid waste compost and sewage sludge on mineralization of soil organic matter. *Soil Biology and Biochemistry* 39, pp 1375 – 1382.

Pehnelt, G. and Vietze, C. (2011). Recalculating Default values for Palm Oil. JENA Economic Research Papers- 037. ISSN 1864-7057.

Pieper, W. (1987). Das Scheiss-Buch – Entstehung, Nutzung, Entsorgung menschlicher Fäkalien (The shit book – production, use, Entsorgung human faeces; in Germany). *Der Grüne Zweig* 123, Werner Pieper and Grüne Kraft. Germany.

Poincelot, R. P. (1977). The biochemistry of composting, Proc. National Conference on Composting of Municipal Residues and Sludges, p. 33, Information Transfer, Inc., Rockville, MD.

Polprasert, C. (1996). Organic waste recycling. Technology and management. 2nd edition. Published by John Willey and Sons Ltd. Canada.

Rao Bhamidimarri, S.M., and Pandey, S.P. (1996). Aerobic thermophilic composting of piggery solid wastes. *Water Science and Technology* 33 (8), 89 - 94.

Reeves, D.W. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Research.* 43 (1-2), 131-167.

Ribeiro, H.M., Romero, A.M., Pereira, H., Borges, P., Cabral, F., and Vasconcelos, E. (2007). Evaluation of a compost obtained from forestry wastes and solid phase of pig slurry as a substrate for seedlings production. *Bioresource Technology*. 98, 3294-3297.

Roe, N. E. and Kostewicz, S.R. (1992). Germination and early growth of vegetable seed in composts. Proceedings of National Symposium for Stand Establishment in Horticultural crops. P. 191 -201.

Roe, N. E., Stoffella, P. J. and Graetz, D. (1997). Composts from various Municipal solid waste feedstock affect vegetable crops.I. Emergence and seedling growth. *Journal of the American Society for Horticultural Science*. 122 (3): 427 – 432.

Rosen, C.J., Halbach, T.R., and Swanson, B.T. (1993), *HortTechnology*, 3, 167.

Rosen, D., Tel-Or, E., Hadar, Y. and Chen, Y. (1997). Modern Agriculture and the Environment. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Rossi, L., Lienert, J. and Larsen, T.A. (2009). Real-life efficiency of urine source separation. *Journal of Environmental Engineering* 90, 1909 – 1917.

Saber, M., Mohammed, Z., Badr-el-Din, S. and Awad, N. (2011). Composting certain agricultural residues to potting soils. *Journal of ecology and natural environmental* vol. 3(3), pp. 78 -84.

Sanchez – Monedero, M.A., Roig, A., Paredes, C. and Bernal, M. P. (2001). Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. *Bioresource Technology* 78: 301 – 308.

Sanderson, K.C. (1980). Use of sewage-refuse in the production of ornamental plants. *HortScience,* 15, 173 - 178.

Scheuerell S, and Mahaffee, W. (2002). Compost tea: principles and prospects for plant disease control. *Compost Science and Utilization* 10: 313-338.

Scheuerell, S. (2002). "Compost Teas and Compost Amended Container Media for Plant Disease Control." A Doctoral Dissertation, Oregon State University.

Scheuerell, S.J. and Mahaffee, W.F. (2004). Compost Tea as a Container Medium Drench for Suppressing Seedling Damping-Off Caused by *Pythium ultimum*. *Phytopathology*. 94:1156-1163.

Scheuerell, S.J. and Mahaffee, W.F. (2006). Variability Associated with Suppression of Gray Mold (*Botrytis cinerea*) on Geranium by Foliar Applications of Non-aerated and Aerated Compost Teas. *Plant Disease* 90:1201-1208.

Schouw, N.L., Danteravanich, S., Mosbaek, H and Tjell, J.C. (2002). Composition of human excreta – a case study from Southern Thailand. *Science of the Total Environment Journal 286* (1-3), 155-166.

Schwartzbrod, J. and Gaspard, P. (1998). Quantification and Viability Determination for Helminth Eggs in Sludge (Modified EPA France, 1993 Method). Faculty of Pharmacy, University "Henri Poincare" Department of Microbiology B.P.403 F-54001 Nancy Cedex/France. pp 3-6.

Sellami, F., Hachicha, S., Chtourou, M., Medhioub, K. and Ammar, E. (2008). Maturity assessment of composted olive mill wastes using UV spectra and humification parameters. *Bioresource Technology*, 99(15): 6900-6907.

Senesi, N., Plaza, C., Brunetti, G. and Polo, A. (2007). A comparative survey of recent results on humic-like fractions in organic amendments and effects on native soil humic substances. *Soil Biology and Biochemistry*, 39(6), 1244-1262.

Serra, J.B. and Ventura, F.C. (1999). Protein quality assessment in cocoa pod husk. *Food Research International*, 32: 201-208.

Shammas, N. K. and Wang, L. K. (2007). Biosolids composting. In: L. K. Wang, N. C. Pereira, Y. T. Hung and N. K. Shammas (Eds.), Handbook of Environmental Engineering: Biosolids Treatment Process, vol. 6, Humana Press Inc, Totowa, NJ, pp. 645–704.

Shammas, N. K. and Wang, L. K. (2009). Biosolids composting. In: L. K. Wang, N. C. Pereira, Y. T. Hung and N. K. Shammas (Eds.), Handbook of Environmental Engineering: Biosolids Treatment Process, vol. 8, Humana Press, pp. 669–714.

Sheperd, R and Farleigh, C. A. (1989). Sensory assessment of foods and the role of sensory attributes in determining food choice. In R. Sheperd

(Ed), Handbook of the psychophysiology of human eating. Chinchester: Wiley.

Shrestha, K., Walsh, K. B. and Midmore, D. J. (2012). Microbially Enhanced Compost Extract: Does It Increase Solubilisation of Minerals and Mineralisation of Organic Matter and Thus Improve Plant Nutrition? *Journal of Bioremediation and Biodegradation* 3:149. doi:10.4172/2155-6199.1000149.

Singh, R., Kim, J., Sheperd Jr, M.W., Luo, F. and Jiang, X. (2011). Determining Thermal inactivation of Escherichia coli 0157:H7 in Fresh Compost by simulating early phases of the Composting Process. *Applied and Environmental Microbiology*; 77(12): 4126-4135.

Sobamiwa, O. and Longe, O. G. (1994). Utilization of cocoa-pod pericarp fractions in broiler chick diets. *Animal Feed Science Technology*. 47: 237-244

Soil Survey Staff (1998). Keys to soil Taxonomy. Soil Conservation Service, United States Department of Agriculture. Blacksburg, Virginia, USA, Pocahontas Press, Inc.

Spiers, T.M. and Fietje G. (2000). Green waste compost as a component in soilless. *Compost Science and Utilization*, 8, 19 - 23.

SRI. (2009). *Soil Research Institute, CSIR-Kumasi.*

Sterrett, S.B. (2001). Composts as horticultural substrates for vegetable transplant protection, Compost utilization in horticultural cropping systems, eds Stofella P.J., Kahn B. A. (Lewis Publ, Boca Raton, FL), pp 95 – 119.

Sterrett, S.B., Reynolds, C.W. Schales, F.D. Chaney, R.L. and Douglass. L.W. (1983). Transplant quality, yield, heavy-metal accumulation of tomato, muskmelon, and cabbage grown in media containing sewage sludge compost. *Journal of the American Society for Horticultural Science.* 108:36-41.

STMA. (2012). Sekondi – Takoradi Metropolitan Area. Retrieved 08 June, 2012, from http://www.stma.gov.gh/stma/page/5149/about

Strauss, M., Heinss, U. and Montangero, A. (2000). On-Site Sanitation: When the Pits are full – Planning for Resource Protection in Faecal Sludge Management. In: *Proceedings, Int. Conference, Bad Elster, 20-24 Nov. 1998. Schriftenreihe des Vereins fuer Wasser-, Boden- und Lufthygiene, 105: Water, Sanitation & Health – Resolving Conflicts between Drinking – Water Demands and Pressures from Society's Wastes* (I.Chorus, U. Ringelband, G. Schlag, and O. Schmoll, eds.). IWA Publishing House and WHO Water Series. ISBN No. 3-932816-34-X.

Subair, S., Fylets, J.W. and O'halloran, I.R. (1999). Ammonia Volatilization From Liquid Hog Manure Amended With Paper Products In The Laboratory. *Journal of Environmental Quality* 28: 202-207.

Sun, X. (2006). Nitrogen Transformation in Food-waste composting. A thesis submitted to the faculty of Graduate studies and research in partial fulfilment of the requirement for the degree of Master of Applied science in Environmental Systems Engineering. University of Regina, Saskatchewan.

Taiz, L. and Zeiger, E. (1991). Plant Physiology. The Benjamin/Cummings Plublishing Company, Inc. pp 565.

Thambirajah, J.J. (1988). Composting of Agricultural Wastes: A Rural Technology. *Wallaceana* 51:5-8

Ticknor, R.L., Hamphill, D.D., Jr., and Flower, D.J. (1985). Growth response of Photinia and Thuja and nutrient concentration in tissues and potting medium as influenced by composted sewage sludge, peat, bark and sawdust in potting media, *Journal of Environmental Horticulture*, 3, 176 - 180.

Toledano, J., Kumar, S. and Danielou, M. (2004). Government of Ghana-Ministry of Food and Agriculture, The World Bank-Africa Region-Rural Development, Tree Crops Development Initiative, Reconnaissance Mission Report.

Torjusen, H., Lieblein, G., Wandel, M. and Francis, C. A. (2001). Food system orientation and quality perception among consumers and producers of organic food in Hedmark County, Norway. *Food Quality and Preference*, 12 207 – 216.

Torondel, B. (2010). Sanitation ventures literature review: on-site sanitation waste characteristics. *London School of hygiene & Tropical medicine.*

Tsai, Y.F. (1994). Production of compost from mushroom wastes. Bull. Taichung District Agric. Improvement Station, 44: 13-21.

Turner, C. (2002). The thermal inactivation of *E. coli* in straw and pig manure. *Bioresource Technology*, 84; 57 – 61.

Udoetok, I. A. (2012). Characterization of ash made from oil palm empty fruit bunches (oefb). *International journal of environmental science*. Volume 3, no. 1

UNDP, (1996). Urban Agriculture: Food, Jobs and Sustainable Cities. UN Development Program, Publication Series for Habitat II, Vol.1. UNDP, New York, USA.

United Nations Educational Scientific Cultural Organisation. (2006). Water a shared responsibility: *The United Nations World Water Dev't report 2.* Paris: UNESCO.

US Composting Council. (2000). Field Guide to Compost Use, US Composting Council, Hauppauge, New York.

USDA and USCC (2001).Test Methods for the Examination of Composting and Compost. The United States Department of Agriculture and the United States Composting Council.

USEPA. (1979). Process Design Manual for Sludge Treatment and Disposal, EPA625/1-79-001, US Environmental Protection Agency, Washington, DC.

USEPA. (1993). Standards for the Use or Disposal of Sewage Sludge 40 Code of Federal Regulations Part 503, US Environmental Protection Agency, Washington, DC.

USEPA. (2000). In-Vessel Composting of Biosolids, Biosolids Technology Fact Sheet, US Environmental Protection Agency, EPA 832-F-00-061, Office of Water, Washington, DC.

USEPA. (2002). Use of Composting for Biosolids Management, Biosolids Technology Fact Sheet, US Environmental Protection Agency, EPA 832-F-02-024, Office of Water, Washington, DC.

Vega-Sanchez, F. E., Gouinn, F.R. and Willson, G.B. (1987). Effects of curing time on physical and chemical properties of composted sewage sludge and on the growth of selected bedding plants. *Journal of Environmental Horticultural* 5 (2): 66 -70.

Vengadaramana, A. and Jashothan, P.T.J. (2012). Effect of organic fertilizers on the water holding capacity of soil indifferent terrains of Jaffna peninsula in Sri Lanka. *Journal of Natural Product and Plant Resources*, 2(4): 500 – 503.

Vinnerås, B., Palmquist, H., Balmér, P., Weglin, J., Jensen, A., Andersson, Å. and Jönsson, H. (2006). The characteristics of household wastewater and biodegradable waste - a proposal for new Swedish norms. *Urban Water* 3, 3-11.

Walkley, A. and Black, A.I. (1934). An Examination of the Degtjareff Method for Determining Soil Organic Matter and Proposed Modification of the Chromic Acid Titration Method, *Soil Science* 37: 29-38

Wandel, M. and Bugge, A. (1997). Environmental concern in consumer evaluation of food quality. *Food Quality and Preference*, 8 19 – 26.

Waste Balkan Network. (2011). Composting. www.wastedb.eu

Welke, S. (1999). Effectiveness of compost extracts as disease suppressants in fresh market crops in BC. Organic Farming Research Foundation. Grant Report 99 – 31. Santa Cruz, California.

Weltzien, H. C. (1990). The use of composted materials for leaf disease suppression in field crops. Monograph. *British Crop Protection Council*, 45:115 – 120.

Weltzien, H. C. (1991). Biocontrol of foliar fungal disease with compost extracts. pp 430-450, In: J. H. Andrews and S. S. Hirano (eds.), Microbial Ecology of Leaves. Springer-Verlag, New York.

WHO. (2004). Integrated Guide to sanitary parasitology. © World Health Organization

Wilkens, J. L. and Hillers, V.N. (1994). Influences of pesticide residue and environmental concerns on organic food preference among food cooperative members and non-member in Washington State. *Journal of Nutrition Education*, 26, 26 – 33.

Willson, G.B. (1993). Combining raw materials for composting. In: J. Goldstein (ed). *The Biocycle Guide to Yard Waste Composting*. The JG Press, Emmaus, Pennsylvania. pp 102-105.

Witter, E., and Lopez-Real, J. (1988). Nitrogen losses during the composting of sewage sludges, and the effectiveness of clay soil, zeolite, and compost in adsorbing the volatilized ammonia. *Biological Wastes* 23, 279 - 294.

Wong, J.W.C., Mak, K.F., Chan, N.W., Lam, A. and Fang, M. (2001). Co-composting of soybean residues and leaves in Hong Kong. *Bioresource. Technology*, 76: 99 -106.

Wong, M.H. and Chu, L.M. (1985). The responses of edible crops treated with extracts of refuse compost of different ages. *Agricultural Wastes* 14: 63 – 74.Yara International (2013). Yara's various production

processes. Retrieved 10 June, 2013 from www.yara.com/about/production_sites/production_process_story/production_processes/

Yohalem, D. S., Nordheim, E. V. and Andrews, J.H. (1994).The effect of water extracts of spent mushroom compost of apple scab in the field. *Phytopathology*, 86: 914 – 922.

Zhang, W., Han, D. Y., Dick, W. A., Davis, K. R. and Hoitink, H. A. J. (1998). Compost and compost water extract-induced systemic acquired resistance in cucumber and Arabidopsis. *Phytopathology*, 88: 450 – 455.

Zibrilla, I. and A.A. Salifu. (2004). Information gathering from urban and peri-urban communities with potential land areas for vegetable production. Report submitted to Urban Agriculture Network – Northern Ghana. 30th June 2004, 16 pp. (mimeo)

APPENDICES

APPENDIX 1: Logging Sheets

Date	Time Period/ Interval	Vehicle no.	Vehicle Capacity	Vehicle ownership	Quantity of FS discharged	Type of FS discharged	Source/ Locality	Remarks

APPENDIX 2: Growing media effects (factor 1) on vegetative properties of tomato transplants after three weeks of treatment application.

Media (substrate)	One week after treatment	Two weeks after treatment	Three weeks after treatment
Plant height (cm)			
Compost only	12.72	22.42	27.14
Compost: CRH mix (1:1)	14.21	22.09	26.70
CRH only	7.09	10.26	14.17
LSD *(P < 0.05)(n =3)*	0.488	0.832	0.984
Stem diameter (mm)			
Compost only	0.29	0.37	0.39
Compost: CRH mix (1:1)	0.33	0.37	0.40
CRH only	0.20	0.25	0.29
LSD *(P < 0.05)(n =3)*	0.008	0.014	0.012
No. of leaves			
Compost only	2.97	5.10	6.47
Compost: CRH mix (1:1)	3.38	4.53	6.27
CRH only	2.07	2.90	4.53
LSD *(P < 0.05)(n =3)*	0.117	0.299	0.229
Root length (cm)			
Compost only	11.37	10.50	11.44
Compost: CRH mix (1:1)	15.05	13.30	11.67
CRH only	9.99	9.19	9.02
LSD *(P < 0.05)(n =3)*	0.979	0.857	0.695
Chlorophyll content (CCI)			
Compost only	9.69	8.53	9.63

Compost: CRH mix (1:1)	10.34	8.08	11.52
CRH only	4.28	5.15	6.27
LSD *(P < 0.05)(n =3)*	0.924	0.273	0.676
Shoot dry matter (mg/plant)			
Compost only	96.60	215.00	441.30
Compost: CRH mix (1:1)	134.20	246.30	466.70
CRH only	20.70	41.70	118.00
LSD *(P < 0.05)(n =3)*	6.300	0.022	28.480
Root dry matter (mg/plant)			
Compost only	41.90	51.30	74.30
Compost: CRH mix (1:1)	99.60	78.00	101.90
CRH only	9.30	20.4	34.70
LSD *(P < 0.05)(n =3)*	6.110	0.008	8.170
Shoot/root ratio			
Compost only	2.35	4.29	6.16
Compost: CRH mix (1:1)	1.50	3.08	4.54
CRH only	2.25	1.84	3.32
LSD *(P < 0.05)(n =3)*	0.175	0.552	0.625

APPENDIX 3: Effect of nutrient solution (factor 2) on vegetative properties of tomato transplant after three weeks of treatment.

Irrigation nutrient solutions	One week after treatment	Two weeks after treatment	Three weeks after treatment
Plant height (cm)			
CT-1	11.92	16.96	19.87
CT-2	9.79	15.03	17.22
In-fert-1	12.13	21.28	29.24
In-fert-2	12.30	22.13	28.47
W	10.55	15.87	18.56
LSD *(P < 0.05)(n =3)*	0.630	1.074	1.271
Stem diameter (mm)			
CT-1	0.28	0.31	0.33
CT-2	0.25	0.29	0.31
In-fert-1	0.29	0.38	0.42
In-fert-2	0.28	0.37	0.43
W	0.26	0.30	0.32
LSD *(P < 0.05)(n =3)*	0.011	0.009	0.015
No. of leaves			
CT-1	2.97	3.89	5.33
CT-2	2.52	3.56	4.72
In-fert-1	3.03	4.78	6.83
In-fert-2	2.91	4.94	7.00
W	2.60	3.72	4.89
LSD *(P < 0.05)(n =3)*	0.151	0.386	0.296
Root length (cm)			
CT-1	10.41	10.93	10.99
CT-2	11.77	10.43	11.27
In-fert-1	13.31	11.97	10.23
In-fert-2	12.90	11.12	10.08
W	12.31	10.53	10.98

LSD *(P < 0.05)(n =3)*	1.263	1.107	0.897
Chlorophyll content (CCI)			
CT-1	6.25	5.91	6.30
CT-2	5.71	5.29	5.97
In-fert-1	10.01	9.92	14.17
In-fert-2	10.59	9.65	13.21
W	7.97	5.50	6.05
LSD *(P < 0.05)(n =3)*	1.193	0.353	0.873
Shoot dry matter (mg/plant)			
CT-1	80.00	126.10	279.40
CT-2	63.60	110.60	213.30
In-fert-1	97.80	240.00	490.00
In-fert-2	104.70	232.20	506.10
W	73.30	129.40	221.10
LSD *(P < 0.05)(n =3)*	8.130	29.03	36.770
Root dry matter (mg/plant)			
CT-1	48.90	47.20	51.70
CT-2	30.50	32.80	44.40
In-fert-1	42.80	64.00	86.10
In-fert-2	78.50	64.40	102.80
W	50.60	41.10	66.40
LSD *(P < 0.05)(n =3)*	7.880	10.070	10.550
Shoot/root ratio			
CT-1	1.75	2.51	4.84
CT-2	2.17	3.13	4.24
In-fert-1	2.64	3.67	5.70
In-fert-2	1.89	3.33	5.24
W	1.72	2.72	3.33
LSD *(P < 0.05)(n =3)*	0.226	0.552	0.807

APPENDIX 4: Interaction effects between growing media type and nutrient solution type on some vegetative properties of tomato after three weeks of treatment.

	Irrigation nutrient solutions				
Media (Substrate)	CT-1	CT-2	In-fert-1	In-fert-2	W
Plant Height (cm)					
Compost only	25.55	22.35	31.62	30.67	25.50
Compost- CRH mix (1:1)	24.70	20.40	32.92	33.33	22.17
CRH only	9.35	8.90	23.18	21.42	8.00
LSD *(P < 0.05)(n =3)*	2.201				
Stem diameter (mm)					
Compost only	0.38	0.35	0.44	0.41	0.37
Compost- CRH mix (1:1)	0.38	0.37	0.44	0.45	0.35
CRH only	0.22	0.22	0.38	0.43	0.22
LSD *(P < 0.05)(n =3)*	0.013				
Root length (cm)					
Compost only	10.65	11.97	11.77	11.32	11.50
Compost- CRH mix (1:1)	11.38	13.47	11.58	9.67	12.23
CRH only	10.93	8.37	7.33	9.27	9.20
LSD *(P < 0.05)(n =3)*	1.554				
No. of leaves					
Compost only	6.33	5.83	7.00	7.00	6.17
Compost- CRH mix (1:1)	5.83	5.33	7.50	7.00	5.67
CRH only	3.83	3.00	6.00	7.00	5.67
LSD *(P < 0.05)(n =3)*	0.513				
Chlorophyll content (CCI)					
Compost only	7.24	7.07	14.42	12.44	6.97
Compost- CRH mix (1:1)	8.17	7.25	16.85	16.89	8.45
CRH only	3.50	3.58	11.23	10.30	2.73
LSD *(P < 0.05)(n =3)*	1.512				

Shoot dry matter (mg/plant)					
Compost only	455.00	368.30	503.30	515.00	365.00
Compost- CRH mix (1:1)	358.30	253.30	728.30	711.70	281.70
CRH only	25.00	18.30	238.30	291.70	16.70
LSD *(P < 0.05)(n =3)*	63.690				
Root dry matter (mg/plant)					
Compost only	71.70	65.00	66.70	71.70	96.7
Compost- CRH mix (1:1)	75.00	61.70	121.70	153.30	97.7
CRH only	8.30	6.70	70.00	83.30	5.00
LSD *(P < 0.05)(n =3)*	18.260				
Shoot/ root ratio					
Compost only	6.37	5.73	7.59	7.30	3.78
Compost- CRH mix (1:1)	4.97	4.15	5.99	4.69	2.88
CRH only	3.17	2.83	3.51	3.74	3.33
LSD *(P < 0.05)(n =3)*	1.397				
Root volume (cm^3)					
Compost only	0.93	0.83	1.28	1.22	1.28
Compost- CRH mix (1:1)	1.07	0.93	1.22	1.63	1.05
CRH only	0.25	0.37	0.83	0.97	0.30
LSD *(P < 0.05)(n =3)*	0.288				

APPENDIX 5: Growing media effect (factor1) on vegetative properties of pepper transplants at the end of treatment.

Media (substrate)	One week after treatment	Three weeks after treatment
Plant height (cm)		
100% Compost: 0% CRH	15.52	22.99
75% Compost: 25% CRH	15.48	24.39
50% Compost: 50% CRH	14.93	24.18
25% Compost: 75% CRH	12.29	19.61
0% Compost: 100% CRH	4.43	9.94
LSD *(P < 0.01)(n =3)*	0.594	0.639
Stem diameter (mm)		
100% Compost: 0% CRH	0.23	0.28
75% Compost: 25% CRH	0.22	0.28
50% Compost: 50% CRH	0.22	0.29
25% Compost: 75% CRH	0.19	0.23
0% Compost: 100% CRH	0.11	0.14
LSD *(P < 0.01)(n =3)*	0.010	0.010
No. of leaves		
100% Compost: 0% CRH	11.67	18.93
75% Compost: 25% CRH	10.90	19.07
50% Compost: 50% CRH	10.63	19.15
25% Compost: 75% CRH	8.70	15.87
0% Compost: 100% CRH	3.33	10.05
LSD *(P < 0.01)(n =3)*	0.691	0.716
Root length (cm)		
100% Compost: 0% CRH	12.13	16.65
75% Compost: 25% CRH	11.67	15.57

50% Compost: 50% CRH	10.74	17.89
25% Compost: 75% CRH	11.50	16.34
0% Compost: 100% CRH	7.85	13.52
LSD *(P < 0.01)(n =3)*	0.887	0.683
Chlorophyll content (CCI)		
100% Compost: 0% CRH	8.46	11.04
75% Compost: 25% CRH	9.00	11.40
50% Compost: 50% CRH	8.26	11.15
25% Compost: 75% CRH	7.81	9.58
0% Compost: 100% CRH	3.69	9.54
LSD *(P < 0.01)(n =3)*	0.168	0.581
Shoot dry matter (mg/plant)		
100% Compost: 0% CRH	240.00	650.70
75% Compost: 25% CRH	198.00	610.70
50% Compost: 50% CRH	168.00	657.30
25% Compost: 75% CRH	107.90	436.00
0% Compost: 100% CRH	10.10	129.60
LSD *(P < 0.01)(n =3)*	19.280	46.090
Root dry matter (mg/plant)		
100% Compost: 0% CRH	106.50	189.30
75% Compost: 25% CRH	86.90	190.00
50% Compost: 50% CRH	76.00	166.00
25% Compost: 75% CRH	68.20	134.70
0% Compost: 100% CRH	7.90	42.30
LSD *(P < 0.01)(n =3)*	8.740	17.900
Shoot/root ratio		
100% Compost: 0%	2.30	3.29

CRH		
75% Compost: 25% CRH	2.58	3.24
50% Compost: 50% CRH	2.42	4.25
25% Compost: 75% CRH	1.74	3.37
0% Compost: 100% CRH	1.21	3.18
LSD *(P < 0.01)(n =3)*	0.239	0.412

APPENDIX 6: Effect of nutrient solution (factor 2) on vegetative properties of tomato transplants at the end of treatment.

Irrigation nutrient solutions	One week after treatment	Three weeks after treatment
Plant height (cm)		
CT	12.11	19.88
In-fert-1	13.11	23.38
In-fert-2	13.78	22.72
In-fert-3	12.89	21.03
W	11.16	15.10
LSD *(P < 0.01)(n =3)*	0.594	0.639
Stem diameter (mm)		
CT	0.19	0.23
In-fert-1	0.21	0.28
In-fert-2	0.21	0.29
In-fert-3	0.19	0.24
W	0.18	0.19
LSD *(P < 0.01)(n =3)*	0.010	0.010
No. of leaves		
CT-1	8.67	18.25
In-fert-1	9.53	18.50
In-fert-2	9.57	17.28
In-fert-3	8.67	16.89
W	8.80	12.15
LSD *(P < 0.01)(n =3)*	0.691	0.716
Root length (cm)		
CT-1	12.40	17.97
In-fert-1	8.92	14.51
In-fert-2	11.65	16.99
In-fert-3	10.21	15.00
W	10.70	15.52
LSD *(P < 0.01)(n =3)*	0.887	0.683
Chlorophyll content (CCI)		
CT-1	6.60	8.09
In-fert-1	7.67	11.50
In-fert-2	8.22	9.84
In-fert-3	8.76	13.06
W	5.97	10.24
LSD *(P < 0.01)(n =3)*	0.168	0.581
Shoot dry matter (mg/plant)		

CT-1	144.70	499.30
In-fert-1	182.20	616.70
In-fert-2	168.80	693.30
In-fert-3	121.20	472.00
W	107.00	213.00
LSD *(P < 0.01)(n =3)*	19.280	46.090
Root dry matter (mg/plant)		
CT-1	53.20	172.00
In-fert-1	57.70	126.70
In-fert-2	95.20	166.00
In-fert-3	74.60	153.30
W	64.90	104.30
LSD *(P < 0.01)(n =3)*	8.740	17.900
Shoot/root ratio		
CT-1	2.33	2.81
In-fert-1	3.06	5.15
In-fert-2	1.76	4.40
In-fert-3	1.55	3.11
W	1.55	1.85
LSD *(P < 0.01)(n =3)*	0.239	0.412

APPENDIX 7: Interaction effects between media type and nutrient solution type on vegetative properties of pepper transplants at the end of treatment.

	Irrigation nutrient solutions				
Media (Substrate)	CT	In-fert-1	In-fert-2	In-fert-3	W
Plant Height (cm)					
100% Compost: 0% CRH	24.23	26.95	27.32	20.52	15.93
75% Compost: 25% CRH	27.02	25.45	24.22	27.33	17.93
50% Compost: 50% CRH	24.04	23.48	26.57	25.03	21.77
25% Compost: 75% CRH	15.63	22.18	24.53	20.18	15.55
0% Compost: 100% CRH	8.45	13.83	10.98	12.12	4.33
LSD *(P < 0.01)(n =3)*	1.428				
Stem diameter (mm)					
100% Compost: 0% CRH	0.26	0.35	0.36	0.24	0.20
75% Compost: 25% CRH	0.27	0.30	0.28	0.31	0.21
50% Compost: 50% CRH	0.29	0.30	0.30	0.28	0.29
25% Compost: 75% CRH	0.22	0.25	0.30	0.23	0.18
0% Compost: 100% CRH	0.10	0.19	0.19	0.17	0.04
LSD *(P < 0.01)(n =3)*	0.022				
Root length (cm)					
100% Compost: 0% CRH	18.20	15.27	19.90	14.82	15.05
75% Compost: 25% CRH	20.10	13.53	14.90	14.32	14.98
50% Compost: 50% CRH	19.53	13.85	19.50	17.68	18.87
25% Compost: 75% CRH	18.00	15.07	16.25	16.15	16.35
0% Compost: 100% CRH	14.00	14.82	14.40	12.05	12.33
LSD *(P < 0.01)(n =3)*	1.527				
No. of leaves					
100% Compost: 0% CRH	23.33	19.67	21.33	18.67	11.67
75% Compost: 25% CRH	24.00	18.83	18.75	20.77	13.00
50% Compost: 50% CRH	23.00	18.50	18.50	18.83	16.90
25% Compost: 75% CRH	13.67	20.33	17.00	15.17	13.17
0% Compost: 100% CRH	7.27	15.17	10.83	11.00	6.00
LSD *(P < 0.01)(n =3)*	1.601				
Chlorophyll content (CCI)					
100% Compost: 0% CRH	9.81	13.02	10.20	11.90	10.27
75% Compost: 25% CRH	10.09	12.19	10.09	13.73	10.91
50% Compost: 50% CRH	9.78	11.50	10.34	12.91	11.22
25% Compost: 75% CRH	5.73	10.58	9.29	13.19	9.10
0% Compost: 100% CRH	5.05	10.18	9.25	13.54	9.68
LSD *(P < 0.01)(n =3)*	1.299				
Shoot dry matter (mg/plant)					

100% Compost: 0% CRH	633.30	883.30	1070.00	436.70	230.00
75% Compost: 25% CRH	620.00	726.70	696.70	750.00	260.00
50% Compost: 50% CRH	686.70	726.7	810.00	656.70	406.70
25% Compost: 75% CRH	396.70	513.30	720.00	390.00	160.00
0% Compost: 100% CRH	160.00	233.30	170.00	126.70	8.20
LSD *(P < 0.01)(n =3)*	103.060				
Root dry matter (mg/plant)					
100% Compost: 0% CRH	206.70	213.30	296.70	140.00	110.00
75% Compost: 25% CRH	233.30	170.00	166.70	276.70	133.30
50% Compost: 50% CRH	220.00	110.00	150.00	180.00	190.00
25% Compost: 75% CRH	220.00	93.3	180.00	126.70	80.00
0% Compost: 100% CRH	76.7	46.7	36.7	43.3	8.1
LSD *(P < 0.01)(n =3)*	40.020				
Shoot/ root ratio					
100% Compost: 0% CRH	3.41	4.18	3.64	3.15	2.09
75% Compost: 25% CRH	3.06	4.26	4.20	2.71	1.95
50% Compost: 50% CRH	3.43	6.61	5.40	3.69	2.13
25% Compost: 75% CRH	2.07	5.55	4.05	3.08	2.09
0% Compost: 100% CRH	2.09	5.14	4.72	2.93	1.01
LSD *(P < 0.01)(n =3)*	0.920				

APPENDIX 8: Questionnaires

Questionnaire to ascertain the perception of farmers on human waste (faecal sludge) composting and use of faecal sludge based co-compost in crop production.

INTRODUCTION

Human waste management in urban areas is a challenge facing many city authorities. Lack of proper disposal means has led to the widespread pollution of water bodies, drainage ditches etc resulting in loss of human lives especially children. As part of the partial fulfilment of the requirement for the degree of M. Phil. Environmental Science, students of the University of Ghana are required to solve social and environmental issues relating to their research work. It is in view of this that the following questionnaire is prepared to help identify problems relating to human waste composting and its subsequent use in crop production. Your co-operation is therefore highly needed.

Questionnaire No.: ..... Community: ..... Interviewer: .....
Date:.....

Particulars of respondents

(i) Name: ..... (ii) Gender: M / F (iii) Marital status:.....

(iv) Age: ..... (v) Educational Status.....

(1) Do you know about composting? Yes or No

(2) What type of composting: (a) Poultry manure (b) Market waste (c) Municipal and domestic solid waste (d) Other

(3) Do you prepare compost? Yes or No. if No, skip to (8)

(4) If yes, how do you prepare the compost: (a) Pile up waste (b) Pile up waste with periodic turning (c)
Other.....

.....

.....

.....

(5) How long does it take you to compost? (a) 1 - 4 weeks (b) 4 – 8 weeks (c) 8 – 12 weeks (d) 12 weeks and over.

(6) Is composting a difficult task to do? Yes or No

(7) Is composting an expensive venture? Yes or No

(8) Do you know that human waste can be composted? Yes or No

(9) If yes, how is composting of human waste done:.....

.....

.....

.....

(10) Does composting human waste make it safe for use? (a) Yes (b) No (c) I don't know

(11) Would you compost human waste? Yes or No

(12) Why?.....

.....

.....

.....

(13) Would you apply composted human waste to your crops? Yes or No, if No skip to (17)

(14) If Yes, how would you apply the composted human waste? (a) Broadcast (b) Placement (c) Band placement (d) Pellet application (e) Other

(15) Which crops would you cultivate with the composted human waste.....

.....

.....

.....

(16) What quantity of composted human waste would you apply to the crops?

Crop	Quantity
Lettuce	
Cabbage	
Sweet pepper	
Maize	
Plantain	
Tomato	

(17) Would you recommend it to the other farmers? Yes or No

(18) Other

comments.....

Questionnaire to ascertain the willingness of consumers to patronise human waste grown farm produce

INTRODUCTION

Human waste management in urban areas is a challenge facing many city authorities. Lack of proper disposal means has led to the widespread pollution of water bodies, drainage ditches etc resulting in loss of human lives especially children. As part of the partial fulfilment of the requirement for the degree of M. Phil. Environmental Science, students of the University of Ghana are required to solve social and environmental issues relating to their research work. It is in view of this that the following questionnaire is prepared to help identify problems relating to human waste composting and its subsequent use in crop production. Your co-operation is therefore highly needed.

Questionnaire No.: ..... Community: ..... Interviewer: .....
Date:.....

Particulars of respondents

(i) Name: ..... (ii) Gender: M / F (iii) Marital status:.....

(iv) Age: ..... (v) Educational Status.....

(1) Where do you buy your vegetables? (a) Market (b) farm (c) Other

(2) Do you ask what type of fertilizer is applied to the crops? Yes or No

(3) If yes, does the type of fertilizer used affect your willingness to buy the produce? Yes or No

(4) Do you know about composting and compost use in crop production? Yes or No

(5) Would you patronise farm produce cultivated with compost? Yes or No

(6) Do you know human waste can be composted? (a) Yes (b) No (c) Don't know

(7) Do you agree human waste should be composted (a) Yes (b) No (c) Don't know

(8) Are you aware some farmers in Ghana are using composted human waste for crop production? (a) Yes (b) No (c) Don't know

(9) Do you agree composted human waste is safe to use in crop production (a) Yes (b) No (c) don't know

(10) Would you patronise produce cultivated with composted human waste? Yes or No

(11)

Why?.....

.....

(12)Other

comments.....