CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF SOME MARKETED SOLID WASTE COMPOSTS IN GHANA

A THESIS SUBMITTED

BY

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DECLARATION

This thesis is a result of research work undertaken by Jonathan Nartey Hogarh in the Environmental Science Programme, University of Ghana, Legon, under the supervision of Dr. Derick Carboo, Dr. Kwabena Ofosu-Budu, Dr. Nii-Aryi Ankrah and Prof. Alexander K. Nyarko.

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DEDICATION

This work is dedicated to my family

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ABSTRACT

The study assessed the chemical and biological characteristics of composts made from municipal solid waste in Accra and agricultural waste in Kade in Ghana. In Accra, compost samples were taken at residential level (Household composting), decentralised community level (Asiedu-Keteke composting facility) and at large-scale metropolis level (Teshie composting plant). The compost samples from Kade were produced at the University of Ghana Agricultural Research Station. Composting operations at Teshie and Asiedu-Keteke were from mixed feed stock of organic material, newspapers, bottles, plastics, etc. and represented composting of un-segregated solid waste. The Household compost was produced from kitchen waste, whilst the Kade compost was produced from agricultural wastes (a mixture of cocoa pod husk, poultry droppings and saw dust). The Household and Kade composts were, thus, from purely organic sources. Public interest in composting in general was also assessed by way of questionnaires.

The results indicated that the nutrient value, mainly nitrogen, phosphorus and potassium in the Accra composts, which were from municipal solid waste (MSW) were low compared to the compost from Kade, which was from agricultural waste. The differences in nutrient value reflected differences in feed-stocks for the composting. The composts from the mixed waste stream (Teshie and Asiedu-Keteke) did contain higher concentrations of heavy metals such as lead and cadmium compared to the composts from pure organic sources (Household and Kade). However, the concentrations of the heavy metals found in the mixed waste composts, were not of levels that would pose significant health risk. The Asiedu-Keteke composts were found not to be matured and thus, may have restrictions for its use, particularly, for crop cultivation. All the

other composts studied were found to be matured.

The social survey indicated that respondents were less familiar with MSW derived composts in comparison to their knowledge on animal manure or yard waste composts. However, there was a potential for a positive public response to solid waste composting.

CHAPTER ONE

INTRODUCTION

This chapter introduces the essence of this research and the specific questions that the research seeks to address.

1.1 GENERAL INTRODUCTION

The fast rate of urbanisation in developing countries, and increase in agricultural and agro-industrial activities have led to increase in the quantity and diversity of municipal solid, agricultural and agro-industrial wastes that are released into the environment. In Accra for example, the rate of generation of MSW was estimated at 0.4 kg/capita/day (Fobil, 2001). Based on a current estimated population of 3.5 million people in Accra, the projected daily generation of solid waste in the city is approximately 1.4 million kg. This is quite frightening, considering the fact that waste management capacity of the Accra Metropolitan Assembly (AMA), the body responsible for waste management in Accra, is greatly impaired by lack of adequate resources, especially regarding logistics and personnel, as well as finding appropriate waste treatment options. Consequently, MSW management in Accra is woefully inadequate and thus, wastes continue to accumulate on the corridors of the city. Most of the regional capitals in Ghana are facing similar solid waste management problems.

The largest portion of MSW in Accra consists of organic material, which was estimated to be over 65% of the waste fraction (Laryea, 1996; Fobil, 2001). The greatest potential for waste reduction in Accra therefore rests with recycling of these organic components of the waste stream. Similarly, the agricultural wastes generated in the forest regions of the country consist of rich organic materials. At Kade for instance, agricultural and agro-industrial activities generate lots of solid waste such as saw-dust, rice straw, cocoa husk, animal droppings, etc. When these wastes are left unattended, they attract rodents and other destructive animals to the farms. Organic waste is known to pollute the environment in several respects. Its putrifiable nature, aided by high ambient temperatures in the country (averagely 30°C), promotes decomposition very fast and generate obnoxious odour, which accounts for the unpleasant smells associated with the waste stream. Organic waste also attracts pathogens, flies and vermin. Besides, organic waste left unattended, especially in urban cities, has often been washed into drainage channels to choke them, causing floods when it rains. In some cases, such floods have led to the loss of lives and properties in Accra. Thus, when left alone, organic waste constitutes a major health and environmental hazard. However, when used as compost, organic waste may cease to be a principal contaminant in the environment.

Waste management task in both the urban and forest areas would be greatly reduced if effective ways are found to treat the organic portion of the waste stream. There are three main solid waste management treatment options available to waste managers. These are landfilling, incineration, and composting. Landfilling is the controlled dumping of solid waste into sanitary pits, which have been constructed for that purpose. Sanitary pits are however expensive to construct and there is also the risk of leaching from the pits into ground water. Incineration on the other hand is the controlled burning of waste at high temperatures to reduce its volume. Incineration is costly, since it demands the use of energy to burn the waste and also introduces pollutants into the atmosphere. Organic wastes contain high moisture making them difficult and expensive to burn. Composting, which is the biological decomposition of organic matter of waste under controlled conditions, is less expensive and a better approach to recycle organic waste.

In this respect, composting presents a unique opportunity for recycling of the high organic content in the MSW in urban centres as well as the agricultural waste in the forest regions in Ghana. In the city of Accra, composting as a recycling option has the capacity to recover about 50% of solid waste generated for reuse in various economic ventures (Laryea, 1996; Fobil, 2001).

The benefits of composts are numerous. It has been documented to benefit the biological, chemical and physical properties of soil. Biologically, composts enhance the development of soil micro flora, render plants less vulnerable to attack by parasites and promote faster root development of plants (Shiralipour *et al*, 1992). Chemically, composts improve soils by increasing their nutrient content, convert mineral substances in soil into forms available to plant and slowly release these minerals to the soil. Furthermore, compost improves many physical properties of soil, including the soil's texture, water retention capacity, infiltration, resistance to wind and erosion, aeration capacity, and structural and temperature stability (Shiralipour *et al*, 1992). Recent reports have also indicated several innovative uses of composts, some of which include erosion control, turf remediation, landscaping, reforestation, wetlands restoration and disease control for plants and animals (US EPA, 1997).

The quality of compost, which is described through its chemical and biological characteristics, is useful in ensuring sustainability of a composting programme (Woodbury, 1998). This is because it aids in the determination of appropriate utilization options for the particular compost in question. For example, some compost for certain quality reasons, may not be suitable for use in agriculture but could be utilized in land reclamation activities. Another reason why compost quality is important is to avoid the use of contaminated products that could have undesirable environmental and health implications. Lately, concerns have been raised about composts that were produced from mixed waste stream. In the US, such composts have been found to contain high levels of heavy metals (Woodbury, 1998).

In Accra, solid waste composts are produced from mixed waste stream with potential sources of contamination. Analysis of MSW of Accra, indicated that the waste stream contains broken bottles, batteries, metals, plastics or rubber remnants and residues (Fobil *et al*., 2002); and these could potentially introduce heavy metal contaminants into MSW compost products (Woodbury, 1998). This could have undesirable implications for the end use of the compost. Information on chemical and biological characteristics of compost products in Ghana is important for appropriate utilisation of compost products in the country. This could possibly expand the scope of utilisation of the compost products. Currently virtually all of solid waste composts in Ghana are channelled into crop production. But this might not be the most appropriate utilisation option. For example, there were poor tomato yield when some Accra MSW composts were used in crop cultivation in comparison with agricultural waste composts from Kade. Thus, knowing the nutrient content of the compost products is important for appropriate categorisation of end uses.

1.2 AIM AND OBJECTIVES

The overall aim of this research was therefore to assess and compare some chemical and biological characteristics of different solid waste composts in Accra and Kade as a factor for determining compost utilisation options.

The specific objectives were:

- to evaluate the macro-nutrient content and organic fertilizer value;
- to assess heavy metal content in the composts;
- to assess the level of maturity of the composts;
- to determine phytotoxicity in the composts;
- to assess public interest in composting;
- to predict suitable compost utilisation options based on compost quality information.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews pertinent literature on composting and identifies the gaps in the existing knowledge.

2.1 WHAT IS COMPOSTING

Composting is the biological decomposition of biodegradable organic fraction of waste under controlled and aerated conditions to a state sufficiently stable for nuisance-free storage and handling and for safe use in land application (Diaz *et al.*, 1994).

Composting is carried out by successive microbial populations that break down organic materials into carbon dioxide, water, minerals, and stabilized organic matter. Carbon dioxide and water are released into the atmosphere, while minerals and organic matter are converted into a potentially reusable soil-like material called compost.

The following general formula illustrates the inputs and outputs for the organic matter in the presence of oxygen:

$$\text{organic matter} + O_2 + \text{nutrients} \xrightarrow{\text{bacteria}} \text{new cells} + \text{stabilized organic matter (Compost)} + CO_2 + H_2O + NH_3 + SO_4^{2-} + \ldots + \text{heat}$$

(Tchobanoglous *et al.*, 1993)

The loss of water and carbon dioxide typically reduces the volume of remaining material by 25%

to 60% (Diaz *et. al*., 1994).

2.1.1 Technologies

There are two basic composting technologies used in composting. These are windrow-based and in-vessel technologies.

2.1.1.1 Windrow-based composting technology

In the windrow-based technology, waste is brought to a central open-air facility and formed into windrows (heaps) that are three to five feet high. The windrows are turned periodically to maintain a stable temperature and rate of decomposition, and water is added as needed to maintain appropriate moisture content. After a desired level of decomposition is reached, the composted product is ready for assembly and distribution to end-users.

2.1.1.2 In-vessel based composting technology

In-vessel composting takes place in an enclosed environment such that oxidative biological decomposition of the waste is effected by an active supply of air through pipes. This system of composting, compared to the windrow-based one, is not carried out in the open and is more sophisticated. In-vessel systems also, tend to be more capital intensive and require a larger initial investment to set up. In addition, the greater technical complexity of these systems requires a work force that is highly trained (but fewer in number) for operating the composting facility.

2.2 SOLID WASTE COMPOSTING IN GHANA

There are two main different types of solid waste that are composted in Ghana. These are municipal solid waste and agricultural/agro-industrial wastes.

2.2.1 Municipal Solid Waste Composting

Municipal solid waste generally refers to refuse generated in towns and cities. These wastes are usually generated from domestic homes, institutions such as offices and hospitals, as well as from market places. MSW composting processes all of the biodegradable components of the waste stream that decompose easily – paper, food waste, wood and yard trimmings. On the average these materials account for about 65% (by weight) of the MSW in Accra (Fobil, 2001). The significant volume reductions associated with composting and the possible uses of compost make MSW composting attractive as a potential means of diverting waste from landfills.

Three (3) categories of MSW composting can be identified in Ghana. These are residential composting, decentralized community composting and centralized large-scale composting; all of which are windrow based. Examples from Accra of these three composting categories are reviewed in the proceeding sections – 2.2.1.1, 2.2.1.2 and 2.2.1.3.

2.2.1.1 Residential composting

Residential or household composting is practiced in a few homes in Accra. One common feature of homes that practice composting is that they have large compounds and are located in the affluent suburbs of the city. The residents are engaged in the composting mostly for domestic horticultural purposes. Household composting is a simple way to manage domestic refuse that is generated in the kitchen and garden. This type of composting effectively reduces waste quantities for collection. The composting unit consists of simple wooden receptacles into which all compostable organic wastes generated at home are channelled.

2.2.1.2 Decentralized community composting

Decentralized composting is normally practiced at a neighbourhood or community scale and provides small groups a way to compost at a relatively low cost. This is different from household composting in that it involves composting of wastes from both household and commercial sources. The feeding stock for the composting is therefore more varied and exposed to contaminations, especially from plastics that are usually used for packaging of goods sold at the market places and many other different non-compostable materials. In Accra, the Asiedu-Keteke Sub-metropolitan Assembly is engaged in a mini-composting project, which is an example of decentralized community composting. The project involves the pooling of mixed solid wastes from households, commercial establishments and institutions in the Asiedu-Keteke area for composting. The mixed waste is heaped in the open for about three (3) to six (6) months with regular turning. There are no clear cut parameters for indicating maturity of the composts and this accounts for the varied periods at which the compost is harvested. There is no facility to separate the organic fraction of the mixed waste before composting. After composting however, a screen is used to sieve the compost to remove contaminants such as broken bottles, plastics and rubber remnants, metals and many others. The compost is then bagged and offered for sale.

2.2.1.3 Centralized large-scale composting

Centralized composting involves the use of large-scale, mechanized composting plant that normally demands a substantial level of financial investment. Solid wastes that are used for large-scale composting are gathered from a far wider area and are mixtures of refuse from all over a city or town. Centralized-large scale composting has the advantage of generating between ten (10) tonnes to more than 500 tonnes of compost per day; however it is very expensive to maintain (Hoornweg *et. al*., 2000). Since centralized composting is on a significantly larger scale, environmental, social and technical considerations are approached carefully, within appropriate jurisdictions for citing, designing, operations, maintenance and environmental compliance for waste delivery. Accra currently has only one centralized large scale composting plant, which is cited at Teshie-Nungua. The plant was established in the 1980's under German assistantship, both technical and financial. The system of operation at the composting site is such that mixed refuse, more heterogeneous in characteristics, are brought to the site in tipper trucks from different areas in the Accra metropolis. The refuse are then heaped into windrows for at least three months. There are no clear cut parameters for determining compost maturity. Composts are assumed to be matured when it turns black and soil-like, which takes between three and six months. The windrows are turned occasionally with heavy-duty trucks. Sewage sludge is also added occasionally to the compost heap. When the compost is matured, it is conveyed by conveyer belt to a magnetic separating device and a sieve, which together separates all foreign materials (metals, plastics, bottles, etc.) from the compost. It is then ready to be sold, either in bags or delivered in large quantities by tipper trucks to users.

2.2.2 Agricultural/Agro-industrial Waste Composting

Agricultural waste is a term used to describe crop residues and farm animal wastes. Agro-industrial waste describes waste produced by agro-industrial activities such as timber processing. In Ghana, agricultural/agro-industrial wastes constitute a major problem in the forest regions where there is intense agricultural/agro-industrial activities. Crop residues left on farms could attract rodents such as grasscutters and other animals such as hogs that are destructive to farms. Agricultural/agro-industrial waste is however a good source of organic nutrients that could be recycled through composting. The Agricultural Research Station (ARS) of the University of Ghana in Kade is currently involved in the composting of agricultural/agro-industrial wastes that are generated in the Kade sub-region of Ghana. Kade is a forest region with heavy timber production activity. There is also intense cultivation of crops such as cocoa, rice, citrus and palm fruit, as well as poultry in Kade. At the ARS, saw-dust from the timber industries, cocoa pod husks and poultry manure are used in preparing composts to manage the wastes generated in the Kade sub-region.

2.3 POTENTIAL END USES OF COMPOSTS

The traditional use of compost has been to amend soils for crop cultivation. In Accra, and Ghana as a whole, composts have been mainly utilized for this purpose. However, current literature indicates new innovative uses to which composts could be put, the potential of which are yet to be explored in Ghana. Recent innovative uses include bioremediation, disease control for plants and animals, erosion control, turf remediation, landscaping, reafforestation, land reclamation and wetlands restoration (USEPA, 1997).

2.3.1 Crop Production

Solid waste compost has the potential to be used in large quantities by the agricultural industry for crop cultivation. It can be used to increase the organic matter, tilth and fertility of agricultural soils (Dick and McCoy, 1993). It also has the ability to improve on the aeration and drainage of heavy soil, enhances the water-holding capacity and aggregation of sandy soils and increases soils cation exchange capacity (i.e. its ability to absorb nutrients). In addition, compost enhances soil porosity, improves resistance to erosion, improves storage and release of nutrients and strengthens disease suppression (US EPA, 1993). The near neutral pH of compost also, is beneficial for growing most agricultural crops (Senesi, 1989).

An important use of compost in crop production is in its application as a soil amendment to eroded soils. Farmers in the tropics are increasingly concerned about the depletion of organic matter in soil and are aware that soil fertility is dependent upon maintaining a sufficient amount of organic matter in the soil. Compost is a good source of organic matter that can enrich soil and add biological diversity. When applied to eroded soils, compost can help restore both organic content and soil structure (Kashmanian *et. al*., 1990).

The use of compost can help restore and build up nutrients in soil. The nutrients in compost are released slowly to plants through microbial activity over an extended period of time, thereby reducing the potential for nutrients to leach from the soil (Rynk, 1992). The gradual release of nutrients from composts also indicates that only a fraction of the nitrogen and phosphorus available in compost is available to the crop in the first year. When applied continuously, the supply of plant nutrients from compost is enough to keep plants healthy for several years. Studies on the residual properties of compost on agricultural soils have reported measurable benefits for eight (8) years or more after the initial application (Rynk, 1992).

Applying compost to soils may reduce the likelihood of plant diseases (Parr *et al*., 1986). This is due to firstly, the high temperatures that result from the composting process which kill pathogenic and weed seeds. Secondly, beneficial microorganisms in compost may inhibit or simply compete with soil-borne pathogens, thereby suppressing some types of plant disease.

Thus, applying compost reduce the need to apply fungicides or pesticides to crops. Research indicates that some compost, particularly those prepared from feedstocks that contain tree barks, release chemicals that inhibit the activity or growth of some plant pathogens (Hoitink and Fahy, 1986; Hoitink *et. al.*, 1991).

2.3.2 Bioremediation and Pollution Prevention

Each year agricultural effluents, industrial residues, and industrial accidents contaminate soils, air and water bodies. A new compost technology, known as compost bioremediation, is currently being used to restore contaminated soils, manage storm-water, control odours, and degrade volatile organic compounds (VOCs) (US EPA, 1997). Compost bioremediation refers to the use of a biological system of micro-organisms in a mature, cured compost to sequester or break down contaminants in water or soil. Micro-organisms consume contaminants in soils, ground and surface waters. The contaminants are digested, metabolized, and transformed into humus and inert by-products, such as carbon dioxide, water, and salts. Compost bioremediation has proven effective in degrading or altering many types of contaminants, such as chlorinated and non-chlorinated hydrocarbons, wood-preserving chemicals, solvents, heavy metals, pesticides, petroleum products, and explosives. The ultimate goal in any remediation project is to return the site to its pre-contamination condition, which often includes revegetation to stabilize the treated soil. In addition to reducing contaminant levels, compost advances this goal by facilitating plant growth. In this role, compost provides soil conditioning and also provides nutrients to a wide variety of vegetation.

2.3.3 Wetlands Restoration, Reafforestation, and Habitat Revitalization

Compost is used to reclaim degraded wetlands (Hey, 1994). In the United States for example, there are reports of steady decrease in organic matter in the soils of wetlands over the last three centuries. Over 100 million acres of U.S. wetlands have been drained, and watersheds now contain only about half the amount of organic matter they contained in the 17th century (Hey, 1994). As a result, annual floods have worsened, ground water quality has deteriorated, and wildlife diversity has declined. An innovative attempt at arresting the situation has been through compost application. Compost, with its high organic matter content, can absorb up to four times its weight in water and can replace essential organic material in wetlands (US EPA, 1997). In addition to wetlands restoration, compost also can help restore forests and revitalize habitats. Compost can play an important part in reafforestation efforts by providing an excellent growing medium for young seedlings. In the same way, compost can help to re-vegetate barren habitats, providing the necessary sustenance for native wildlife populations. By enhancing the chemical and mineral properties of soil, compost facilitates native plant growth, which provides food for indigenous and endangered animal populations (US EPA, 1997).

2.4 PERTINENT SOLID WASTE COMPOST CHARACTERISTICS

Various feedstock sources and composting methods can result in similarly varying characteristics of solid waste compost. Thus, generalizations about the physical and chemical properties of solid waste compost are difficult to make without analysis of the specific compost to be used. The beneficial characteristics of MSW compost depend on a number of factors including pH, compost maturity, nutrient content of the compost, visual quality (aesthetics), and the absence of high soluble salts, plastics, pathogens and metal contaminants (Shiralipour *et al*, 1992).

2.4.1 pH

pH is the measure of acidity (or alkalinity) or hydrogen ion activity on a logarithmic scale. The pH scale ranges from 0 to 14, with a pH of 7 indicating neutrality. A pH change of one (1) unit means a 10 – fold increase or decrease of acidity. Most compost has a pH of between 6 and 8 (E & A Environmental Consultants, 1997). Based on the amount and pH of compost applied, its application can alter the pH of the soil or growing media.

2.4.2 Soluble Salts (Electrical Conductivity)

Soluble salts refer to the amount of soluble ions in a solution of compost and water. The concentration of soluble ions is typically estimated by determining the solution's ability to carry an electrical current. Plant essential nutrients are actually supplied or made available in an ionic form. While some specific soluble salts (e.g. sodium chloride) may be more detrimental to plants, most compost does not contain sufficient levels of these salts to be of concern in landscape applications (Gallardo-Lara and Nogales, 1987). Excess soluble salts can cause phytotoxicity to plants (Stewart and Meek, 1997). Compost may contribute to, or dilute, the cumulative soluble salts content of a growing medium. Reduction in soluble salts content can be achieved through watering at the time of planting. Most compost has a electrical conductivity of 1.0 to 10.0 mS/cm (E & A Environmental Consultants, 1997).

2.4.3 Nutrient Content

Nitrogen (N), Phosphorus (P, usually expressed as P_2O_5) and potassium (K, usually expressed as K_2O) are the three (3) nutrients utilized by plants in the greatest quantities, and therefore, are the nutrients most often contained in commercial and retail fertilizers. When purchased in bags of fertilizers, these three (3) are measured and expressed on a dry weight basis or in the form of percentage (%). In composts, knowing the nutrient content can help to make correct decisions regarding the addition of supplemental fertilization. Although concentrations of nutrients found in compost are typically not high, in comparison to most inorganic fertilizer products, compost is usually applied at much greater rates, and therefore, can represent a significant cumulative quantity. The nutrient content of compost products vary widely. (Senesi, 1989). The use of certain composts may reduce or eliminate the necessity to fertilize certain plants during the first six to twelve (6 – 12) months following its application (Parr *et. al.*, 1986). In general, nutrients found in compost are in organic forms, thus released slowly as the compost decomposes.

2.4.4 Organic Matter

Organic matter content is the measure of carbon based materials in compost. Organic matter content is typically expressed as a percentage of dry weight. Organic matter is an important ingredient in all soils and plays an important role in soil structure, nutrient availability, and water holding capacity (Epstein *et al.*, 1976). It is useful for estimating the age and physical properties of the compost. It may also be necessary for determining compost application rates for certain uses, such as turf establishment and agricultural crop production. Application rates are often expressed as the quantity of organic matter needed on a per acre basis. Therefore, the organic matter content of the compost must be known in order to convert the suggested application ratio into a usable form (tons/acre). There is no ideal organic matter content for compost, and it may vary widely, ranging from 30 to 70% (E & A Environmental Consultants, 1997).

2.4.5 Moisture Content

Moisture content is the measure of the quantity of water in a compost product; expressed as a percentage of total weight. The moisture content of compost affects its bulk density (weight per unit volume) and, therefore, affects handling and transportation. Overly dry compost (35% moisture or below) can be dusty and irritating to work with, while very wet compost (55 to 60%) can become heavy and chimpy, making its application more difficult and delivery more expensive. Preferred moisture content for finished compost is 40 to 50% (E & A Environmental Consultants, 1997).

2.4.6 Compost Maturity

Compost maturity is the degree or level of completeness of composting. Maturity is not described by a single parameter. It is a concept that combines the results of several biological and chemical tests. It infers a level of chemical stability, a reduced C:N ratio, a high NO_3:NH_4 ratio, a reduced oxygen requirement or reduced carbon dioxide evolution, a more uniform particle size, and organic fraction that resembles soil humic substances (Brinton, 2000). Some immature compost may contain high amounts of free ammonia, low molecular weight organic acids or other water soluble compounds which can limit seed germination or root development, or cause odour (Garcia *et al*., 1992a,b; Zucconi *et al*., 1981). All users of compost require a mature product free of these potentially phytotoxic compounds.

2.4.7 Aesthetics

The process of composting changes the appearance of solid waste from bulky matter into a dark soil-like product. As the compost process proceeds, the particle size of the organic material decreases. However, the textiles, metal objects, plastics and glass that once contaminated the raw MSW can still be visible because they are non-compostable. Although these non-compostable materials get shredded during composting, they significantly affect the visual quality of the soil when the compost is applied to land. These substances present major constraints to the more widespread use of MSW compost.

2.4.8 Heavy Metals

The concentration of heavy metals in compost is regulated due to its potential for toxicity to humans, animals, or plants. Heavy metals appear in the MSW stream from a variety of sources. Batteries, consumer electronics (both domestic and industrial electronic appliances), ceramics, light bulbs, house dust, paint chips, lead foils such as wine bottle closures, used motor oils, plastics, some inks and glass can all introduce metal contaminants into the solid waste stream. Compost made from the organic material in unsegregated solid waste stream will inevitably contain these elements. In small amounts, many of these trace elements (e.g. zinc, copper and nickel) are essential for plant growth. However, in higher amounts they may decrease plant growth (Chaney and Giordaro, 1977). Other trace elements (e.g. cadmium, lead and mercury) are of concern primarily because of their potential to harm soil organisms, animals and humans who may eat contaminated plants (Allaway, 1977).

2.5 ENVIRONMENTAL COSTS AND BENEFITS OF COMPOSTING

Composting may not generate immediate monetary profit. However, when viewed as a component of an integrated solid waste management programme, composting can provide economic benefits on a much larger scale. The costs of composting includes raw materials, production, marketing, and hidden environmental costs; whereas the benefits involve the market value of the compost, savings from avoided waste disposal costs, as well as various positive environmental impacts (Hoornweg, 2000).

Traditional cost accounting systems usually do not include the hidden costs and benefits of environmental and social factors since they are difficult to quantify. Table 1 presents some of the environmental costs and benefits of composting which are rarely accounted for.

Table 1: Environmental costs and benefits of composting

Costs	Benefits
• Potential odour emissions • Improper disposal of rejects	• Reduced landfill space • Reduced surface and groundwater contamination • Reduced methane gas emissions • More flexible overall waste management system • Reduced transportation costs • Enhanced recycling of materials such as paper, metal and glass • Reduced erosion and improved efficiency of synthetic fertilizers • Reduced air pollution from burning waste

Source: Hoornweg, 2000,

There are other benefits which may not directly impact on the operation of the composting facility but do affect the overall health and well being of society. Water contamination can occur from leachate infiltration or from disposing of waste into open water bodies. Poor water quality has been linked to various human infections and diseases. Each year, according to the World Health Organization (WHO), about 900 million people experience diarrhoea or contact diseases such as typhoid and cholera which are spread by contaminated water (Cited in Hoornweg, 2000).

Providing alternative waste treatment options, such as composting, will reduce the quantities of waste blocking rivers, canal and drains, and stagnant water where mosquitoes prefer to breed and transmit diseases such as malaria. Because of these hidden costs, benefits and savings, composting should not be evaluated solely by the sale of finished compost. The traditional cost accounting approach used by some municipal authorities has resulted in the closure of several compost operations established in developing countries (Selvam, 1996).

2.6 EMERGENCE OF COMPOST QUALITY FOCUS

The intent and need to report quality of compost scientifically is a natural outcome of growth of the compost industry. Recognition of compost quality is necessary to expose issues of allowable risk, government regulation and market limitations. It also allows for appropriate or suitable identification of utilization options. There is some evidence that some consensus is emerging among many countries, especially the developed countries, regarding the need for compost quality characterisation methods (Brinton, 2000). Yet, there remain significant disagreements, particularly as to the level of contamination that is accepted for compost, especially within agriculture, and how this is to be monitored and achieved. At the same time, a more biological approach to compost quality has emerged even more recently, with focus on measuring stability and phytotoxicity (Garcia *al. et.*, 1992a; Zucconi *et. al.*, 1981).

2.7 COMPOST QUALITY

In order to market compost successfully to many end users whilst ensuring its environmental integrity, concerns about potential threats to plants, animals and humans must be addressed. One primary concern is the potential presence of heavy metals and phytotoxic organic compounds in compost products (Chaney and Ryan, 1993), as well as the risk posed by immature compost (Zucconi *et. al.*, 1981).

2.7.1 Heavy Metals and Compost

Of all the chemical parameters for assessing good compost quality, heavy metal content has been the focus of attention. This is due to the potential for accumulation in animals from ingested compost, or in humans and animals from feed or food grown on compost-amended soils (Woodbury, 1992). The heavy metals may also have effect on water quality as well as soil organisms.

2.7.1.1 Heavy metals of concern for animal and human health

Lead, cadmium and mercury can be harmful to animals and humans at relatively low concentrations. The concentration of these heavy metals should receive close scrutiny in relation to the application of solid waste composts to agricultural soils.

- **Lead**

Lead in solid waste compost may come from lead-acid batteries, plastics and rubber remnants, lead foils such as bottle closures, used motor oils and discarded electronic gadgets, including televisions, electronic calculators and stereos (Richard and Woodbury, 1992).

Plants take up only a small proportion of the lead from most soils, and long-term studies suggests that very little increase in the lead content of crops will occur even with substantial addition of MSW (Woodbury, 1992). In fact, there is some evidence that MSW composts can actually decrease the uptake of lead by crops, presumably because the organic matter in the compost binds the lead content and decrease its availability to plants (Woodbury, 1992). The application of such composts will, however, increase the lead content of uncontaminated soils (Chaney and Ryan, 1993).

- **Cadmium**

Cadmium in MSW compost may come from nickel-cadmium batteries, discarded consumer electronic products such as televisions, calculators and stereos, and plastics (Woodbury, 1992).

Studies of MSW compost application to cropland have not shown much change in the cadmium content of crops (Chaney and Ryan, 1993). Therefore, mixed MSW compost is less likely to contribute cadmium to human and animal diets via plants. Like lead however, cadmium in MSW compost becomes potentially dangerous if the compost is applied in areas such as play fields where children could come into direct contact with the contaminated compost and could mistakenly ingest it. Oral ingestion of cadmium can cause damage to the kidney or various forms of cancer, at even very low concentrations (Yu, 2000).

- **Mercury**

Household batteries are the most significant contributors of mercury in MSW composts (Richard and Woodbury, 1992).

The concentration of mercury in MSW composts is usually very low and there is little likelihood of significant uptake by plants (Woodbury, 1992). Concerns over hazard to food chains from mercury in compost is stemmed from evidence of methylation of mercury in aquatic systems, and from episodes of methylmercury poisoning from inadvertent human consumption of treated seeds (Allaway, 1977).

Table 2: Global compost standards as of April 1996 (mg/kg dried matter)

Country	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
USA	41	39	1200	1500	300	17	420	2800
Canada	13	2.6	210	128	83	0.83	32	315
Austria	-	4	150	400	500	4	100	1000
Belgium	-	1	70	90	120	0.7	20	280
Denmark	-	1.2	-	-	120	1.2	45	-
France	-	8	-	-	800	8	200	-
Germany	-	1	100	75	100	1	50	300
Switzerland	-	3	150	150	150	3	50	-
Spain	-	40	750	1750	1200	25	400	4000
Indonesia *	10	3	50	80	150	1	50	300

* Refers to standards proposed by the World Bank - suggested for all developing countries as a good starting point.
Source: World Bank, 1997

2.7.1.2 Effects of heavy metals on water quality

In addition to affecting plant and animal health, heavy metals contained in MSW composts may be leached from the soil and enter either ground or surface water. As with plant uptake, soil pH, organic matter content, and other soil characteristics affect the amount of leaching (Maynand, 1993).

Little research has been conducted to determine the effect of MSW composts on water quality and aquatic ecosystems. In a recent study, it was found out that the initial leachate concentrations of all metals studied exceeded European Community drinking standards, but after one year only nickel still exceeded the limit (Woodbury, 1992). While data on leaching of heavy metals from

MSW composts is scarce, evidence from long-term applications of sewage sludge suggests that the rate of leaching is low. Leaching of metals into groundwater is likely to occur with heavy, repeated applications of MSW composts over many years in areas with sandy soils or other conditions that limit the opportunity for absorption of metals by soil (Chaney and Ryan, 1993).

2.7.1.3 Effects of heavy metals on soil organisms

Little is known about the effect of heavy metals in MSW composts on soil organisms such as invertebrates (e.g. earthworm) and microorganisms (e.g. nitrogen-fixing bacteria). When sewage sludge is applied to land, the concentration of some heavy metals (e.g. cadmium) in earthworms is increased, but this does not pose a significant risk to the worms or wildlife that consumes them (Woodbury, 1992). There is actually contradictory evidence as to whether metals in MSW composts may harm soil microorganisms, including nitrogen-fixing bacteria (Woodbury, 1992).

2.7.1.4 Potential benefits of heavy metals in composts

Heavy metals such as boron, zinc and copper in MSW compost have potential beneficial effects for agriculture and horticulture. Soils that have been cropped for many years may be deficient in these nutrients and MSW compost could mitigate such deficiencies.

2.7.2 Toxic Organic Compounds and MSW Compost

Toxic organic compounds, including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated aromatics (PACs), are potential concerns with MSW compost. Research has shown that PCBs are quite stable in the presence of both natural soil bacteria and fungi (Nissen, 1981); therefore, any PCBs that do find their way to the feedstock will most likely be present in the compost. PAHs are another potential concern in MSW compost, degrading to acids that contribute to the phytotoxicity of unstable composts. PACs also can pose some risk. While they have been found to bind to the organic fraction of compost, little information is available regarding their availability to organisms in the compost product (Gillett, 1992).

2.7.3 Concept of Compost Maturity

Maturity in compost has been defined as the degree of completeness of composting (Brinton, 2000). Immature and poorly stabilized composts pose problems during storage, marketing and use. Consequently, determination of compost maturity is recognised as a significant parameter for evaluation in the compost industry. In storage, immature composts may become anaerobic and leads to odour and/or the development of toxic compounds, as well as bag swelling and bursting. Continued active decomposition when these composts are added to soil or growth media may have negative impacts on plant growth due to the presence of phytotoxic compounds, reduced oxygen concentration in the soil root zone as well as the availability of nitrogen. There have been several efforts to develop and refine methods which evaluate compost maturity, but no one method is universally accepted. In fact, compost maturity is not a single property that can be singly tested for. It must be assessed by measuring two or more biological and/or chemical properties of the compost.

2.7.3.1 The maturity index: a composite of two or more parameters

Matured compost is considered to possess characteristics of completeness of the composting process and show minimal potential for negative effects on plant growth and development. As maturity is not defined by a single parameter, the maturity is determined based on "passing" two or more specific tests.

In the new definition of maturity index a two-tiered system is applied beginning with a minimum characterisation of carbon-nitrogen ratio (C:N ratio) and then proceeding to description of at least one parameter from the two dissimilar groups (A and B lists) below. Compost samples must first pass the C:N ratio standard (<25) prior to results from tests in Groups A and B (Brinton, 2000). The C:N ratio screen is applied loosely as this ratio alone is felt to be a poor indicator of maturity.

Table 3: Proposed Compost Parameters Tier System to Determine Maturity Index

Carbon: Nitrogen Ratio (C:N)	
Group A	**Group B**
Carbon dioxide evolution	Ammonium: Nitrate ratio (NH_4:NO_3)
Oxygen utilization	Ammonia concentration
Humus colour	Volatile organic acids concentration
	Germination test

Source: Brinton, 2000

2.7.3.2 Phytotoxicity and compost maturity

The presence of compounds that are toxic to plants (phytotoxicity) is a common problem associated with immature composts (Zucconi *et. al.*, 1981; Garcia *et. al.*, 1992a,b). Such composts may contain ammonia and/or inorganic or organic compounds that may inhibit seed germination and impair root development. During the early stages of composting significant quantities of ammonia and a wide variety of water-soluble and/or volatile organic acids (e.g.

acetic acid, butyric acid) are generated. However, with time in a typical aerobic process, these materials will undergo biological conversion to non-phytotoxic compounds.

The premise for using soluble nitrogen (ammonium-nitrate ratio) for maturity indicators is that during early composting very little of nitrate-nitrogen is formed. As the thermophilic stage is passed, the mesophillic microorganisms that convert organic nitrogen to ammonium- and nitrate-nitrogen begin to flourish. The appearance of significant quantities of nitrate-nitrogen is an indicator of maturing compost. Normally, in mature composts the nitrate-nitrogen levels exceed the levels of ammonium-nitrogen by several factors. Therefore, the determination of ammonium-nitrogen and nitrate-nitrogen ratios is a useful parameter to assess degree of maturity.

A direct assessment of phytotoxicity can be made by germination and root elongation measurements after exposure of seeds to growth media containing water extracts of compost (Zucconi *et. al.*, 1981; Garcia *et al.*, 1992a). Inhibition of aqueous extracts of composts to seed germination have been found to be indicative of the presence of phytotoxins such as low molecular weight organic acids, excess ammonium and phenolic substances in compost products (Garcia *et. al.*, 1992a). These phytotoxins have been reported to cause injuries to existing plants or to germinating crops after application of refuse-derived composts (Zucconi *et. al.*, 1981).

2.8 PUBLIC ACCEPTANCE AND SOCIOLOGICAL PROBLEMS OF COMPOSTS

The feasibility of a composting programme is very much dependent on public acceptability of the compost products. This is because when there is less public patronage of the compost, the marketability of the product is a problem. Public acceptance of compost can be influenced by several factors including economics, public policy, and by educational and cultural issues (Pratt *et. al.*, 1977). Solutions to some of the potential environmental and health problems of composting, such as odours and flies at composting sites, or food chain implications when composts are used for crop cultivation, would greatly help in creating a better public image for compost products and thus, increase acceptability by the public.

2.9 SUMMARY OF LITERATURE REVIEW

From the literature review, it was realised that the management and disposal of urban residues in an economical and environmentally acceptable manner is one of society's most pressing problems. Land application of municipal solid waste (MSW) compost offers a potential means for using this waste material in agriculture, in contrast to current disposal practices of landfilling and incineration. Composting is a way of transforming organic waste materials left over from agricultural production or in municipal refuse and processing into a useful resource. The recycling of organic wastes by composting is an important part of sustainable agriculture. Nearly all crop farmers like to apply good-quality compost to their fields since organic fertilisers improve soil properties, and help maintain stable soil moisture content and prevent soil-borne diseases.

The quality of compost, which is described through its chemical and biological characteristics, is useful in ensuring sustainability of a composting programme. This is because it aids in the determination of appropriate utilisation options for the particular compost in question. In Ghana, solid waste composts are produced from mixed waste stream with potential sources of contamination from materials such as broken bottles, batteries, metals, plastics or rubber remnants and residues that are all contained in the waste stream.

Various parameters were found to be used in assessing good quality compost. These include absence of trace metals and phytotoxic compounds in the compost. In small amounts, many of these trace elements (e.g. zinc, copper and nickel) are essential for plant growth. However, in higher amounts they may decrease plant growth. Other trace elements (e.g. cadmium, lead and mercury) are of concern primarily because of their potential to harm animals and humans who may eat contaminated plants. Especially, lead and cadmium can be harmful to animals and humans at relatively low concentrations. It is, thus, of great importance that concentrations of trace metals should receive close scrutiny in relation to the application of solid waste composts to soils. The presence of phytotoxic compounds in compost also means that the compost is not matured and cannot be used for plant growth.

Information on chemical and biological characteristics of marketed compost products in Ghana is currently lacking, yet it is important for appropriate utilisation of compost products in the country. This could possibly expand the scope of utilisation of the compost products. The present study investigated the nutrient content, trace metal contaminants and maturity in some MSW and agro-industrial waste composts that are marketed in Ghana.

CHAPTER THREE

MATERIALS AND METHODS

This chapter presents the sampling sites and the different composts that were analysed, the methods of analysis and the principles upon which the analytical methods were based.

3.1 SAMPLING SITES

MSW composts that were ready for sale were sampled from three composting sites in Accra and agricultural waste compost was sampled from the University of Ghana Agricultural Research Station (ARS) in Kade. The sampling sites were the Teshie-Nungua municipal composting plant, Asiedu-Keteke community composting unit and a household composting in the West Airport residential area. Comparisons were made between the composts from the different composting sites in Accra, as well as with composts from the ARS in Kade. All the composting operations were of the open-windrow type. Operations at Teshie-Nungua and Asiedu-Keteke involved the use of mixed municipal solid waste and represented composting of un-segregated materials. The Household and Kade composts were however from purely organic sources (domestic and agricultural/agro-industrial respectively). The agricultural wastes used in the preparation of the Kade composts were mainly chicken manure, cocoa husk, rice straw and saw dust. The Household compost was mainly from kitchen waste The Asiedu-Keteke compost was from refuse generated in households and market places in the Asiedu-Keteke area and the Teshie compost was from a complex mixture of solid waste (from homes, markets, industries, hospitals, etc.) across the city of Accra. Designing the experiment in this manner offered the opportunity to investigate compost characteristics of both segregated and un-segregated organic waste. The sampled compost materials were assessed in the laboratory for potential fertilizer value, heavy metal content, maturity and phytotoxicity. A social survey was also conducted in Accra to assess public acceptance of MSW compost products.

3.2 SAMPLING PROCEDURE

Composts were sampled from the sites indicated in section 3.1 above, in November 2000, February 2001, and June 2001. Composting at the experimental sites in Accra took at least three months to mature, and sampling was done to coincide with newly matured compost products that were ready to be sold or for use. The sampling periods chosen allowed for the assessment of maturity of compost products that were to be sold. It also allowed for the determination of variations in the chemical and biological characteristics of the composts with time. Ten replicates of each sample were collected randomly from ten different points and layer levels in the compost heap. These were thoroughly mixed in a rubber bucket to obtain composite samples. The composite samples were collected into individual polythene sampling bags and transferred to the laboratory for physico-chemical analysis and bioassays.

3.3 MOISTURE DETERMINATION

Fifty (50) grammes of fresh compost samples were weighed into previously dried (at 105 ^{O}C) and weighed moisture cans. The moisture cans and content were put into an oven for 24h at 105°C. The cans were then removed from the oven and cooled in a desiccator for 30min and weighed. The percentage moisture was calculated as follows:

$$\% \text{ Moisture} = \frac{(W - D)}{W - T} 100 \% \qquad \text{Equation 2.1}$$

In which:

W = wet weight of sample, including moisture can and lid (g);

D = dry weight of sample, including moisture can and lid (g);

T = weight of moisture can with lid (g).

3.4 pH AND ELECTRICAL CONDUCTIVITY

Compost samples that were air-dried to constant weight were passed through a 2.0mm sieve to obtain materials of fairly uniform particle size. Water extracts were prepared using the sieved compost samples at the ratio of 1 solid: 10 liquid (w/v). The mixtures were shaken for about 30min on a shaker. The pH and electrical conductivity of the mixture were then measured as direct readouts, using Suntex pH meter and Jenway conductivity meter respectively.

3.5 MACRO-NUTRIENTS DETERMINATION

3.5.1 Nitrogen

Procedures for measuring total nitrogen, ammonium nitrogen and nitrate nitrogen were adapted from Bremmer, 1965a and 1965b.

3.5.1.1 Total nitrogen

- **Principle**

The modified Kjeldahl method permits the total nitrogen to be precisely determined in compost samples. The method of determination involves three successive phases, which are:

(i) Digestion of the compost material to convert nitrogen (N) to ammonia (NH_3);

(ii) Distillation of the released NH_3 into an absorbing medium; and

(iii) Volumetric analysis of NH_3, formed during digestion process.

- **Procedure**

One (1) gramme of compost (air-dried and passed through a 2.0mm sieve) was weighed into 100ml Kjeldahl flask and 1.33g of catalyst mixture (made up of 1.55g Se, 1.55g of copper sulphate and 96.9g of sodium sulphate) were added, followed by addition of 6ml concentrated sulphuric acid. The mixture was heated for 30min. About 0.5ml of 30% hydrogen peroxide (H_2O_2) was then added to the boiling mixture. Heating was continued until the digest became clear. The flask was then cooled and its content transferred into a 100ml volumetric flask and made up to the mark. An aliquot of 10ml was taken from the digested material and pipetted into a Kjeldahl distillation apparatus. 15ml of 40% sodium hydroxide NaOH solution was added to the aliquot and the mixture distilled. The distillate was collected into a 100ml Erlemeyer flask containing 10ml of 4% boric acid and three drops of mixed indicator (consisting of bromocresol green and methyl red). A blank determination using distilled water was run before the main sample, with 10ml-distilled water replacing the 10ml aliquot. The distillate -boric acid mixture was titrated against 0.01M HCl solution.

- **Calculation**

$$\% \text{ Total N} = 0.14\,(T - B) \times \frac{100}{V} \times \frac{100}{M} \qquad \text{Equation 2.2}$$

In which:

0.14 = equivalent of nitrogen

T = titration volume of sample (ml)

B = titration volume of blank (ml)

V = volume of aliquot pipetted and transferred for distillation (ml)

M = weight of compost sample (mg)

3.5.1.2 Ammonium nitrogen and nitrate nitrogen

- **Principle**

The magnesium oxide (MgO)-Devarda alloy method was used in the determination of ammonium-N and nitrate-N in the compost samples. The MgO-Devarda alloy method is based on the finding that ammonium-N in solutions containing glutamine and other alkali-labile organic-N compounds can be determined quantitatively from the ammonia-N liberated by steam distillation of these solutions with a small amount of MgO for 2 to 4min; and that (ammonium + nitrate)-N in such solutions can be determined quantitatively by the same method if ball-milled Devarda alloy is added immediately before distillation.

- **Procedure**

Two (2) grammes of compost sample (air-dried and passed through a 2.0mm sieve) were extracted with 40ml of 4M potassium chloride (KCl) by shaking for 1h. The mixture was filtered and 10ml aliquot of filtrate was pipetted into micro- Kjeldahl flask.

For the determination of ammonium-N, 0.2g MgO was added to the content in the micro-Kjeldahl flask and distilled for about 15min. The distillate was collected in a mixture of 10ml of 4% boric acid and mixed indicator (bromocresol green and methyl red). To determine nitrate-N, 0.2g of Devarda alloy was added to the content in the micro-Kjeldahl flask. Distillation was carried out for additional 15min and the distillate collected in fresh receiver also containing a mixture of 10ml of 4% boric acid and the mixed indicator. The distillates collected for the ammonium-N and nitrate-N determinations were each titrated against 0.01M HCl. Blank determinations were run in each case.

- **Calculation**

Ammonium-N and Nitrate-N were each calculated as follows:

$$\% = 0.4\,(T - B) \times \frac{40}{V} \times \frac{100}{M} \qquad \text{Equation 2.3}$$

In which T, B, V and M are similarly defined as in section 2.2.5.1.

3.5.2 Phosphorus

3.5.2.1 Total phosphorus

- **Principle**

Total phosphorus analysis in compost requires a conversion of insoluble phosphates to soluble forms by digestion with a mixture of nitric acid and sulphuric acid. Phosphate in the digest is determined with an acidified molybdate solution, which after reduction with ascorbic acid forms with phosphate a blue coloured phosphomolybdate complex. Antimony is added to accelerate colour development.

- **Procedure**

One (1) gramme of compost sample (air-dried and sieved, particle size < 2mm) was weighed into a digestion tube. 30ml of concentrated perchloric acid/concentrated nitric acid mixture in the ratio 1.5:1 was added to the compost sample in the digestion tube. The mixture was heated for about one (1) hour. The cooled digest was filtered using No. 42 Whatman filter paper into 100ml volumetric flask and made to volume with distilled water. The filtrate was then diluted by 10% with distilled water and the phosphorus content determined using molybdate ascorbic acid method of Watanabe and Oslen (1965) as follows:

One (1) millilitre aliquots were taken into 50ml volumetric flasks containing about 35ml distilled water. The pH of the solution was then adjusted by adding two drops of p-nitrophenol indicator and a few drops of 4N ammonium hydroxide (NH_4OH) until the solution turned yellow. Eight

(8) ml of ammonium molybdenum-ascorbic acid solution (reagent B) was added and made to volume, with distilled water. The solution was mixed thoroughly by shaking and allowed to stand for 15min for the blue colour to stabilize.

Reagent A was prepared as follows:

(i) 140 ml of concentrated H_2SO_4 in 1000ml of distilled water;

(ii) 12g of heptamolybdate in 200ml of distilled water;

(iii) 0.29g of potassium antimony tartrate in distilled water.

Solutions (i), (ii), and (iii) were mixed together and made up to 2000ml in a volumetric flask.

Reagent B was prepared freshly by dissolving 1.6892g of L-ascorbic acid in 200ml of reagent A in a volumetric flask. A blank was set up in a 50ml volumetric flask with 8ml of reagent B, two drops of p-nitrophenol indicator, few drops of 4N ammonium hydroxide (NH_4OH) and made to mark with distilled water.

The intensity of the blue colour was measured with spectrophotometer at a wavelength of 712nm.

3.5.2.2 Available phosphorus (Bray and Kurtz no.I method)

- **Principle**

Phosphate in compost can be extracted with acidified ammonium fluoride solution, which removes phosphate ions from 'insoluble' phosphates of iron and aluminium complexes. With a 0.03M ammonium fluoride solution and acidity of 0.025M HCl, the method is said to remove 'absorbed' phosphate. The phosphorus is then determined spectrophotometrically.

- **Procedure**

Available phosphorus was determined using the method of Bray and Kurtz (1943). Ten (10) grammes of each compost sample was weighed into a 100ml extraction tube and 50ml of Bray I solution [0.03M ammonium fluoride (NH_4F) in 0.025M hydrochloric acid(HCl)] were added. The suspension was shaken for 1h on a reciprocating shaker and filtered. Phosphorus in the filtrate was measured as in section 2.5.2.1.

3.5.3 Potassium

3.5.3.1 Total Potassium

- **Principle**

Total potassium analysis in compost requires a conversion of insoluble potassium to soluble forms by digestion with a mixture of nitric acid and sulphuric acid. The potassium content in solution is estimated with a flame photometer.

- **Procedure**

One (1) gramme of compost samples (air-dried and sieved, particle size < 2.0mm) was weighed into a conical flask and digested with 30ml of concentrated sulphuric acid/concentrated nitric acid mixture (1.5:1 v/v). The compost-acid mixture was heated for about 1h until it was left with about 5ml of solution. The digest was allowed to cool and then diluted to 100ml with distilled water. The solution was filtered, and 10ml of the filtrate was diluted to 100ml with distilled water. The concentration of total potassium was read by flame photometer (model ATS 200M, Advanced Technical Services GmbH, Switzerland), previously calibrated with 5ppm standard potassium solution.

3.5.3.2 Available Potassium (Ammonium Acetate Extraction Method)

- **Principle**

The method is based on the principle of equilibrium of soils with an exchanging cation made of solution of neutral normal ammonium acetate (NH_4OAc), in a given soil:solution ratio. During the equilibrium, ammonium ions exchange with the exchangeable potassium ions of the soil. The potassium content in the equilibrium solution is estimated with a flame photometer.

- **Procedure**

Five (5) grammes of compost sample (air-dried and sieved, particle size < 2.0mm) was weighed into extraction bottle and 100ml of 1M ammonium acetate solution was added. The bottle with content was placed in a shaking machine for one hour. At the end of the shaking the extraction mixture was centrifuged for about 20min. The supernatant solution was then filtered. The concentration of the potassium in the filtrate was determined with flame photometer as described in section 2.5.3.1.

3.5.4 Organic Carbon/Matter

- **Principle**

A known weight of compost is treated with an excess volume of standard potassium dichromate solution ($K_2Cr_2O_7$) in the presence of concentrated sulphuric acid (H_2SO_4). Heat of dilution of H_2SO_4 slowly digests the compost at low temperatures and oxidises organic carbon in compost to carbon dioxide (CO_2). The highest temperature attained by heat of dilution reaction, produced on the addition of H_2SO_4 is approximately 120°C, which is sufficient to oxidise the active forms of the soil organic carbon, but not the inert form of carbon, that may be present. The excess of

$K_2Cr_2O_7$ not reduced by the organic matter is titrated back, against a standard solution of ferrous ammonium sulphate, in the presence of sodium fluoride (NaF) or phosphoric acid and a diphenylamine indicator.

- **Procedure**

Organic carbon/matter was determined using the Walkley and Black method (Allison, 1965). Ten (10) ml of 1N potassium dichromate ($K_2Cr_2O_7$) solution and 20ml concentrated sulphuric acid (H_2SO_4) were added to 0.1g compost (sieved through 0.5mm pores). The flask was swirled to ensure full contact of the compost with the solution after which it was allowed to stand for about 30min. The unreduced $K_2Cr_2O_7$ remaining in solution after the oxidation of the oxidizable organic material in the compost sample was titrated with 0.2N ammonium ferrous sulphate solution after adding 10ml of orthophosphoric acid and 2ml barium diphenylamine sulphate indicator.

- **Calculation**

$$\% \text{ Carbon} = \frac{(b - s) / b \times 3}{W} \qquad \text{Equation 2.4}$$

In which:

b = ml $FeSO_4$ used for titration of blank

s = ml $FeSO_4$ used for titration of sample

3 = equivalent weight of carbon

W = g weight of compost

$$\% \text{ Organic matter} = \frac{(b - s) / b \times 3}{W} \times 1.724 \qquad \text{Equation 2.5}$$

In which:

1.724 = Van Bemmelen factor for converting total organic carbon into organic matter.

3.6 HEAVY METALS DETERMINATION

One (1)g of air-dried and sieved compost samples (particle size < 0.5mm) was weighed into a 100 ml acid washed volumetric flask and digested with 20ml of a nitric, perchloric, and sulphuric acid mixture, prepared in the ratio of 3:1:1 (Varma, 1986). The compost-acid mixture was heated in a fume chamber until it was left with about 5ml of liquid. The digest was diluted with deionised water to 100ml and then filtered to obtain a clear solution, from which the following heavy metals: cadmium, copper, lead, nickel and zinc were determined, using an atomic absorption spectrophotometer (Shimadzu AA-630-12, Japan). Standard solutions of known concentrations were prepared for each heavy metal, and the absorbances of the standard solutions were measured at specified wavelengths (see appendix). The absorbance of each heavy metal in sample solution was also read at the appropriate wavelength. A calibration curve of standard concentrations against absorbances was prepared for each heavy metal, from which the concentration of the heavy metal in sample solution was extrapolated.

3.7 COMPOST MATURITY DETERMINATION

3.7.1 Measurement of Compost Respiration (CO_2 Evolution)

Microbial respiration of composts is used as indicator of compost maturity. High respiration value indicates the immaturity of the compost.

- **Principle**

For measurement of CO_2 evolution, an alkali of defined concentration is placed in the bottom of a jar that contains compost sample. As CO_2 evolves from the compost, it is trapped in the alkali solution. After a measured period, the alkali is removed and the un-reacted portion is determined by titration. By means of subtraction, the amount of CO_2 that combined with the alkali can be determined.

- **Procedure**

Compost (50g) was weighed into a petri-dish and placed under a jar. Twenty (20) ml of 1.0M NaOH was also pipetted into a beaker and placed under the jar. The jar was kept air-tight by greasing its mouth with an aluminium foil placed on the laboratory bench. The jar was kept standing for a period of 24 hours at room temperature. A blank jar, of same condition but without compost sample was also set up. After the 24h period, the alkali solutions from both the blank and sample jar were exposed, and about 30ml of 3M barium chloride (excess) was added to each NaOH solution to precipitate the carbonate as insoluble barium carbonate. The unreacted NaOH was titrated with 1.0M HCl using phenolphthalein as indicator.

- **Calculation**

The following formula was used to calculate the amount of CO_2 evolved from the compost during the exposure to the alkali.

Milligrams of $CO_2 = (B - V)\,N\,E$ Equation 2.6

Where:

B = volume of acid needed to titrate the NaOH in the blank jar;

V = volume of acid needed to titrate the NaOH in the sample jar;

N = Normality of the acid

E = equivalent weight. To express the data in terms of CO_2, E = 22 was used.

3.7.2 Measurement of Humus Colour

- **Principle**

Humus colour of compost becomes dark with maturity. Absorbance of humus extracted with alkali solution at 400 and 600nm are measured. The log of absorbance at 400nm minus log of absorbance at 600nm is used as a measure for the humus colour (Garcia *et. al.*, 1992b).

- **Procedure**

Ground compost sample was oven dried at 80 °C for 24h and 0.5g was weighed into an extraction bottle. 50ml of 0.1M NaOH was added and shaken for 1h. The mixture was allowed to stand over-night and then filtered to obtain a clear solution. The absorbance of the filtrate was measured at 400nm and 600nm on a spectrophotometer.

- **Calculation**

Humus colour, represented as $\Delta \log K = \log K\ 400 - \log K\ 600$ Equation 2.7

$$= \log (K\ 400 / K\ 600)$$

where K400 and K600 is the absorbance at 400 and 600 respectively.

- **Evaluation**

If the $\Delta \log K$ value is below 0.7, the compost is matured (Garcia, 1992).

3.7.3 Germination Test

- **Principle**

The germination experiment to determine compost maturity is based on the principle that immature compost contains phytotoxins that inhibit the germination of seeds (Iannotti *et al.*, 1994; Keeling *et al.*, 1993).

- **Procedure**

The germination test was conducted using three different seeds: cabbage, carrot, and tomato. Samples of compost (air-dried and passed through a 2.0mm sieve; 20g) were shaken with 50ml distilled water for 1h. The solutions were filtered. One ml of filtrate was pipetted into a 50mm petri dish lined with filter paper. Three replicates were used per extract. Distilled water was used as a control. Ten (10) viable seeds were placed in each dish. Seeds were kept at ambient laboratory temperatures and monitored until there was extensive germination in the control plates. Germination was then stopped by adding 1ml 50% (v/v) ethanol to each dish. Treatments were evaluated by noting the number germinated seeds and the length of the root radical. Un-germinated seeds were defined as being zero (0) cm long.

- **Calculation**

Germination Index = (% Germination) x (% Root Length) Equation 2.8

$$\text{Where, \% Germination} = \frac{\text{Mean germination in compost extract}}{\text{Mean germination in water}} \times 100$$

$$\text{And \% Root Length} = \frac{\text{Mean root length in compost extract}}{\text{Mean root length in water}} \times 100$$

3.8 ASSESSMENT OF MSW COMPOST ACCEPTABILITY

Public assessment of the acceptability of MSW composts in Accra was conducted through administration of questionnaires and interviews. The objective of this assessment was to seek the views of the public regarding the making and utilization of composts and associated problems in the Accra municipality. The questionnaires were administered in Teshie, Asiedu-Keteke and the West Airport residential area, in order to capture both the user and non-user public of composts. In all, 200 individuals were administered with questionnaires (see appendix II).

3.9 STATISTICAL ANALYSIS

Statistical treatment of data was basically through analysis of variance and t-test, with differences that corresponded to p values less than 0.05 being considered significant. The data was expressed as mean ± standard error of mean (SEM). The histogram or pie chart was also used, when appropriate, to describe individual data. The statistical package of Microsoft Excel was used in the statistical treatment of data and plotting of graphs.

CHAPTER FOUR

RESULTS

This chapter presents the results that were obtained from this project. The interpretations and implications of the results for composting as a viable waste management option in Accra are looked at in the discussion section in the next chapter.

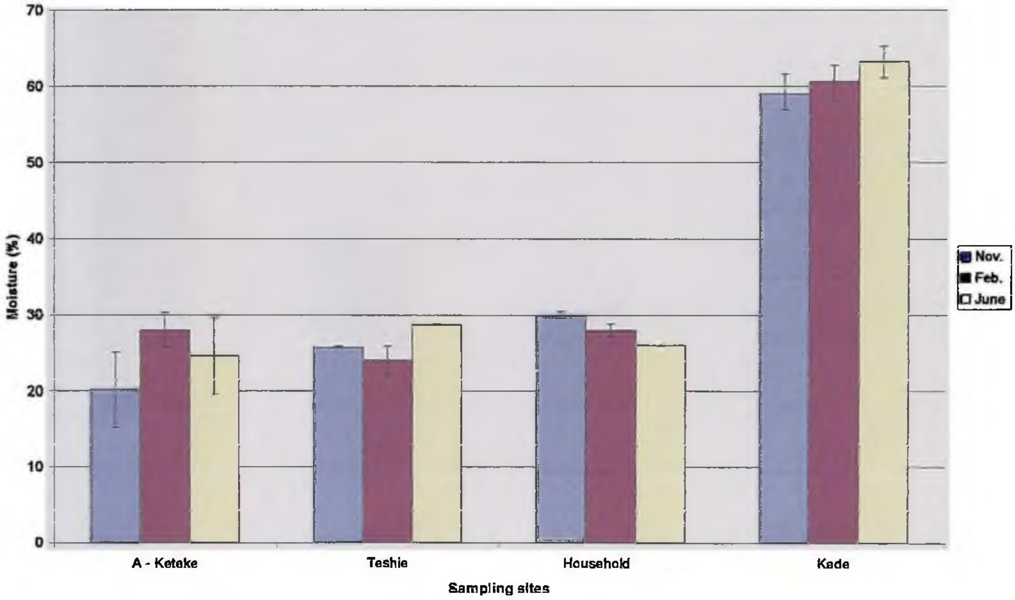
4.1 MOISTURE CONTENT OF COMPOSTS

Figure 1 shows the moisture content of compost samples from composting sites in Accra (Asiedu-Keteke, Teshie and Household) and in Kade (Agricultural Research Station). The Kade samples appeared almost as twice in moisture content as the Accra samples.

Statistical analysis to check variations within each of the composting sites indicated that there were no significant differences among the November, February and June readings for the Asiedu-Keteke samples and also among the three different months for the Kade samples. However, for the Teshie samples, there were significant differences between the samples for November and those for June ($p<0.05$), and also those for February and June ($p<0.05$). In the case of the Household samples, differences were observed between samples collected in November and those collected in June ($P<0.05$). The samples collected in February and June for the Household were also significantly different ($p<0.05$).

The statistical comparisons showed that the Kade samples were significantly different from samples from all the other sites for each of the three different months ($p<0.01$). There was also a significant difference between the Teshie and Household samples in November ($p<0.05$).

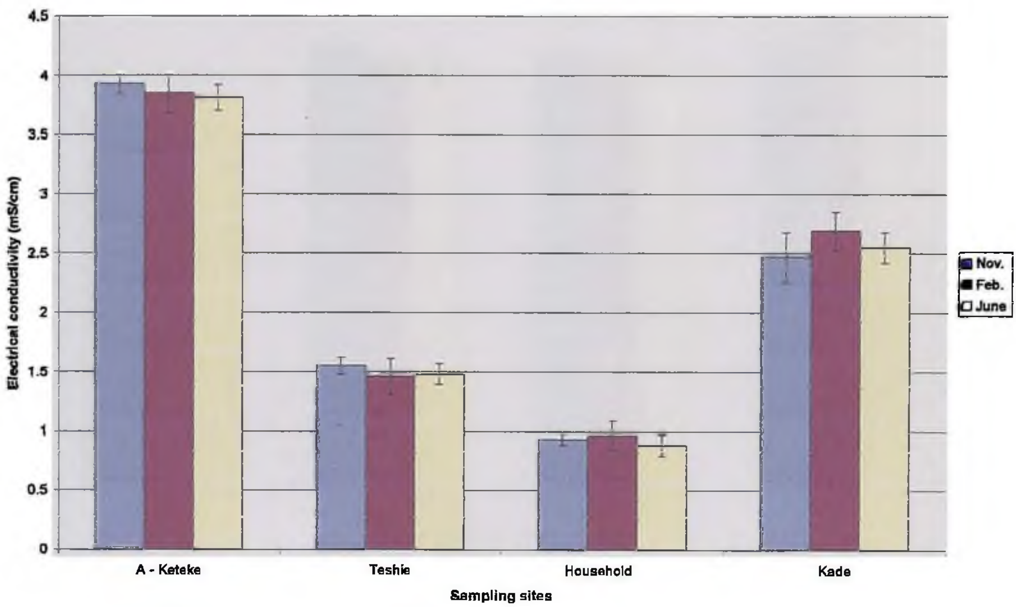
Figure 1: Moisture content of composts



4.2 ELECTRICAL CONDUCTIVITY (mS/cm)

Figure 2 is a graphical representation of the electrical conductivity of compost samples from Asiedu-Keteke, Teshie, a Household in Accra and the Kade Agricultural Research Station composting sites. The graph shows that composts from Asiedu-Keteke had the highest electrical conductivity. This was followed in a decreasing order by the composts from Kade, Teshie and the Household. Statistical analyses did not revealed any significant differences for samples analysed at the different time points. However comparisons between the different composting sites indicated significant differences ($p<0.01$) in all cases.

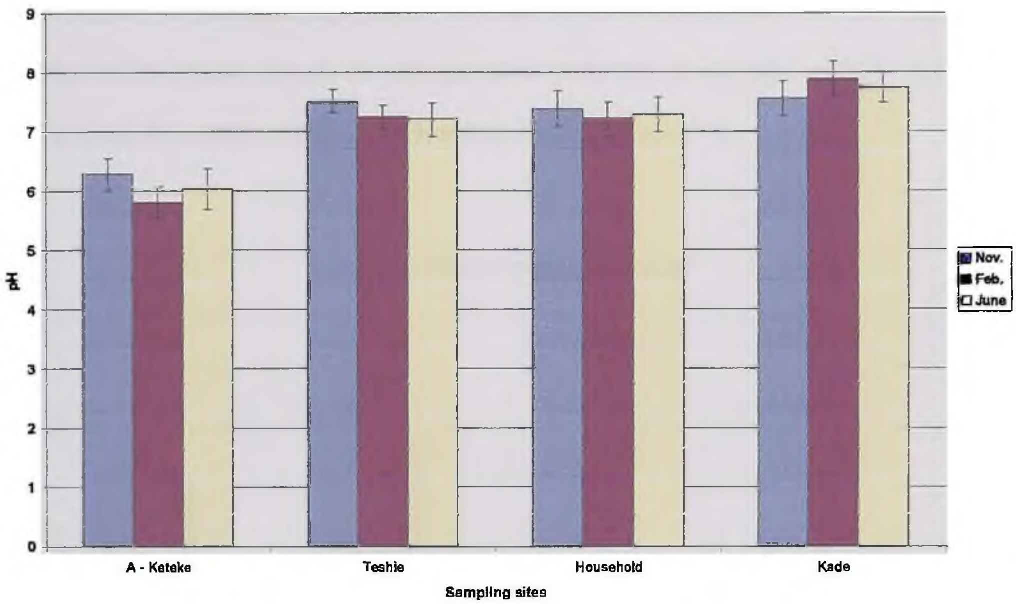
Figure 2: Electrical conductivity of composts



4.3 pH

Figure 3 gives a graphical representation of pH of waste composts from the different sampling sites. Initial analysis of variance confirmed that significant differences existed between pH values of the different sampling sites ($p<0.01$). Post-hoc t-test showed that the pH of the Asiedu-Keteke was different from the three other sites. Differences also existed between Kade and each of the three remaining sites. Teshie and the Household, statistically had the same pH values. Values within each of the composting sites were also found not to be statistically different.

Figure 3: pH of composts



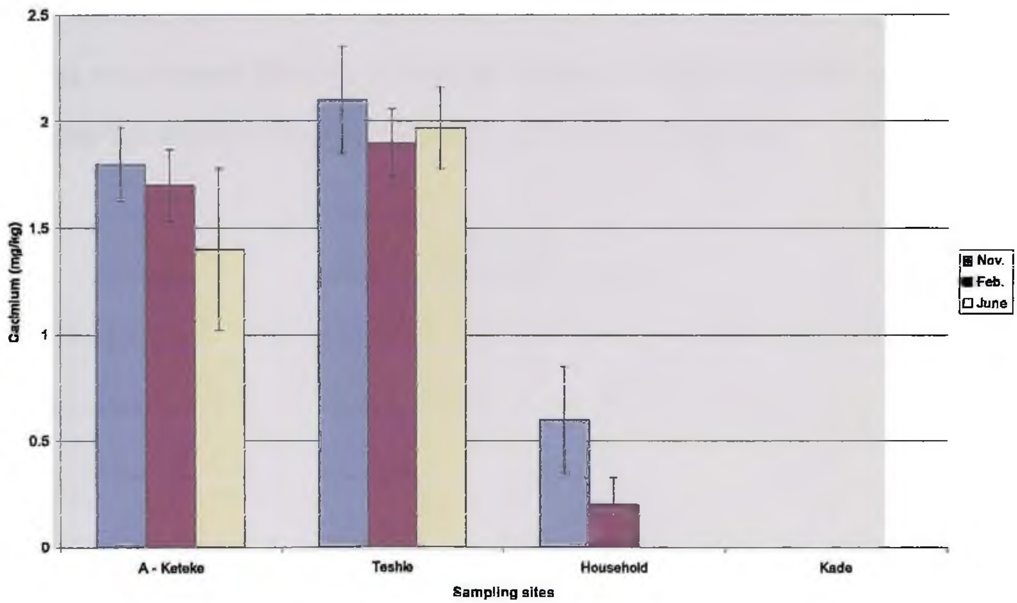
4.4 HEAVY METALS

4.4.1 Cadmium

Cadmium levels of the composts are presented in figure 4. Cadmium levels in Kade compost were below the detection limit of 0.01mg/kg. Similarly, readings were very low for the samples from the Household. The Teshie and Asiedu-Keteke composts were not statistically different. However, both were significantly higher in cadmium content ($p<0.01$), compared to those from Kade and the Household. For the Asiedu-Keteke and Household samples, least cadmium contents were recorded for the samples that were taken in June (1.4mg/kg and 0.0mg/kg respectively), whilst highest levels were recorded for those collected in November (1.8mg/kg and

0.6mg/kg respectively). For Teshie composts however, the least cadmium value was recorded in February (1.9mg/kg) and the highest value was recorded in November (2.1mg/kg). Comparisons made between the different time points for each of the sampling sites revealed significant difference within Asiedu-Keteke for samples taken in November and June ($p<0.05$) and within the Household for samples taken also in November and June ($p<0.05$).

Figure 4: Cadmium content in composts

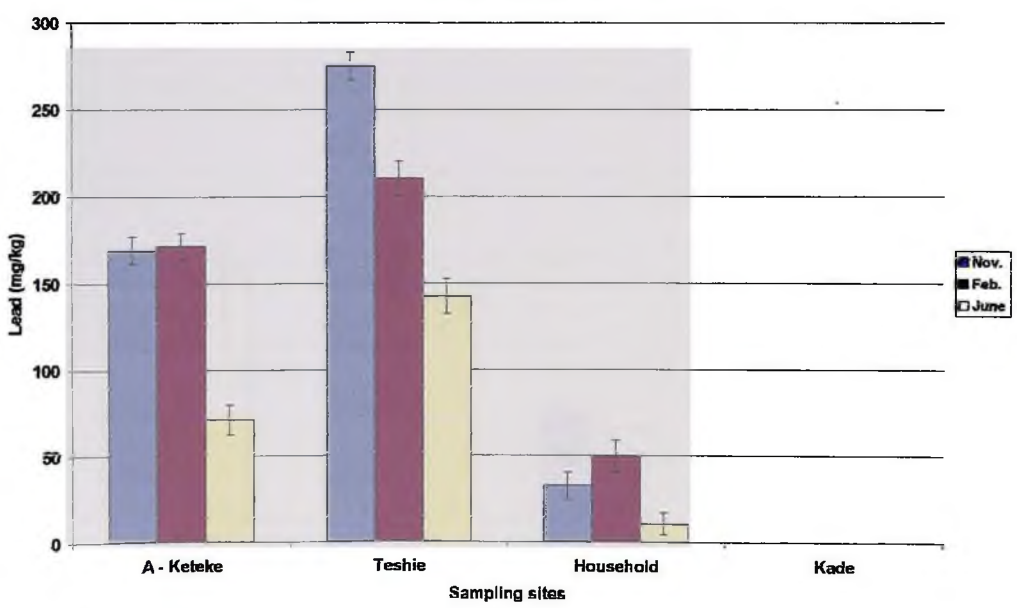


4.4.2 Lead

The lead content of the compost samples from the sampling sites are represented in figure 5. The lead content was highest in the Teshie composts and also quite high in the Asiedu-Keteke samples. The Teshie compost lead content ranged between 142.0 to 275.0mg/kg, whilst the Asiedu-Keteke compost had values between 71.1 to 171.4mg/kg. As was the case of cadmium, lead in the Kade compost was also below the detection limit of 0.01mg/kg. The Household samples also recorded very low readings. In each of the composting sites in Accra, the June samples showed the least readings.

Analysis of variance confirmed significant differences between the composting sites ($p<0.01$). Within Asiedu-Keteke, samples collected in November 2000 and February 2001 were statistically the same whilst the sample collected in June 2001 was different ($p<0.05$). Within Teshie however, lead levels were significantly different ($p<0.05$) for each of the months that sampling was collected. Within the Household, samples collected in November and June were statistically not different, but differed from those collected in June ($p<0.05$).

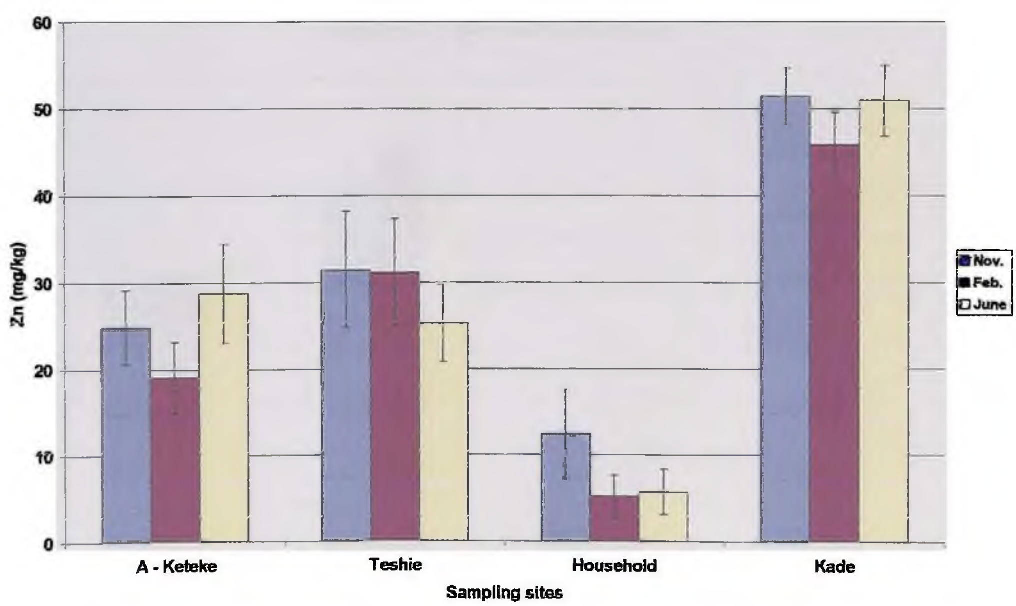
Figure 5: Lead content in composts



4.4.3 Zinc

Figure 6 shows zinc content of compost samples from the four experimental sites. The Kade samples had the highest level for zinc (the mean for the three months was 49.37mg/kg), whilst the Household had the least. In general, the samples from Accra had low mean zinc contents: Asiedu-Keteke – 25.5mg/kg, Teshie – 29.2mg/kg and the Household – 7.8mg/kg. For each site, the differences observed among the different time points of November 2000, February 2001 and June 2001 were in each case found not to be statistically significant. The following comparisons between the different composting sites were however found to be statistically significant: Teshie and Household ($p<0.01$), Teshie and Kade ($P<0.01$), Asiedu-Keteke and Household ($p<0.05$), Asiedu-Keteke and Kade ($P<0.01$) and Household and Kade ($p<0.01$).

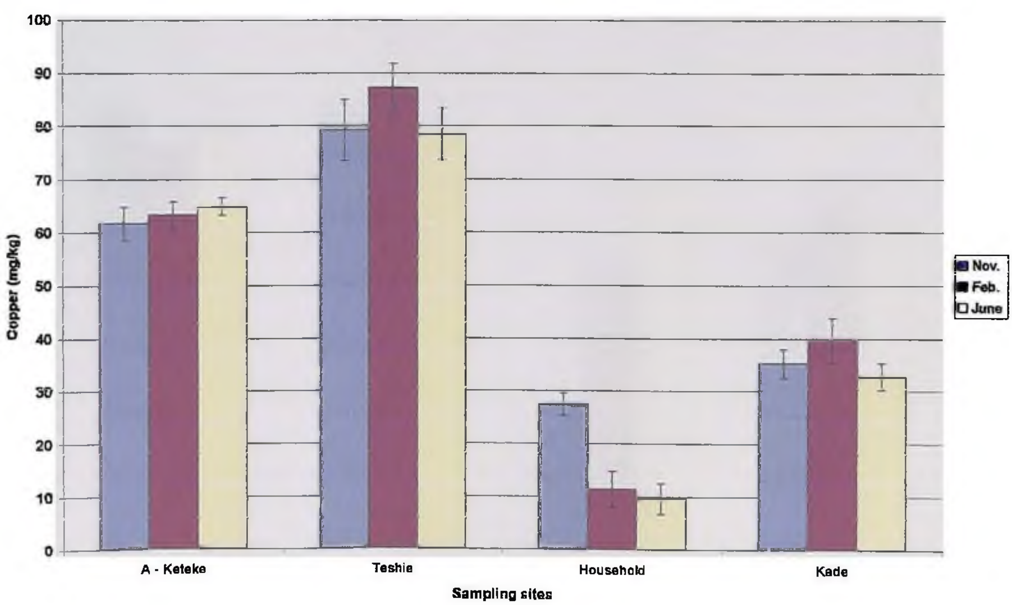
Figure 6: Zinc content in composts



4.4.4 Copper

Figure 7 shows the copper content in compost samples from the sampling sites. In general, minimal mean values were observed in the Household and Kade samples, with high values in Asiedu-Keteke and Teshie. The mean Household and Kade values were respectively 16.1mg/kg and 35.8mg/kg, whilst the Asiedu-Keteke and Teshie values were respectively 63.3mg/kg and 81.6mg/kg. With the exception of the Household, in which samples collected in November were significantly higher than those collected in February and June ($p<0.01$), there were no significant differences among the time points within each of the other sites. Comparisons between the mean values of the different sites however indicated significant differences as follows: Asiedu-Keteke and Teshie ($p<0.05$), Asiedu-Keteke and Household ($p<0.05$), Asiedu-Keteke and Kade ($p<0.01$), Teshie and Household ($p<0.01$), Teshie and Kade ($p<0.01$) and Household and Kade ($p<0.05$).

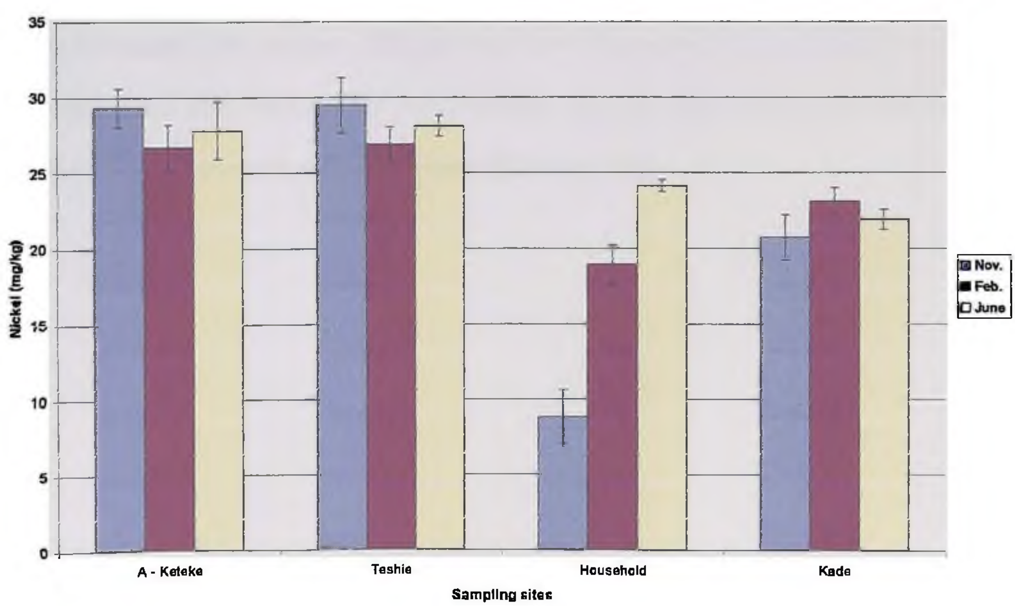
Figure 7: Copper content in composts



4.4.5 Nickel

The levels of nickel in the composts from the four sampling sites are indicated in figure 8. The Asiedu-Keteke, Teshie and Kade samples did not show significant statistical variation when nickel levels for each month for the different sites were compared. The nickel level of Household samples on the other hand showed a progressive increase ($p<0.05$) from November 2000 (8.8mg/kg), through February 2001 (18.9mg/kg) to June 2001 (24.1mg/kg). Comparisons between the means for the different sites indicated that the Asiedu-Keteke and Teshie samples were not significantly different. Significant differences were recorded for the means of the following pairs: Asiedu-Keteke and Kade ($p<0.05$), and Teshie and Kade ($p<0.05$). The nickel content of Household samples were also statistically different from those from Asiedu-Keteke and Teshie ($p<0.05$). The mean nickel content of the Household compost (17.3 mg/kg) was not significantly different from the mean value for the Kade compost (21.9 mg/kg).

Figure 8: Nickel content in composts



4.5 NUTRIENT CONTENT

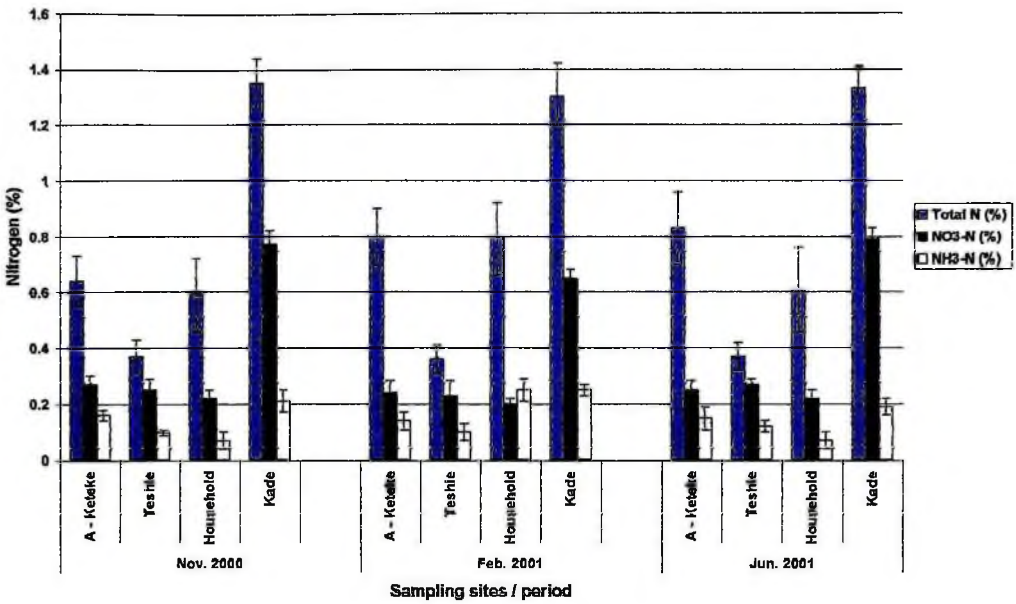
The plant nutrients of the composts that were investigated are nitrogen, phosphorous and potassium.

4.5.1 Nitrogen

Figure 9 gives a graphical representation of total nitrogen, nitrate nitrogen and ammonium nitrogen in the different compost materials that were studied at the specified months.

Generally, the Kade samples had the highest total nitrogen content for each of the three different months, whilst the Teshie samples had the least. The highest, 1.35%, as recorded for Kade and registered in November 2000 was statistically different from values from all the other sites ($p<0.05$), whilst the least, 0.36%, which was recorded for Teshie in February 2001 was also similarly statistically different from readings from the three remaining sites ($p<0.05$). Statistical analysis confirms that the total nitrogen of composts for each of the experimental sites remained constant for each of the experimental months. That is, total nitrogen for Asiedu-keteke was the same in November 2000, February 2001 and June 2001. This pattern was repeated for each of the three other sites. Total nitrogen for Asiedu-keteke and Household were also statistically not different from each other for each of the three different months.

Figure 9: Nitrogen content of composts



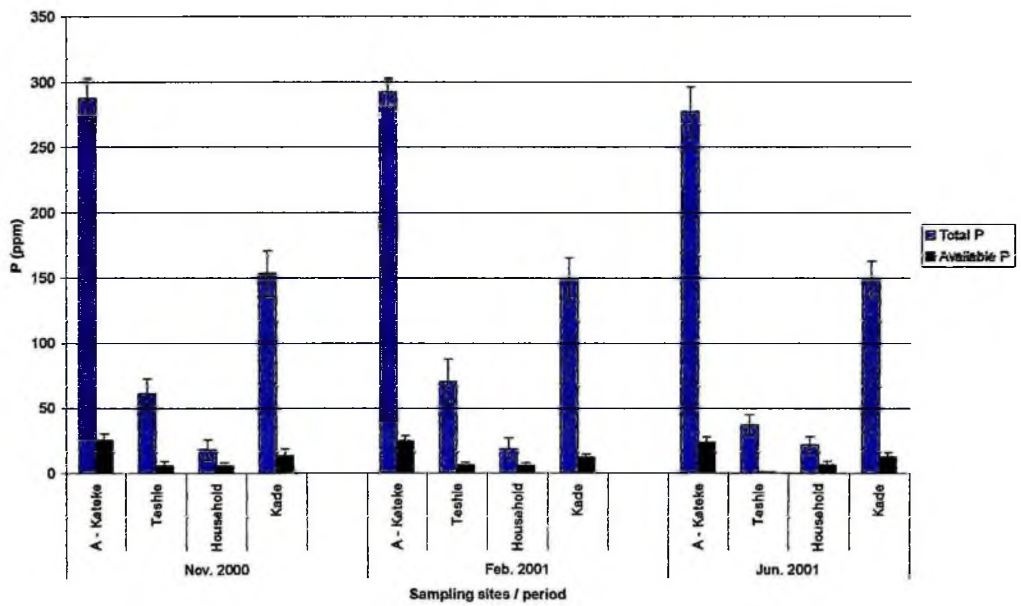
Except for the Household sample in February where ammonium nitrogen was slightly higher than nitrate nitrogen (difference not statistically significant), the nitrate nitrogen was always greater.

4.5.2 Phosphorus

The total as well as available phosphorus content in the various waste composts studied are depicted in figure 10. The Asiedu-Keteke composts were found have of the highest phosphorus value for each of the three months that samples were taken. The Household samples had the least phosphorus levels. Generally, the total phosphorous content was constant for each of the experimental sites for the three different months. The only exception was the Teshie samples, which compared to levels in November 2000 and February 2001, dropped significantly in June 2001 ($p<0.05$). The Teshie and Household composts were similar in available phosphorus for

November and February ($p>0.05$), although their total phosphorus were significantly different for the two months ($p<0.05$). Also in June, the Teshie sample was higher in total phosphorus (36.89ppm) compared to the Household (21.70ppm), but the Household had higher available phosphorus (6.68ppm) than Teshie (0.98ppm) for the same period.

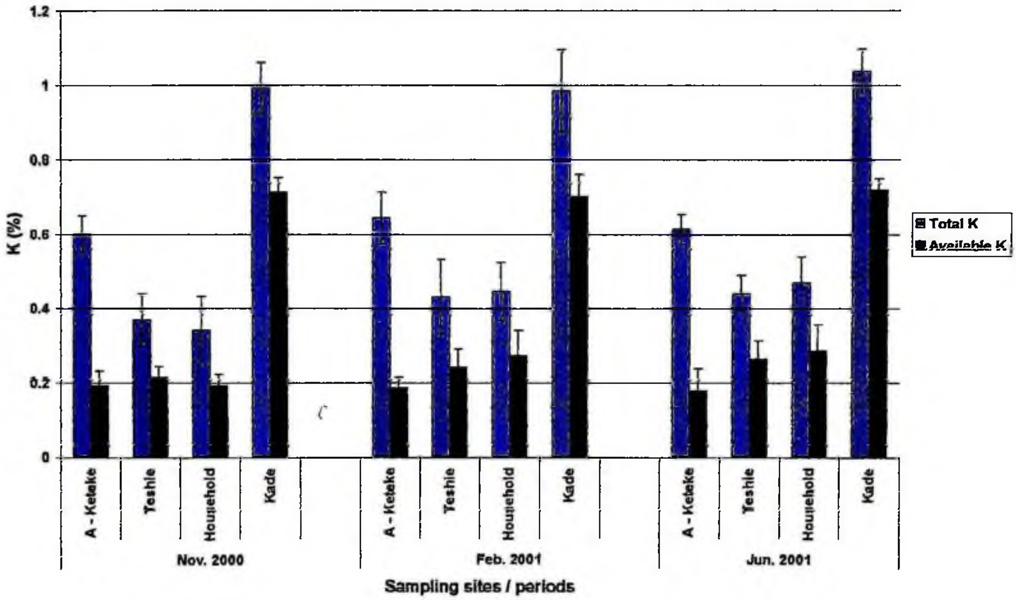
Figure 10: Phosphorus content of composts



4.5.3 Potassium

Figure 11 shows the total and available potassium content of waste composts from the four sites at stated sampling periods. The Kade samples had highest total and available potassium, whilst the Teshie and Household samples had the lowest. For each of the sites, the levels of total and available potassium were constant for November 2000, February 2001 and June 2001. The mean total and available potassium of the Kade compost were statistically different from those for Teshie, Household and Asiedu-Keteke ($p<0.01$ in each case). Total potassium for Asiedu-Keteke were also statistically different from the levels in the Teshie and Household composts ($p<0.05$). There were no statistical differences in the available potassium for Asiedu-Keteke, Teshie and Household composts.

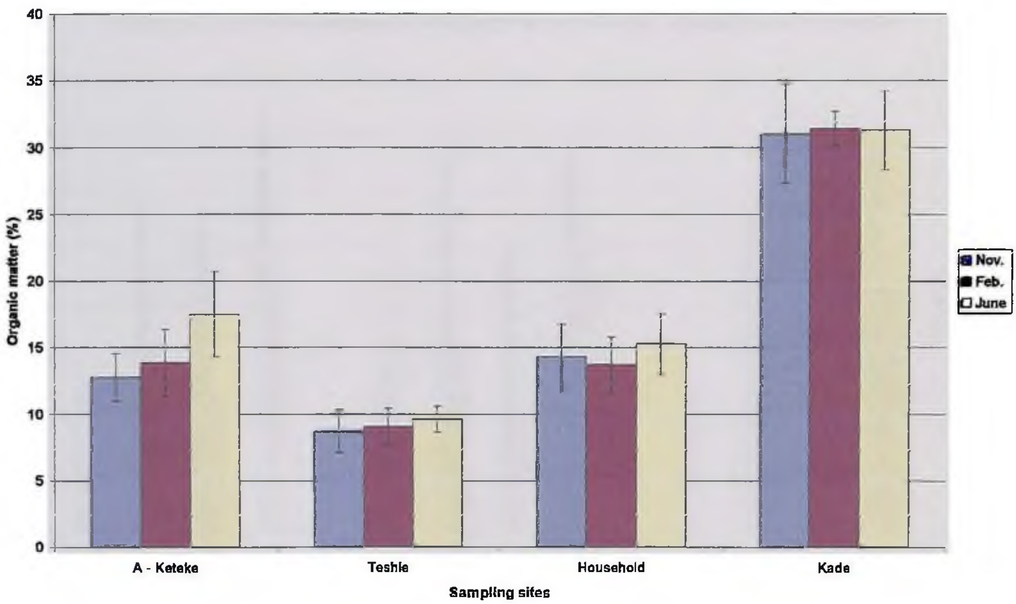
Figure 11: Potassium content of composts



4.6 ORGANIC MATTER

Figure 12 shows the levels of organic matter in the compost samples that were studied. Kade had the highest level of organic matter content while Teshie had the lowest. For Asiedu-Keteke compost, samples collected in June had higher organic matter, but this was not statistically different from those collected in November or February ($p>0.05$). Similarly, for Teshie, Household and Kade, there were no time point variations for each sampling site. The mean organic matter value for Asiedu-Keteke compost and that for the Household were statistically the same. But both the Asiedu-Keteke and Household samples were statistically different from (i) the Teshie samples ($p<0.05$) and (ii) the Kade samples ($p<0.01$).

Figure 12: Organic matter content of composts

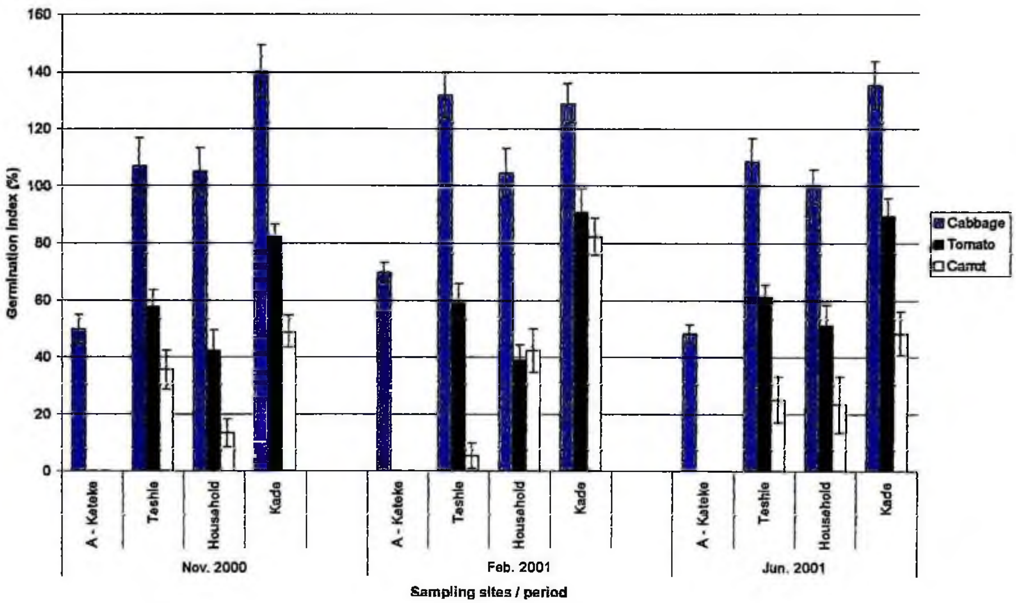


4.7 GERMINATION INDEX

Figure 13 shows the germination index of composts from the experimental sites using cabbage, tomato and carrot seeds. In general, the cabbage seeds gave the best response in the germination test. Carrot seeds performed poorly in the test. The Asiedu-Keteke composts exhibited the greatest inhibition to seed germination. Compost from Kade had the least inhibitory effect on seed germination.

Using the cabbage seed response as basis for comparisons, by virtue of its favourable response to the germination test, the Household, Teshie and Kade samples were each found to have at least 100% germination index for each of the three different months. The germination indeces of the

Figure 13: Germination index of composts using cabbage, tomato and carrot seeds

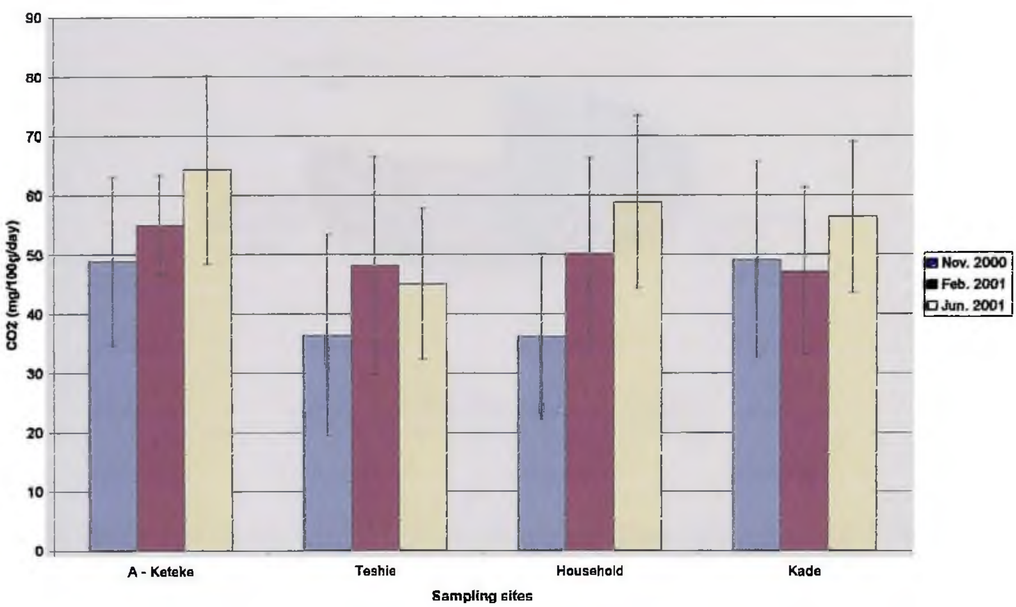


Asiedu-Keteke samples on the other hand, were between 48 and 70%, the highest value being in Feb 2001. The minimum of 30% difference between the Asiedu-Keteke and the rest of the composting sites was found to be statistically significant ($p<0.05$). Statistically, the Household and Kade samples each maintained constant germination indeces for the three different months. The germination indeces of the Teshie and Household samples were also statistically not different from each other in November 2000 and June 2001.

4.8 CARBON DIOXIDE EVOLUTION

Figure 14 shows the level of carbon dioxide evolution from the different composts.

Figure 14: Carbon dioxide evolution from composts

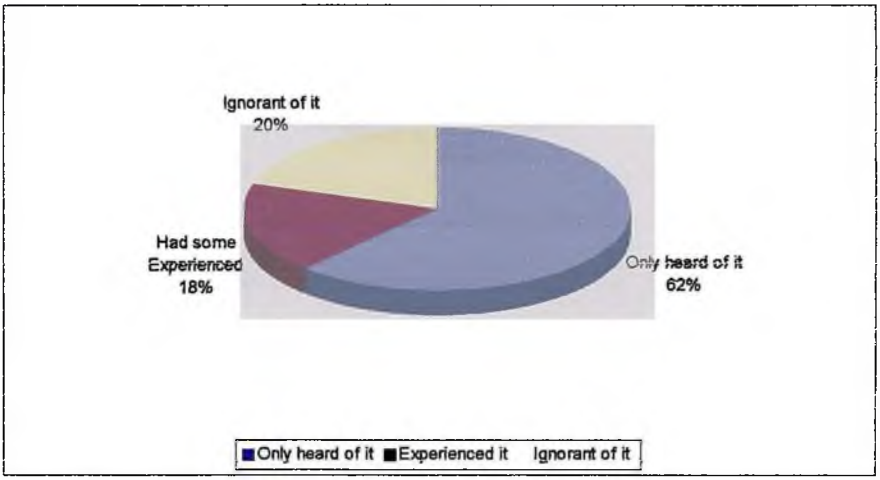


Generally, carbon dioxide evolution from the composts was lower in November, with highest readings occurring in June. Analysis of variance however did not detect significant differences among the samples; with respect to either within each of the composting sites or among the different sites.

4.9 PUBLIC ACCEPTANCE OR INTEREST IN MSW COMPOSTING IN ACCRA

4.9.1 Familiarity with composting in Accra

Figure 15: Level of composting familiarity

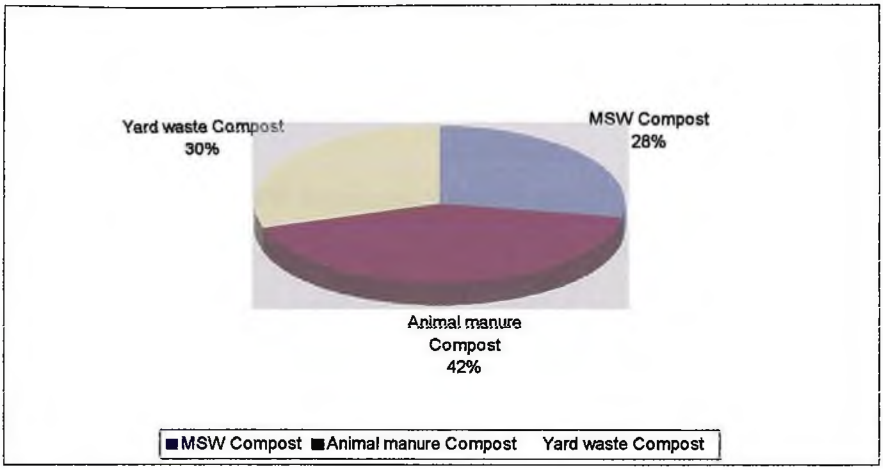


The pie chart above shows that 62% of the sample population had only heard of composting whilst 20% were completely ignorant of it. The remaining 18% of the sample population however has actually had an experience with composting, either as users or makers of compost.

4.9.2 Public awareness of compost types in Accra

Figure 16 shows the distribution of the types of composts that the public was aware of in Accra. Only 28% of respondents were aware of compost that was derived from MSW. Respondents were more familiar with the idea of composting animal waste or farm (yard) waste than composting of MSW.

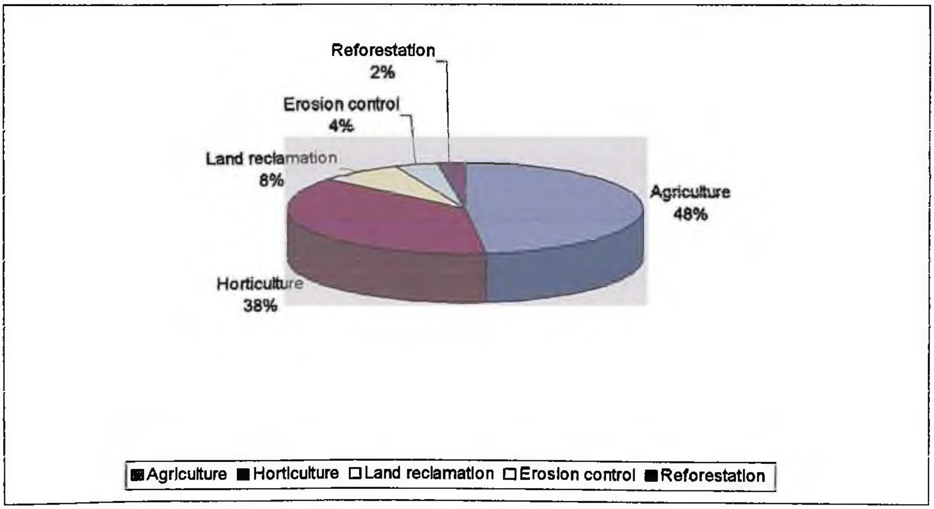
Figure 16: Public awareness on composts types



4.9.3 Public knowledge on compost utilization options in Accra

Figure 17 shows a proportional representation of the known uses of compost as expressed by respondents in Accra.

Figure 17: Distribution of known compost utilization options

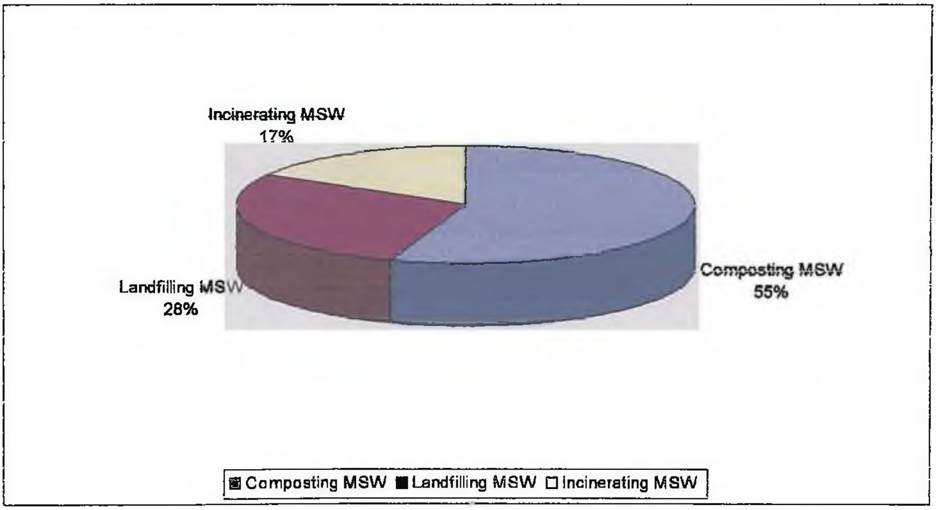


Agriculture and horticulture were the most widespread known utilization options whilst other options like land reclamation, erosion control and reafforestation were less known among the populace.

4.9.4 Public preference on MSW treatment options in Accra

Figure 18 is a representation of public preference of MSW treatment options in Accra. The indication was that more people would prefer to have MSW treated by way of composting.

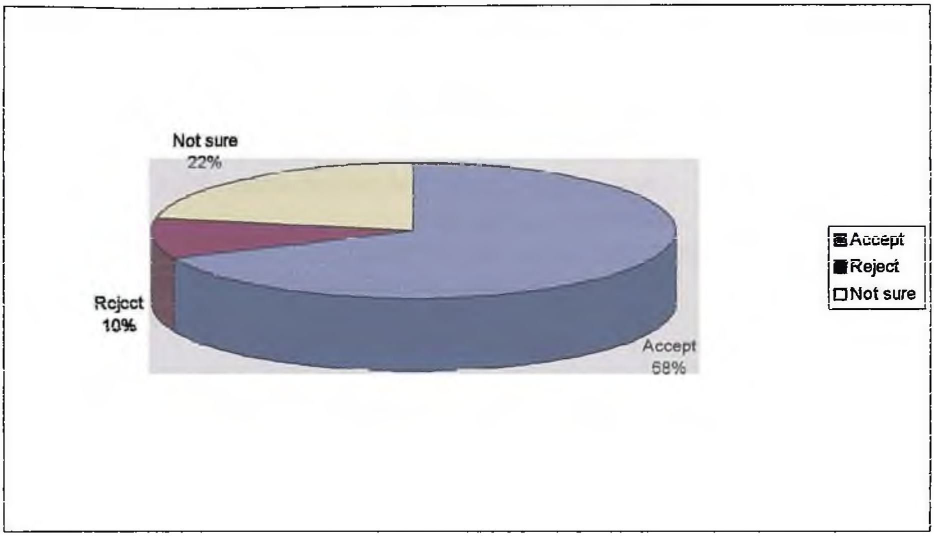
Figure 18: Distribution of public preference to treatment of solid waste



4.9.5 Acceptability of food products cultivated with MSW compost

Figure 19 shows the acceptability pattern in Accra of food products cultivated with MSW compost. Majority of the sample population (68%) would accept such food products whilst a sizable proportion was unsure (22%) whether to accept it or not. The remaining 10% rejected the use of MSW composts for food cultivation.

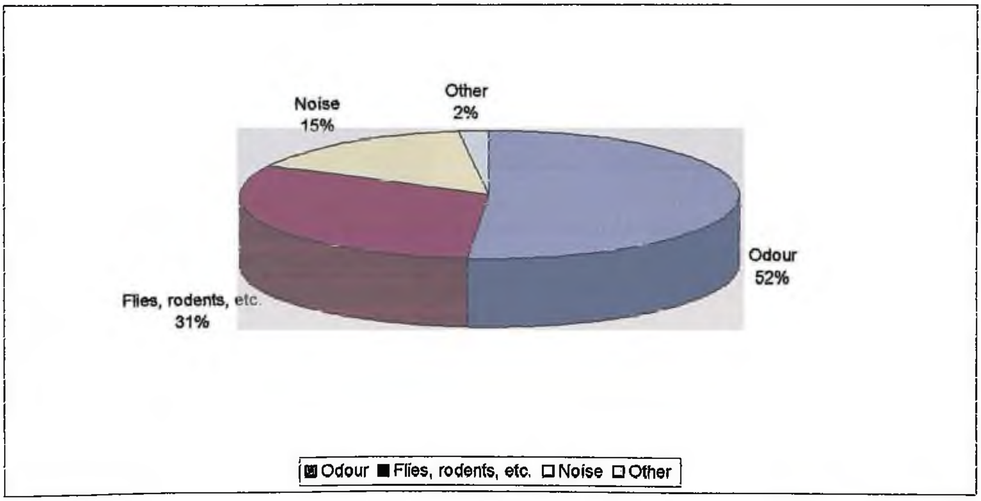
Figure 19: Acceptability of food products cultivated with composts



4.9.6 Problems with MSW composting

Figure 20 shows the proportions of problems as expressed by respondents living in the vicinity of MSW composting activity.

Figure 20: Composting associated social problems



There were 52% complaints of odour, especially at the Teshie composting site, whilst 31% of complains were related to disturbances from flies and rodents, 15% to noise associated with composting activity in the area.

4.9.7 Potential for public participation in reuse of organic waste

Figure 21a gives the distribution of respondents who reuse their organic wastes for one purpose or another. The respondents, 76.6 % who said yes to reuse of organic waste actually gave it to their domestic or farm animals as fodder. Some of the respondents, 23.4% all engaged in farming or horticultural activities did reuse their domestic or farm organic wastes for composting.

Figure 21a: Distribution of respondents who reuse organic wastes

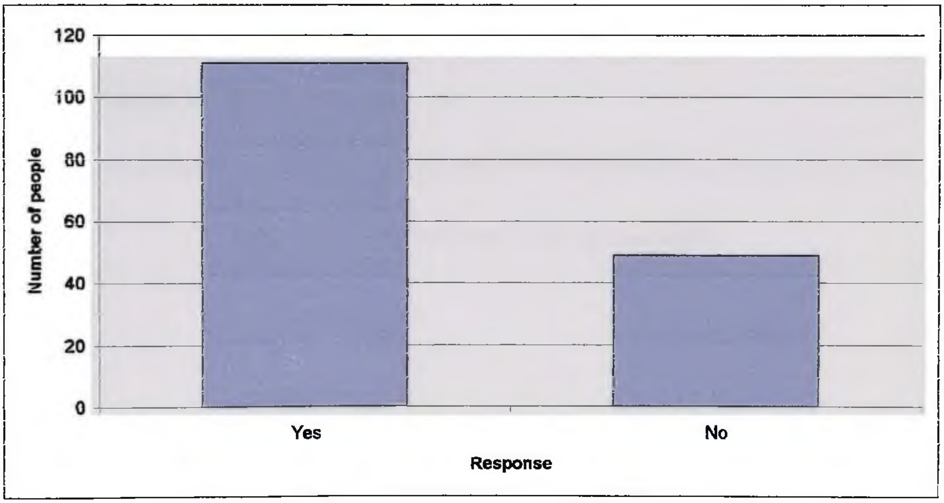
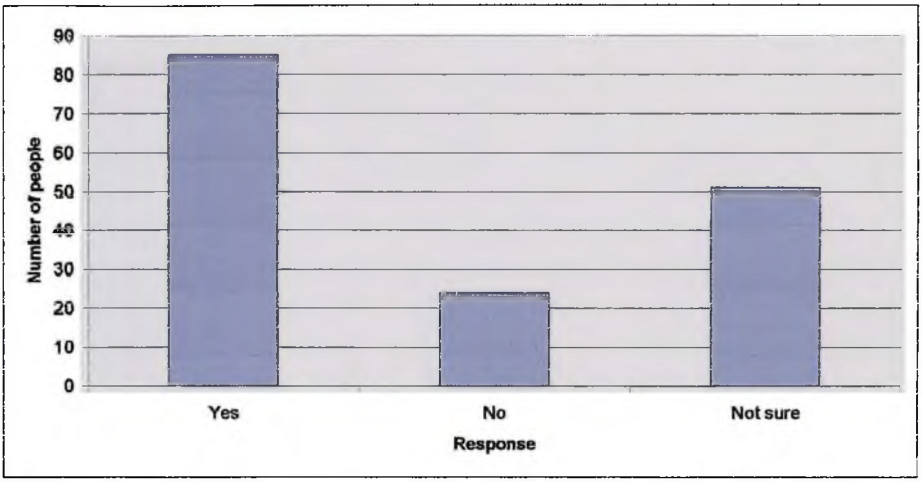


Figure 21b gives a representation of respondents who were willing to segregate their domestic organic waste at source so that it could be collected separately for composting. About half of the respondents said yes to separation of waste into organic and non-organic fractions at source, whilst the other half of respondents said either no, or were unsure of whether they could participate willingly in such an exercise.

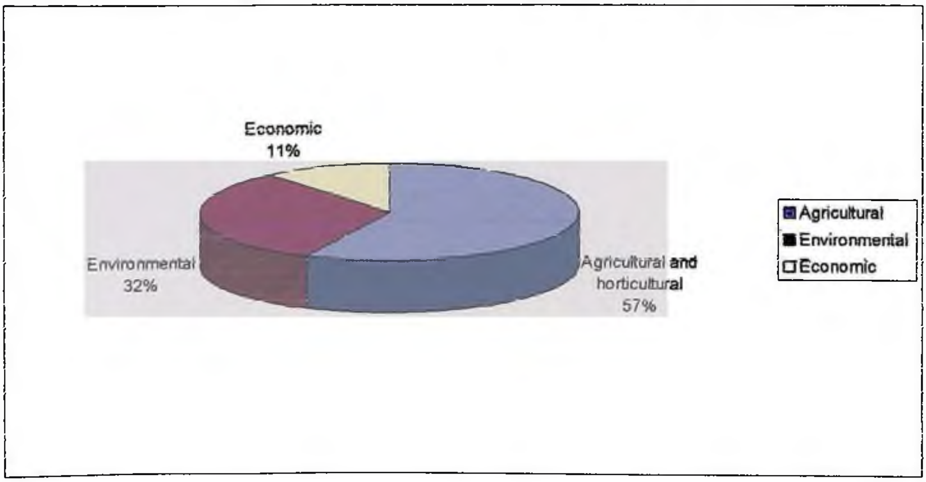
Figure 21b: Willingness to source separate domestic organic waste for composting



4.9.8 Motivating factors for composting

Figure 22 shows factors that may motivate respondents to consider composting activity in Accra.

Figure 22: Factors that would motivate composting



Agricultural factors were realized, as the most motivating that would influence respondents to consider composting activity. It attracted 57% response whilst environmental factors formed 32%. Those who claimed that they would engage in composting purely for the purpose of selling the compost were only 11%.

CHAPTER FIVE

DISCUSSION

This chapter discussed the possible environmental and health risks that may be associated with the composts and the various utilisation options most appropriate for the composts.

pH and electrical conductivity are used as estimates for water-soluble ion composition of a compost product. This is important when compost is being considered for plant growth purposes. It has been reported that the optimal pH range for composts is between 6.0 and 8.0 (E & A Environmental Consultants, 1997). The average pH values for Asiedu-Keteke, Teshie, Household and the Kade composts were 6.04, 7.32, 7.30 and 7.73 respectively. The near neutral pH of compost is beneficial for growing most agricultural crops. All the composts investigated had pH that fell within the optimal range. It may therefore be concluded that solid waste composts in Ghana have pHs that favour cultivation of most crops. The pH of the Asiedu-Keteke composts was however slightly acidic and perhaps would be more suitable for the cultivation of acid loving plants.

The Asiedu-Keteke and Teshie composts, which were used in this study to illustrate composting of mixed refuse, were expected to have similar pH readings, whilst the Household composts, manufactured from only household organic waste, were also expected to have pH close to that of the pure organic waste composts from Kade. However, the Teshie and the Household composts, rather, had similar pH. This presupposes that the pH values were independent of whether the composting was done with segregated or un-segregated waste.

There were marked conductivity variations in the composts that were studied. The Asiedu-Keteke composts had an average conductivity of 3.86 mS/cm, whilst the Teshie compost registered an average of 1.50mS/cm. The averages for the Household and Kade were respectively, 0.92 and 2.57mS/cm. Thus, no two different composts were the same. All the values however fell within tolerant limits for plants, as most plants, reportedly, cannot tolerate soluble salt content greater than 4mS/cm (Mamo *et. al.*, 1998).

Graphically, there were marked distinction in moisture contents between the Kade compost samples and the samples from Accra. The Kade samples appear almost as twice in moisture content as the Accra samples. Average moisture contents of 24.3%, 26.1%, 28.0% and 60.9% were established for the composts from Asiedu-Keteke, Teshie, Household and Kade respectively. The significant differences observed in results presented in section 4.1 could possibly be attributed to differences in levels of evaporation from the composts. At the Household level however, the compost was watered occasionally and this may explain why on the average, the Household compost had slightly higher in moisture level compared to the Teshie and Asiedu-Keteke composts. On the whole however, it was observed that composts in Accra had about the same moisture content, but were almost one half the moisture content of the Kade composts. The high moisture content of the Kade compost may possibly be attributed to its high organic matter content, which is likely to retain moisture in the composting windrow. When the moisture content is high, it increases the bulk density of the compost. As stated in section 2.3.5, the preferred moisture range for composts is 40 to 50 %. Compost that is dry (35% moisture or below) can be dusty and irritating to work with, while compost that is wet can become heavy and clumpy making its application more difficult and delivery more expensive. Thus, the Accra composts, as it were, are too dry and dusty and irritating to work with, but more easily transportable for applications in distant areas.

The macronutrients - nitrogen, phosphorus and potassium are important nutrients of waste derived composts. The total nitrogen content of the Kade composts were far and above the total nitrogen contents of composts from each of the three experimental sites in Accra (figure 9). The marked difference in total nitrogen between the Kade composts and those that were examined from Accra could be attributed to differences in the feed-stock for the composting. The agricultural wastes that were used in the preparation of the Kade composts contain poultry manure, which as animal manure, is a richer source of nitrogen than the MSW (Gilmour *et. al.*, 1977). This presupposes that to increase the nitrogen content of the Accra composts for the purpose of soil fertilization, it may be necessary to introduce sources of animal manure in the composting processes. Thus, it was expected that the sludge that was occasionally added to the composting at Teshie should enhance its nitrogen content. However, the nitrogen content of the Teshie compost was rather lower compared to the Asiedu-Keteke and the Household ones. As witnessed at the Teshie composting plant, the energy build up within the composting heaps often result in outlet of smoke and sometimes patches of fire that burns the composting heaps. The fire was normally quenched with sludge water. Organic nitrogen when burnt is expected to combine with oxygen to form nitrates, which has the tendency to leach easily.

In the case of phosphorus content (figure 10), although both composts were produced from mixed refuse, the Asiedu-Keteke compost was far richer in phosphorus than the Teshie compost. It is difficult to explain the reason for the differences since most of the raw materials that were used in producing the Asiedu-Keteke composts were also captured in the raw material base of the Teshie compost.

Generally, levels of potassium in refuse-derived composts are not high and this was reflected in the composts from Accra. The Kade compost on the other hand had much higher potassium content, which was about 1% (figure 11). The Kade compost would therefore be of better value as a potassium fertilizer than the Accra composts. Differences in the potassium content could be attributed to the different feed stock for the composting. Cocoa pods in the agricultural waste that was used in the preparation of the Kade compost might be contributing to the high potassium content of the compost.

The higher the content of the elements – nitrogen, phosphorus and potassium in compost, the greater the fertilizer value of the compost. As the levels of these elements were generally low in the composts studied, higher application rates might be required when they are to be used for soil fertilization. The amount used would depend on the specific type of soil as well as the nutrient requirements of the particular crop to be cultivated.

Organic matter content is a measure of carbon-based materials in compost. There is no ideal level organic matter content for composts, but the preferred range is 50 to 60% (E & A Environmental Consultants, 1997). The levels of organic matter of the composts studied were low (below 50%). The Accra composts however, were extremely low, ranging approximately between 8 to 15% (figure 12). At high temperatures as in the case of the Teshie composting, there is the likelihood of carbon loss during the composting process (Thomas, 1977). This may explain the lower organic matter value of the Teshie compost compared to the Asiedu-Keteke compost. In general however, all the Accra composts (Asiedu-Keteke, Teshie and the Household) were found to be low in organic matter. Perhaps this could be improved by providing additional sources of organic matter such as animal manure in the composting of MSW in Accra.

The C/N ratio values for all the composts studied were less than 25 indicating that they were matured (Brinton, 2000). The C/N ratio value alone is however believed not to be sufficient in indicating compost maturity.

The CO_2 evolution test has been shown to provide further information regarding the maturity of the composts (Garcia *et. al.*, 1992b). At the beginning of composting the biodegradable mixtures give off a lot of carbon in the form of CO_2. As composting progress, the evolution rate decreases (Garcia *et. al.*, 1992b). At compost maturity, the rate of CO_2 evolution is low and fairly constant to reflect the minimal microbial activity. The values obtained for the Accra and Kade composts are comparable to the value of 63.00mg/100g/day that was obtained for a study to assess stability and maturity of composted MSW (Iannotti et al, 1994). This suggests stable microbial activity in all the compost products of the present study and thus presumes a significant level of compost maturity.

The humus colour parameter that indicates compost maturity is given by a Δ log K value of light intensity through compost extract below 0.7 (Garcia *et. al.*, 1992b). From table 8 (see appendix I), the humus colour parameter value for all the compost samples was below 0.7 meaning that the composts were all matured.

Essentially, matured compost should contain more nitrates and less ammonia (Brinton, 2000). At the onset of composting, the composting medium is characterised by large amounts of ammonium nitrogen. At compost maturity however, most of the ammonium nitrogen is converted to nitrate nitrogen. The latter is more stable, odour free and provides nitrogen for plants. The literature is however silent on the specific value of NH_4/NO_3 ratio for compost maturity but the ratio should be less than 1. The lower the ratio value, the more matured the compost product. In this respect, it could be deduced that the Kade compost was the most matured, followed by the Household, the Teshie and the Asiedu-keteke composts in descending order (table 14).

The germination index experiment, which was the last maturity parameter that was assessed, was more pronounced using the cabbage seeds than the carrot and tomato seeds. Generally, the germination index values were higher with the cabbage seeds than the carrot and tomato seeds. But a similar pattern was shown with each seed, in terms of seed inhibition of the different composts (figure 13). On the average, there was least seed inhibition in the Kade composts, followed by the Household and Teshie composts. Seed inhibition was greatest in the Asiedu-Keteke compost. Germination index was zero (0) for the Asiedu-Keteke compost using carrot and tomato seeds. With the cabbage seeds, whilst the Kade, Teshie and Household composts produced 100% or more germination index, the Asiedu-Keteke compost produced about 50%.

The extent of seed inhibition in the Asiedu-Keteke composts suggests that the compost might not be matured. This may seem to confirm the earlier pattern that was observed using the NH_4/NO_3 parameter, in which the Asiedu-Keteke compost similarly gave the least maturity indication. The implication, inferring from Garcia *et. al.* (1992b), is that phytotoxins might be present in the Asiedu-Keteke composts. According to Garcia, *et. al.* (1992b), when organic matter contains phytotoxic substances which affect germination, some of these substances possibly do not degrade and are responsible for the inhibition detected in composts.

Phytotoxicity in composts has been attributed mostly to low molecular weight organic acid derivatives as well as the presence of polyphenolic substances (Garcia *et. al.*, 1992b). The Asiedu-Keteke composting facility is situated in an area with intense automobile repair activities. Also predominant in the area are wood-treatment activities for furniture manufacturing. These economic activities may possibly be introducing organic acid derivatives and phenolic compounds into the Asiedu-Keteke compost.

Various heavy metals are known to be contaminants of waste composts (Woodbury, 1992). The World Bank proposed value of 3.0mg/kg of cadmium in compost for developing countries. The results showed that the cadmium content of all the composts were within the World Bank proposed limits of 1997. The composts from pure organic waste had much lower levels of cadmium when compared with the composts from mixed refuse. This indicates that source separation of waste is important in reducing cadmium content of solid waste composts. The relatively higher cadmium content in the mixed refuse derived composts might be coming from discarded cadmium batteries as well as other discarded electronic devices in the MSW

(Woodbury, 1998).

Although the cadmium contents of all the composts fell within the World Bank proposed limit, the value for Teshie, 2.63mg/kg was close to the upper proposed limit of 3.0mg/kg. Concerns over cadmium contamination of composts and probable transfer to foods stems primarily from the fact that cadmium has been found to accumulate in kidneys and result in hypertension (Schroeder, 1964). Levels of cadmium found in plants grown on fields treated with sludge, containing over 200mg/kg cadmium, were found to be significantly lower than in plants exposed to airborne cadmium, or in plants grown in soils or culture solutions containing added inorganic cadmium (Allaway, 1977). Similarly, cadmium in food of plant origin is very likely less digestible, and therefore less hazardous, than equal amounts of cadmium in soluble inorganic forms contained in water or inhaled as dusts. Therefore, the possibility of cadmium content of the Accra composts posing human health risk when utilized for food crop cultivation is minimal.

The Kade compost was free of lead (figure 6) whiles the Household compost registered low lead values ranging between 10.5 to 49.5mg/kg. The results showed that the lead values obtained in June were relatively lower than compared with that of composts obtained in the other two months. This suggests possible loss of lead from the composts during the rainy season, since the composting media were all exposed to the direct effects of prevailing weather and leaching is likely to occur as a result of rainwater.

The World Bank proposed value for compost lead for developing countries is 150mg/kg. Both the Asiedu-Keteke and Teshie composts had lead levels that exceeded the World Bank limit. The high lead in these composts might be due to lead-acid batteries, plastics and rubber remnants, lead foils such as bottle closures, used motor oils and electronic gadgets such as television sets, calculators and stereos (Richard and Woodbury, 1992) that are discarded into the municipal refuse. Since lead concentrations were very low in the Household compost and below detection limit in the Kade compost, it is possible that separating MSW at source could reduce the level of lead contamination.

Plate 1: MSW compost windrow at Asiedu-keteke (Notice the contaminants before separation).

The high lead contents of the Asiedu-keteke and Teshie composts raise potential health risk concerns as these composts are used for crop cultivation in the Accra metropolis. But research have indicated that, where organic residue is incorporated into the soil, lead contained in the residue appears to offer very little hazard as far as toxicity to human and animals is concerned, and only modest toxicity to plants (Woodbury, 1998). On soils that were treated with as much as 3,200kg/ha of lead in the form of soluble salts, the concentration of lead in corn leaves was increased but the lead concentration in the grain was unchanged. Therefore, production of crops where only the edible seed is harvested may be an effective way of preventing lead toxicity to human and animals. In general, potential hazards of lead toxicity are reduced whenever the lead is incorporated in soil, in contrast to the potential hazards from atmospheric lead (Allaway, 1977).

Plate 2: MSW compost windrows at Teshie composting site (notice contaminants before separation).

Poultry manure has been reported to contain about 120mg/kg of zinc (Kardos et. al., 1977), which is attributed to antibiotics and other zinc containing chemicals used in the poultry industry. This could be responsible for the high zinc levels in the Kade compost as large amount of poultry manure was used in the composting at Kade. The average values for the Accra composts; Asiedu-keteke – 25.5mg/kg, Teshie – 29.2mg/kg and the Household – 7.8mg/kg were very low compared to the World Bank proposed level of 300mg/kg for developing countries.

The trend of copper levels in the composts was quite similar to the preceding elements discussed. When compared to the limit of 80mg/kg proposed by the World Bank for developing countries, all the composts from the sites investigated were found to be within the acceptable limit. The marked difference in copper content of the pure organic source composts (Household and Kade) and the mixed refuse composts (Teshie and Asiedu-keteke) could be attributed to contamination at source of the mixed waste. This implies that separation of organic solid waste at source could reduce level of copper contamination in composts

The proposed World Bank limit for nickel in composts for developing countries is 50mg/kg. Generally, the levels found in the composts studied were below 30mg/kg (figure 8), although the Household and Kade composts had lower nickel levels compared to those from Asiedu-Keteke and Teshie. This difference may be similarly explained as in the case of the previous elements. It emphasizes source separation of organic waste as a way to reduce heavy metals in MSW composts.

Overall, the heavy metals content (cadmium, lead, zinc, nickel and copper) of the composts was low and likely to pose no health risk from their unrestricted use. However, the Asiedu-Keteke compost which at certain time points was found to have lead content above the World Bank limit, not matured and potentially phytotoxic, may be restricted in its application for crop production. It could however be applied in areas that require less stringent specifications, for example, reafforestation, land reclamation or erosion control.

In terms of visual purity of the final product after separation of contaminants, the Asiedu-Keteke compost was of better visual quality than the Teshie compost. This could be observed when plate 3 is compared to plate 4. The final product of Asiedu-Keteke composting was absolutely free of visible contaminants, however, the final separated product from the Teshie composting facility still bore traces of contaminants as could be observed in plate 4. It could therefore be inferred that the manual separation process at the Asiedu-Keteke composting facility was more effective than the automated process adapted at the Teshie facility. In view of the differences in visual quality of the two final products, application of the Teshie compost to land could possibly cause land pollution from small objects and plastic remnants.

Plate 3: Matured compost at Asiedu-Keteke composting site after separation of contaminants.

Plate 4: Matured compost at Teshie composting site after separation of contaminants (notice traces of contaminants).

Plate 5: Manually operated sieve used for separation of contaminants from compost at the Asiedu-Keteke site.

Plate 6: Conveyor belt carries compost down into the green automated separator at Teshie site.

Plate 7: Separated compost is carried up the conveyor belt from the green separating device into the shed where compost is stored and ready for bagging.

Plate 8: Bagged composts arranged for sale by road-side.

The results from the composting awareness survey in Accra (figure 15) showed that a sizable proportion of respondents knew about composting. However, out of the proportion that knew of composting, only 28% were aware of the fact that compost could be derived from MSW as an environmental management strategy (figure 16). Majority of respondents were more familiar with composting animal waste or yard waste. This means that some education would be needed on the part of the Accra Metropolitan Assembly to increase awareness in the metropolis about composting MSW. This is important because after explaining what MSW composting was as part of this survey, majority (55%) were in favour of it, and would prefer to have solid waste in the city treated this way, in preference to landfilling that attracted only 28% and incineration 17% (figure 18). With regards to the utilisation of compost products in general, respondents knew agriculture and horticulture as the main options available (figure 17). This means that there are still potentially untapped areas of uses and therefore new market opportunities that could be explored for compost products.

The results showed that respondents (68%) have no problem in accepting food products that were cultivated with MSW derived composts (figure 19). Those that were unsure about the acceptability of such food products, together with those that rejected such food products out-right, cited possible transfer of chemical and biological contaminants to the food products as the main reason. However, the chemical analysis conducted on the composts showing low levels of toxic heavy metals should allay these fears. But biological contaminations, in terms of microbial concerns need to be investigated to increase public confidence in the use of composts for food cultivation. Respondents who favoured composting MSW saw it as cheaper means of producing fertilizer for farming. This was reflected in the motivating factors for composting, reported in section 4.9.8, in which respondents saw agriculture and horticulture as motivating for composting MSW than environmental factors.

The survey also tried to capture respondents that reuse their domestic or farm organic waste for any activity. It was realized that 69.4%, out of 160 respondents who have knowledge of composting, uses the organic wastes as animal fodder (figure 21a). The anticipation was that, if respondents were prepared to reuse organic waste as fodder, then they might also be willing to source separate domestic organic waste. In the survey, most of the respondents were found to be willing to source separate their domestic organic waste. Perhaps, the recognition that organic waste is a useful resource may have influenced respondents' decision to source separate waste. It is important that this system of waste handling is encouraged in Ghana. It has been reported that waste separation offers the opportunity to produce very clean compost products from MSW (Tom and Woodbury, 2000). In the US for example, source separated MSW composts had maximum lead levels of about 150mg/kg, whilst final screening as it is done in Ghana had maximum lead concentration of over 800mg/kg (Tom and Woodbury, 2000). Thus, source separation could cut down on, for example, lead contamination by as much as 81.3%.

5.1 SUGGESTIONS FOR IMPROVEMENT OF QUALITY OF SOLID WASTE DERIVED COMPOSTS

The study suggests that compost quality improvement would be based on two main factors: (i) process control factors and (ii) feed stock factors. The decreased total nitrogen of the Teshie compost was attributed to inadequate composting process control factors. The control factor of concern here was turning of the compost heap to allow adequate aeration of the composting process. This is important to avoid over heating of the composting medium with attendant nutrient depletion effects. Feed stock factors have implications for the nutrient value as well as contamination of the final product. As it was realized, the nutrient value of the Accra composts studied was low compared to the Kade compost. One main reason accounting for this difference was the fact that the Kade compost contains animal manure whilst the Accra compost does not. Solid waste composts, thus, could possibly be improved by introducing animal manure into the composting feed stock. The higher heavy metal contaminants detected in the Asiedu-Keteke and Teshie composts could all be attributed to contamination in the feed stock. For example, studies by Fobil (2001) reported an average daily production of non-organic wastes (comprising of textile, metal, glass, plastic, paper, and miscellaneous components) in Accra to be about 40%; all of which could introduce heavy metal in compost products. The results showing differences with respect to heavy metal contamination in the Kade and Household composts on one hand and the Asiedu-Keteke and Teshie composts on the other, indicates that composting of feed stocks that are of pure organic fractions are of better quality than feed stocks from mixed refuse. Therefore to decrease the level of contamination in the Asiedu-Keteke and Teshie composts, it may be important to consider the following options:

- Reduce or eliminate contaminant levels in products destined to become MSW.
- Separate clean organic materials at source for composting.
- Separate contaminants at source for collection and proper disposal.
- Separate contaminants from MSW at a centralized facility prior to composting.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The main purpose of the study was to assess the chemical and biological characteristics of solid waste derived composts in Ghana as a factor for determining compost utilization options. The different criteria of the composts that were investigated were the nutrient/fertilizing value, heavy metal concentrations, phytotoxicity and maturity. Utilization options were then looked at based on the compost quality. Public acceptance of MSW composts in Accra was also assessed.

The nutrient or fertilizing value of the composts was low and this was dependent on the feed stock for producing the different composts (i.e. MSW and agricultural waste composts). Of all the composts studied, the Asiedu-Keteke compost was the only one that inhibited seed germination, indicating that it was not matured and its application may cause problems to crops. Heavy metals, especially lead and cadmium, found in the Asiedu-Keteke and Teshie composts did not reach toxic levels and likely to have significant food chain implications. Based on the lower heavy metal concentration of the Household and Kade composts, it is suggested that compost quality of Teshie and Asiedu-Keteke MSW composting, could be improved by instituting a system that would encourage segregation of the organic fraction of waste at source. The chemical and biological characteristics of the Teshie, Household and Kade composts make them suitable for unrestricted applications.

There is the need to increase public awareness on composting as an environmental management strategy in the Accra metropolis.

6.2 RECOMMENDATION FOR FUTURE RESEARCH

- Further work is required to determine the exact application rates regarding the use of solid waste derived composts in Ghana for crop cultivation. Such a work should investigate the nutrient content of the specific soil of application as well as the nutrient requirements of the particular crop to be cultivated. The availability of this information, coupled with current findings on nutrient content of the composts, would allow for a more informed decision to be made in choosing compost for crop cultivation.

- To increase MSW compost marketability, it is recommended that, engineering and economic investigations should be conducted into recent innovative utilization options such as erosion control, turf remediation, landscaping, reafforestation, wetlands restoration, habitat revitalization and disease control for plants and animals. This would increase the utilization options and as such increase the market potential for the product.

- Studies to find out the capacity and ability of people to source separate solid waste in Ghana would be an interesting and important investigatory step towards the mobilization of pure organic fraction of the waste for composting. If the compostable fraction of MSW could be recovered for composting, it would greatly reduce potential contaminations in the final product.

- The parameters considered in this study were not exhaustive when considering full quality status of composts. Other heavy metals such as mercury and arsenic, which also have serious health risk implications, need to be assessed in composts.

- Further studies also need to be conducted to quantify the extent to which source separation of solid waste impacts on the quality of compost.

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APPENDICES

APPENDIX I

Table 4: Moisture content of composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	20.2 ± 4.9	25.7 ± 0.2	29.9 ± 0.6	59.0 ± 2.6
Feb.	28.0 ± 2.2	24.0 ± 1.9	28.0 ± 0.8	60.6 ± 2.3
June	24.6 ± 5.0	28.7 ± 0.11	26.0 ± 0.3	63.2 ± 2.1

Table 5: Electrical conductivity of composts (mS/cm)

	A - Keteke	Teshie	Household	Kade
Nov.	3.93 ± 0.09	1.55 ± 0.07	0.93 ± 0.05	2.47 ± 0.21
Feb.	3.85 ± 0.17	1.46 ± 0.15	0.96 ± 0.13	2.69 ± 0.16
June	3.81 ± 0.11	1.48 ± 0.09	0.88 ± 0.09	2.55 ± 0.13

Table 6: pH of composts

	A - Keteke	Teshie	Household	Kade
Nov.	6.28 + 0.27	7.51 + 0.20	7.38 + 0.30	7.55 + 0.30
Feb.	5.81 ± 0.50	7.24 ± 0.30	7.21 ± 0.31	7.89 ± 0.21
June	6.03 ± 0.35	7.20 ± 0.27	7.29 ± 0.30	7.74 ± 0.25

Table 7a: Levels of Cadmium in composts (mg/kg)

	A - Keteke	Teshie	Household	Kade
Nov.	1.8 ± 0.17	2.1 ± 0.25	0.6 ± 0.25	0
Feb.	1.7 ± 0.17	1.9 ± 0.16	0.2 ± 0.13	0
June	1.4 ± 0.38	1.97 ± 0.19	0	0

Table 7b: Levels of lead in composts (mg/kg)

	A - Keteke	Teshie	Household	Kade
Nov.	168.9 ± 8.1	275 ± 7.8	32.5 ± 7.6	0
Feb.	171.4 ± 7.3	210.1 ± 9.9	49.5 ± 9.2	0
June	71.1 + 8.4	142 + 10.2	10.5 + 6.3	0

Table 7c: Levels of zinc in composts (mg/kg)

	A - Keteke	Teshie	Household	Kade
Nov.	24.8 ± 4.3	31.4 ± 6.7	12.4 ± 5.1	51.4 ± 3.3
Feb.	19 ± 4.1	31.1 ± 6.2	5.2 ± 2.5	45.8 ± 3.7
June	28.7 ± 5.7	25.2 ± 4.5	5.7 ± 2.6	50.9 ± 4.1

Table 7d: Levels of copper in composts (mg/kg)

	A - Keteke	Teshie	Household	Kade
Nov.	61.7 ± 3.1	79.2 ± 5.8	27.4 ± 2.1	35.2 ± 2.7
Feb.	63.3 ± 2.5	87.2 ± 4.6	11.3 ± 3.5	39.5 ± 4.3
June	64.9 ± 1.7	78.5 ± 4.9	9.6 ± 2.9	32.7 ± 2.5

Table 7e: Levels of nickel in composts (mg/kg)

	A - Keteke	Teshie	Household	Kade
Nov.	29.3 ± 1.3	29.5 ± 1.85	8.8 ± 1.8	20.7 ± 1.5
Feb.	26.7 ± 1.5	26.9 ± 1.1	18.9 ± 1.3	23.1 ± 0.9
June	27.8 ± 1.9	28.1 ± 0.7	24.1 ± 0.4	21.9 ± 0.7

Table 8a: Germination index of composts using cabbage seeds

	Asiedu - Keteke	Teshie	Household	Kade
Nov.	49.8 ± 5.1	106.79 ± 10.1	104.81 ± 8.5	104.81 ± 9.2
Feb.	69.71 ± 3.5	131.61 ± 7.9	104.59 ± 8.4	104.59 ± 6.9
June	48.27 ± 3.2	108.38 ± 8.5	100 ± 5.9	100 ± 8.4

Table 8b: Germination index of composts using tomato seeds

	Asiedu - Keteke	Teshie	Household	Kade
Nov.	0.0	57.6 ± 5.9	42.3 ± 7.2	82.2 ± 4.3
Feb.	0.0	58.7 ± 7.1	39.0 ± 5.4	90.9 ± 8.1
June	0.0	61.1 ± 4.4	51.1 ± 7.2	89.4 ± 6.3

Table 8c: Germination index of composts using carrot seeds

	Asiedu - Keteke	Teshie	Household	Kade
Nov.	0.0	5.3 ± 6.7	13.5 ± 4.9	49.1 ± 5.7
Feb.	0.0	25.2 ± 4.5	36.3 ± 7.7	46.0 ± 6.5
June	0.1 ± 0.0	13.5 ± 8.1	23.4 ± 9.9	48.4 ± 7.6

Table 9: Carbon dioxide evolution from composts (mg/100g/day)

	A - Keteke	Teshie	Household	Kade
Nov.	48.84 ± 14.2	36.49 ± 16.9	36.18 ± 13.9	49.13 ± 16.5
Feb.	54.95 ± 8.4	48.15 ± 18.3	50.15 ± 16.1	47.18 ± 14.1
June	64.30 ± 15.9	45.10 ± 12.7	58.83 ± 14.5	56.39 ± 12.8

Table 10: Humus colour of composts (Δ log K)

	A - Keteke	Teshie	Household	Kade
Nov.	0.50 ± 0.22	0.33 ±0.18	0.32 ± 0.25	0.43 ± 0.10
Feb.	0.44 ± 0.17	0.42 ±0.11	0.39 ± 0.13	0.41 ±0.05
June	0.59 ± 0.15	0.48 ± 0.20	0.41 ± 0.08	0.45 ± 0.12

Table 11(a): Organic carbon of composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	7.40 ± 1.8	5.07 ± 1.6	8.28 ± 2.5	17.98 ± 3.7
Feb.	8.04 ± 2.5	5.23 ± 1.4	7.96 ± 2.1	18.20 ± 1.3
June	10.15 ± 3.2	5.59 ± 1.0	8.86 ± 2.3	18.15 ± 2.9

Table 11(b): Organic matter of composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	12.76 ± 1.8	8.74 ± 1.6	14.28 ± 2.5	31.00 ± 3.7
Feb.	13.86 ± 2.5	9.02 ± 1.4	13.72 ± 2.1	31.38 ± 1.3
June	17.50 ± 3.2	9.64 ± 1.0	15.28 ± 2.3	31.29 ± 2.9

Table 12(a): Total nitrogen content composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	0.64 ± 0.09	0.37 ± 0.06	0.59 ± 0.13	1.35 ± 0.09
Feb.	0.79 ± 0.11	0.36 ± 0.05	0.79 ± 0.13	1.30 ± 0.12
June	0.83 ± 0.13	0.37 ± 0.05	0.61 ± 0.15	1.33 ± 0.08

Table 12(b): Nitrate-nitrogen content of composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	0.27 + 0.03	0.25 + 0.04	0.22 + 0.03	0.77 + 0.05
Feb.	0.24 ± 0.04	0.23 ± 0.05	0.20 ± 0.02	0.65 ± 0.03
June	0.25 ± 0.027	0.27 ± 0.02	0.22 ± 0.03	0.79 ± 0.04

Table 12(c): Ammonium-nitrogen content of composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	0.16 ± 0.02	0.10 ± 0.01	0.07 ± 0.03	0.21 ± 0.04
Feb.	0.14 ±0.03	0.10 ± 0.03	0.08 ± 0.04	0.25 ± 0.02
June	0.15 ± 0.038	0.12 ± 0.02	0.07 ± 0.03	0.19 ± 0.03

Table 13: Carbon-nitrogen ratio of composts (computed from tables 11a and 12a)

	A - Keteke	Teshie	Household	Kade
Nov.	11.56	13.70	14.03	13.32
Feb.	10.18	14.53	10.08	14.00
June	12.23	15.11	14.53	13.65

Table 14: Ammonium-nitrate ratio of composts (computed from tables 12c and 12b)

	A - Keteke	Teshie	Household	Kade
Nov.	0.59	0.40	0.32	0.27
Feb.	0.58	0.44	0.44	0.39
June	0.60	0.44	0.32	0.24

Table 15(a): Total phosphorus content of composts (ppm)

	A - Keteke	Teshie	Household	Kade
Nov.	287.20 ± 15.6	60.90 ± 11.4	17.83 ± 7.8	153.23 ± 17.4
Feb.	292.20 ± 10.5	70.30 ± 17.2	18.71 ± 8.3	149.05 ± 16.1
June	276.70 ± 19.1	36.89 ± 8.1	21.70 ± 6.2	149.50 ± 12.9

Table 15(b): Available phosphorous in composts (ppm)

	A - Keteke	Teshie	Household	Kade
Nov.	25.41 ± 4.8	5.69 ± 3.5	5.66 ± 2.4	13.11 ± 5.7
Feb.	24.57 ± 4.3	6.34 ± 1.9	6.01 ± 1.7	12.24 ± 2.3
June	23.32 ± 4.1	0.98 ± 0.1	6.68 ± 2.5	12.96 ± 3.2

Table 16(a): Total potassium content of composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	0.60 + 0.05	0.37 + 0.07	0.34 + 0.09	0.99 + 0.07
Feb.	0.64 ± 0.07	0.43 ± 0.10	0.45 ± 0.076	0.98 ± 0.11
June	0.61 ± 0.04	0.44 ± 0.05	0.47 ± 0.07	1.04 ± 0.06

Table 16(b): Available potassium in composts (%)

	A - Keteke	Teshie	Household	Kade
Nov.	0.19 ± 0.04	0.21 ± 0.03	0.19 ± 0.03	0.71 ± 0.04
Feb.	0.19 ±0.03	0.24 ± 0.05	0.27 ± 0.07	0.70 ± 0.06
June	0.18 ± 0.06	0.26 ± 0.05	0.29 ± 0.066	0.72 ± 0.03

Table 17: Composting familiarity in Accra

Level of familiarity	Number of Response
Only heard of composting (A)	124
Have had experience with compost (B)	36
Completely ignorant of composting (C)	40

Table 18: Type(s) of compost(s) that respondents have encountered or heard of

Type of compost	A	B	TOTAL
Municipal solid waste (MSW) compost	68	17	85
Animal waste compost	94	36	130
Yard waste compost	71	21	92

Table 19: Known uses of composts as expressed by respondents

Uses of compost	A	B	TOTAL
Agriculture	124	36	160
Horticulture	97	29	126
Land reclamation	21	5	26
Erosion control	13	3	16
Reforestation	5	3	8

Table 20: Preferences expressed on treatment of MSW

Treatment Option	A	B	TOTAL
Composting MSW	91	31	122
Landfilling MSW	55	7	62
Incinerating MSW	37	0	37

Table 21: Acceptability of food products cultivated with MSW composts

	A	B	TOTAL
Accept	97	30	127
Reject	18	0	18
Not sure	35	6	41

Table 22a: Respondents' proximity to composting facility

	A	B	TOTAL
Staying close to composting facility	50	12	62
Staying away from composting facility	74	24	98

Table 22b: Problems expressed by respondents living in vicinity of composting facilities

Problems	A	B	TOTAL
Odour	41	10	51
Flies, rodents, etc.	29	2	31
Noise	15	0	15
Other	2	0	2

Table 23a: Respondents that had reuse domestic or farm organic waste before

	A	B	TOTAL
Had reuse organic waste before	75	36	111
Had not reuse organic waste before	49	0	49

Table 23b: Uses to which respondents put the organic wastes

	A	B	TOTAL
Used as animal fodder	57	31	85
Used for composting	18	18	26

Table 24: Willingness to source-separate domestic organic waste

	A	B	TOTAL
Number willing to source-separate waste	65	20	85
Number that reject source-separation of waste	22	2	24
Number unsure of whether to source-separate waste	37	14	51

Table 25: Factors that would motivate respondents to compost MSW

	A	B	TOTAL
Agricultural and horticultural	90	27	117
Environmental	45	20	65
Economic	16	6	22

APENDIX II

PRIMARY DATA COLLECTION QUESTIONNAIRE

TOPIC: AN ASSESSMENT OF PUBLIC ACCEPTANCE AND INTEREST IN COMPOSTING IN ACCRA

1. Stakeholder identity

   a. Direct user of compost b. Compost maker c. Non-user public

2. Have you ever heard of / have experience with compost?

   a. Have only heard about composting.

   b. Have had experience with composting.

   c. Have no idea what composting is about.

Continue with questionnaire if your choice of answer to question 2 above is either (a) or (b).

3. Which type(s) of compost have you encountered or heard of?
   a. Municipal solid waste compost (MSW)
   b. Animal manure compost
   c. Yard waste compost

4. What was the compost used for?
   a. Agriculture
   b. Horticulture
   c. Land reclamation
   d. Erosion control
   e. Other (please specify) ______________________

5. Which of the following would you prefer?
   a. Composting MSW
   b. Land-filling MSW
   c. Incinerating MSW

6. (i) Would you accept food products cultivated with MSW compost?

   a. Yes b. No 6. Not sure

   (ii) If no, give reason. ______________________________

7. (i) Do you stay in the vicinity of a MSW composting plant?

   a. Yes b. No

   (ii) If yes, are you affected in any way by the composting process?

   ____

8. Do you reuse your domestic or farm organic waste for any activity?

   a. Yes b. No

   If yes, please state what you use it for.

   ____

9. Would you be willing to source separate your domestic organic waste to be used for composting?

   a. Yes b. No c. Not sure

10. What factors would motivate you to be involved in composting activity?
    i. Agricultural and horticultural factors
    ii. Environmental factors
    iii. Economic factors
    iv. None of the above factors