KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

Preparing Compost for the Operation of a Compost Facility Using Newmont Ghana Gold Limited Ahafo Mines as a Case Study

A thesis submitted in partial fulfilment of the requirements for the award of MASTER OF SCIENCE Degree in Environmental Science

By

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DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge it contains no material previously published by another person or material which has been accepted for the award of any other degree of the university, except where the acknowledgement has been made in the text.

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ABSTRACT

The objective of the study was to prepare compost from food waste, dewatered sewage sludge, wood shavings and waste papers mixed at different ratios for the operation of Newmont Ghana Gold Limited (NGGL) compost facility. These materials were mixed at three different ratios with three replicates each. The study was undertaking at the compost shed located within the Integrated Waste Management Facility and on the trial plot of the mines between September 2010 and April 2011. For each combination of materials, three different turning rates of 3, 7 and 14 days were assigned, and some physical and chemical as well as some biological parameters were monitored and measured for a period of three months. There was no significant difference in the quality of the final compost produced from the various formulations in terms of most of the parameters measured. The turning frequency also showed no significant difference between the various formulations. Analysis of heavy metals in the final composts showed metal levels that were far less than the US EPA standards. Helminth eggs, total and faecal coliforms decreased appreciably at the end of the composting process. The different composts applied on a trial plot produced tomato yield that was lower than that of a chemical fertilizer but higher than that of a soil without any amendment. The yield from the soil amended with the compost from the ratio 4:4:0:1 gave the highest yield among the different formulations. Even though the compost gave a slightly lower yield than a chemical fertilizer, co-composting offers a good alternative to the use of chemical fertilizers.

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CHAPTER ONE

1.0 INTRODUCTION

The poor management of solid waste in major cities of developing countries, and its subsequent effects on the environment and human health is a source of principal concern. Not only does this phenomenon constitute an environmental eye-sore, but it is also a major threat to public health and the overall quality of life. To be able to improve the environmental quality, in order to safe guard public health, there is the need for capacity building to produce a critical mass of expertise in solid waste management (Obeng, 1992).

Problems of waste management have existed ever since humans made the transition from hunting and gathering societies to settled communities. In early reference to problems associated with waste generated by humans, the primary concern seems to have been with the nuisance factor and its potential impact on health. Wastes close at hand were unsightly, filthy and foul smelling, thereby bringing discomfort and inconvenience (Brinton, 2000). Technological innovations have now brought in constructed houses designed to remove garbage and human wastes from immediate presence of the household. These human waste and other types of waste can then be converted to other valuable products for the benefit of mankind and for ecosystem sustainability (Grebus *et al*., 1994).

1.1 Problem statement

As part of Newmont Ghana Gold Limited (NGGL) Ahafo operations environmental management system, an integrated waste management system (IWMS) has been adopted. This management system seeks to prevent and minimise waste through reuse and recycling. It has therefore been proposed that organic waste materials from the kitchen, dewatered sewage sludge from the sewage treatment plant, waste paper and all forms of wood waste (e.g. sawdust) be utilised in composting to produce compost for Newmont's Sustainable Agricultural Livelihood Program (NSALP) and also for land reclamation. This will allow NGGL to improve on its IWMS and comply with international environmental standards. Composting at the Ahafo Mine Site started some few years back with only the dewatered sludge and sawdust without any appropriate mix ratios and proper treatment and monitoring. The idea of composting with dewatered sludge and sawdust only seems insufficient since other forms of waste (food waste and waste papers) are also generated at the mine site which can also aid in composting. Hence the idea to conduct a study on the above mentioned waste on how best they can aid in composting and make appropriate recommendations to NGGL management on the smooth operations of the compost facility to ensure efficiency. These wastes can be combined in mixed ratios to produce the best compost for sustainable land reclamation activities.

1.2 Justification

Newmont's waste management policy is waste minimization based on the 3Rs (that is, Reduce Reuse and Recycle). The setting up of the compost is therefore aimed to find out whether the outcome of the compost will make any meaningful impact for the mines and its hosting communities. Since Newmont's operational areas are mainly farming communities, the study will go a long way to train farmers who are on Newmont's Sustainable Agricultural Livelihood Program to embark on their own backyard composting and also provide enough materials for reclamation activities. The main objective of the project is to come out with the best compost formulation which is nutrient rich and safe for land preparation and can support plant growth for sustainable land reclamation.

1.3 Objective

The main objective of this study was to produce the best compost from the solid waste material generated on the Newmont Ghana Gold Limited mine at Kenyasi in the Brong Ahafo Region.

The specific objectives were to:

a. produce compost from dewatered sewage sludge, food waste, sawdust and paper mixed at different ratios.

b. determine the quality of the prepared compost by measuring their nutrient content, pathogen numbers *(Escherichia coli* and *Salmonella spp*);

c. determine the compost life of the different formulations; and

d. determine the growth and yield of tomatoes grown on soils amended with the compost from the different formulations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Composting

Composting is the biological decomposition of biodegradable organic fraction of solid waste by microorganisms under controlled conditions to a state sufficiently stable for nuisance free storage and handling and for safe use in land preparation. Composting involves the interaction of the organic substrate with the organisms in the presence of water and oxygen to produce heat, carbon dioxide and the decomposed organic materials (Cole, 1995). In terms of the management of municipal solid waste and other biodegradable wastes, it is the large-scale centralised composting facility which is viewed as an alternative to landfill and incineration. The composting process of municipal waste involves a number of stages. The initial stage involves collection of waste as source-segregated waste by the householder (Gotaas, 1976).

2.2 Types of Composting

There are three basic types of composting, namely, vermicomposting, anaerobic composting and aerobic composting.

2.2.1 Vermicomposting

Vermicomposting or worm composting is a method of composting using red wiggler worms to process compostable materials. Moistened high carbon bedding such as shredded paper is used as a base to which the food waste or dewatered sewage sludge is added and the worms and microorganisms convert the materials to rich compost called worm castings, a nutrient and microbially rich material which can contain five times more nitrogen, seven times more phosphorus and eleven times more potassium than ordinary soil. These worms require special care and are effective between temperatures of 16 and 25°C and are sensitive to light.

2.2.2 Anaerobic Composting

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

2.2.3 Aerobic Composting

Aerobic composting is a dynamic process in which the work is done by combined activities of a wide succession of mixed bacterial, actinomycetes, fungal and other biolological populations. Since each is suited to a particular environment of relatively limited duration and each is most active in decomposition of some particular type of organic matter, the activities of one group complements those of another (Shuval *et al.,* 1997). The mixed populations parallel the complex environment afforded by the heterogeneous nature of the compostable material. Except for short periods during turning, the temperature increases steadily in proportion to the amount of biological activity until equilibrium with heat losses is reached, or the material become well stabilised. In aerobic composting, mesophilic (low temperature) bacteria are characteristically predominant in the start of the process, soon given way to thermophilic (high temperature) bacteria, which inhabits all parts of the stack where the temperature is satisfactory. Thermophilic fungi usually appear after 5 to 10 days and actinomycetes become conspicuous in the final stages when short duration, rapid composting is practiced.

2.3 Composting Processes

There are three general elements of a composting process

1. Pre-processing: this can include grinding or shredding and separation of solid inorganic waste. In case of co-composting, this pre-processing ends with the addition of sludge to other organic waste / material.
2. Composting: this is done by windrows, aerated static pile or in-vessel composting.
3. Post processing: this consists of grinding or sieving, de-stoning and other steps to prepare the compost for utilization and marketing (EWG, 1997).

Some organic materials like sewage sludge, because of their nature (high moisture content, low carbon-nitrogen ratio, etc.) are usually composted with other organic materials like sawdust, vegetables waste and papers in co-composting.

2.4 Co-composting

Co-composting is a waste treatment method in which different types of waste are treated (composted) together. Co-composting is an attractive and interesting example of integrated waste management method of resource recovery and waste disposal. Example is the composting of sewage sludge with sawdust or papers or vegetable waste or a combination of the above. Both of these waste materials can be converted into a useful product (Obeng and

Wright, 1992). Proper mixing of the materials ensures an optimum carbon-nitrogen ratio to enhance the biodegradation process.

2.5. Factors Affecting Composting

During composting, microorganisms such as bacteria and fungi break down complex organic compounds into simpler substances and produce carbon dioxide, water, minerals, and stabilized organic matter (compost). The process produces heat, which can destroy pathogens or disease-causing micro-organisms and weed seeds. Raw materials are composted fastest when conditions that encourage the growth of the micro-organisms are established and maintained.

The most important conditions include the following:

- Organic materials blended to provide the nutrients that support microbial activity and growth, including a balanced supply of carbon and nitrogen (C:N ratio)
- Sufficient oxygen to support aerobic organisms
- Moisture levels that uphold biological activity without hindering aeration
- Temperatures needed by micro-organisms (thermophilic micro-organisms) that grow best in a warm environment.

In monitoring the composting process to produce acceptable compost, temperature, moisture content and aeration (oxygen/carbon dioxide) are prime parameters to monitor on field (Epstein *et al*., 1997). Laboratory analysis of hydrogen ions concentration (pH), carbon-nitrogen ratio, organic matter, particle size, nitrogen, phosphorus, potassium, total coliform, faecal coliform and helminth egg give important indication about the initial feedstock and the quality of the final compost produced (Golueke, 1977).

2.5.1 Aeration

Oxygen is required for microbes to decompose organic waste efficiently. Some decomposition occurs in the absence of oxygen (anaerobic conditions). However, the process is slow, and foul odours may develop. Because of this, composting without oxygen is not recommended in a residential setting unless the process is conducted in a fully enclosed system (Brodie *et al.*, 2000).

According to De Bertoldi (1982), the oxygen content in the circulating air should not fall below 18% in windrows, although there are few experimental data to support this value. Geris and Regan (1990), also suggested that 30 to 36% free air space is required to achieve adequate aeration for composting in a wide variety of materials. The optimal turning frequency of compost heap varies significantly depending on the type of initial composting material used (Tiquia *et al*., 1996).]

Since aeration is critical in composting, several techniques have been developed to enhance it, thereby promoting decomposition. Basically there are three types:

1. **Windrows** – in this technique, the waste is piled in long rows and turned once or twice per week, if not daily. The turning aerates the mixture and releases excess heat. Turning also increases the releases of volatiles.

2. **Static piles** – this is similar to windrowing except that the piles are not turned. Rather, by grinding the piles on top of a grid of perforated pipes. Air is mechanically drawn or forced through the pipes using vacuum or forced air system. A negative aeration system created by a vacuum at the base of pile enables processed air to be treated before it exhaust to the atmosphere.

3. **Enclosed reactor system –** by composting within an enclosed reactor, the operation can be optimised to complete the process in as little as three days compared with as much as 30 days for windrows. It also facilitates control of volatile emissions by collecting process air in the headspace above the compost, by a diffuser system below the compost, or by exhaust system within the compost.

2.5.2 pH

Composting feedstocks have a pH which will fluctuate during the composting process. The optimal pH range for most biological reactions in composting is between 5.5 and 8.0. The initial pH of garbage, yard clippings, manure and other compostable materials is likely between 5.0 and 7.0 unless it contains ash or highly alkaline materials. If the material has begun putrefying before being received for composting, the pH will be near the lower value, since anaerobic organisms produce acids. When the initial pH is between 6.0 and 7.0, the pH of the composting material may drop a little during the first two or three days of aerobic composting, also due to formation of acids. After two to four days the pH usually begins to rise and will level off at between 8.0 and 9.0 towards the end of the process (Tiquia *et. al.*, 1996).

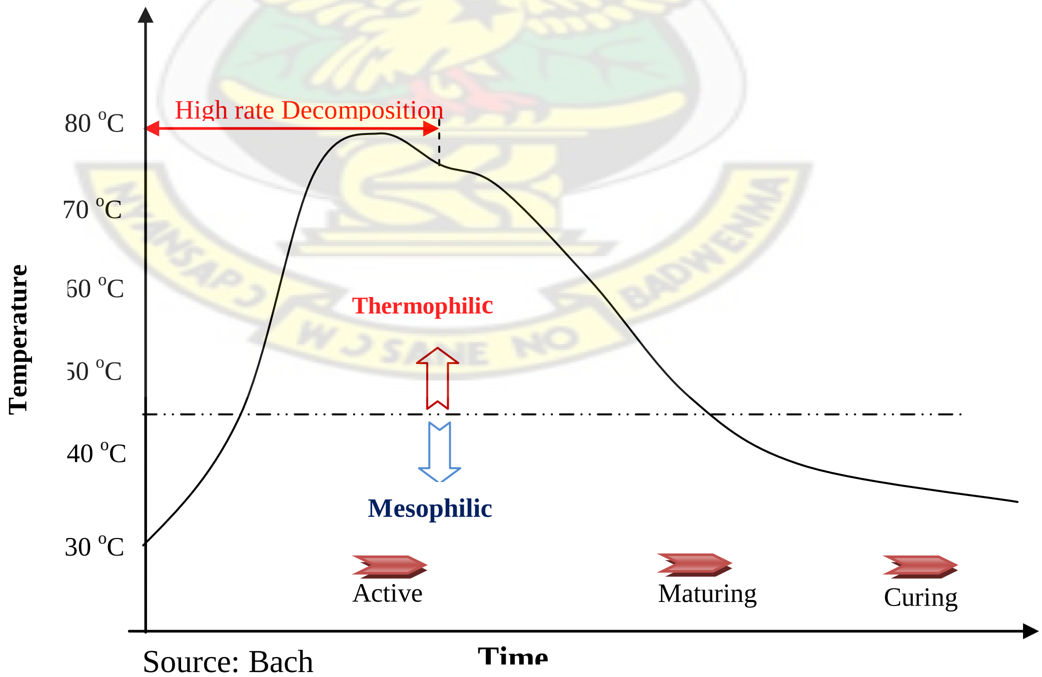
According to Poincelot *et al.* (1999), the control of pH in composting is seldom a problem requiring attention if the material is kept aerobic, but large amounts of organic acids are often produced during anaerobic decomposition on a batch basis. Ash, carbonates, lime or other alkaline substances will act as a buffer and keep the pH from becoming too low. Adding alkaline material is rarely necessary in aerobic decomposition. In fact, it may do more harm than good since the loss of nitrogen by the release of ammonia as a gas will be greater at a higher pH.

Apparently, initial pH values of 5.0 to 6.0 do not seriously retard initial biological activities since active decomposition and high temperatures develop rapidly after material is placed in the stack. Temperatures do appear to increase a little more rapidly when the pH is in the range around 7.0 and above.

2.5.3 Temperature

The composting process can be divided into four major microbiologically important phases based on temperature (Figure 1). These phases may have considerable overlap based on temperature gradients and differential temperature effects on micro-organisms. These phases are:

(i) the mesophilic phase (moderate temperature phase)
(ii) the thermophilic phase (high temperature phase)
(iii) the cooling phase
(iv) the maturation phase.



Source: Bach

Figure 1 Temperature variations during composting process

The composting process is initiated by the microbiological decomposition of organic material at the mesophilic temperature range. Upon active respiration, the temperature within the pile increases to a level which is prohibitive to mesophiles but suitable for thermophiles. This shift is also associated with a decrease in species diversity. The dominant bacteria of the thermophilic phase are spore formers (Bacillus spp.), thermophilic fungi have also been found (Strom, 1999).

Schultze (1995), demonstrated that a linear relationship exists between the rate of oxygen consumption and temperature up to 70°C in municipal refuse composting. Generally, elevated temperatures (greater than 60^{o}C) is effective in the destruction of pathogens, but lead to increasingly rapid thermal inactivation of mesophilic microorganisms. It is now generally agreed that the temperature of the composting process should not exceed 60°C to avoid rapid thermal inactivation of the desired microbial community (Bach *et al*., 1993).

In an experimental study of compost made from shredded paper and food scraps, Strom, (1999) found that only few bacterial species remained active at temperatures above 60°C; those that survived were predominantly Bacillus spp. (Table 1). Fungi were found only in the narrow temperature interval from 55 to 61°C (Table 1).

The elevated temperature range is maintained by periodic turning or the use of controlled air flow (Viel *et al.*, 1987). After the rapidly degradable components are consumed, temperatures gradually fall during the "curing"(maturation) stage. At the end of this stage, the material is no longer self-heating, and the finished compost is ready for use.

Table 1 Relative distribution of microorganisms from solid waste material during laboratory composting at five different temperature ranges

Microbial group	Temperature range (^{o}C)				
	49-55	50-57	55-61	60-65	65-69
Fungi	-	-	17	-	-
Actinomycetes	12	2	+	-	-
Bacillus spp.	23	77	78	100	83
Pseudomonas-type	17	21	-	-	-
Arthrobacter-type	47	+	+	-	-

Symbols: + present in small numbers; - not found

Source: Strom, 1999

2.5.4 Moisture Content

Moisture content of the composting pile is an important environmental variable as it provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of micro-organisms (Richards *et al*., 2002). Very low moisture content would cause early dryness of the pile during composting, which will arrest the biological process, thus giving physically stable but biologically unstable composts (Brinton, 2000). On the other hand, very high moisture may create anaerobic conditions which will prevent or slow down aerobic decomposition and produce odour (Tiquia *et al*., 1996). Moisture content between 50–60% is suitable for efficient composting. The moisture content of compost varies depending on the free air space, aeration, temperature, and other related physical factors. The degree of wetness of the compost pile could be estimated using the moisture meter or a fist full of compost can be taken with the hand and squeezed tightly. If moisture but not free water appears between the fingers, the moisture is ideal; if however, water flows out of the tightly clenched fist, it is too wet (Bokx, 2002). If the material is too dry, water must be sprinkled over the compost pile.

Moisture in this context is defined as weight loss after the sample has been dried to constant weight at 105°C for 24hrs. Bacterial metabolic activity is severely inhibited when the moisture content drops below 40%. Snell (1998), showed that oxygen uptake during composting at moisture levels below 30% was approximately 15% of that at 55% moisture. If anaerobic composting is practiced, the maximum moisture content is not as important, since oxygen maintenance is not a factor. Also if the composting procedure has initial aerobic conditions to produce high temperatures lasting a few days for the destruction of pathogenic organisms, followed by anaerobic composting, the maximum initial moisture content may be as high as 65% to 85%, depending on the character of the composting materials.

2.5.5 Carbon-Nitrogen Ratio (C/N)

Decomposition relies on many different elements, but the most important ones are nitrogen and carbon. Microbial activities are greatest when the carbon-nitrogen ratio (C/N) ratio is 30:1 (Rynk and Mullet, 1992). In other words, the ingredients in the pile should contain approximately 30 times as much carbon as nitrogen. For proper decomposition, the nutrients in the compost heap should be in the right proportions. The C/N ratio will determine how long decomposition will take. When the organisms causing decomposition do not have the proper diet of carbon, the organisms may lose nitrogen to the atmosphere as ammonia. If the initial carbon portion is too high in the compost heap, the process will be considerably slower and very inefficient. Materials can be blended and mixed to achieve a suitable C/N ratio. Below is a table that gives estimate of the C/N ratios of some compost ingredients. (The higher the number, the higher the carbon content and the longer the breakdown time).

Table 2 Approximate C/N ratios of some compostable materials

Material	**(C:N)**
Sewage sludge	6:1 – 16:1
Sawdust	442:1
Wood chips	700:1
Straw	80:1
Food waste	15:1
Vegetable waste	12:1
Fruit waste	35:1
Newsprint (paper)	398:1 – 852:1
Corrugated cardboard	563:1
Rotted manure	20:1

Source: Cole, 1995

2.5.6 Particle Size

Decomposition occurs primarily on or near the surfaces of particles, where oxygen diffusion into the aqueous films covering the particle is adequate for aerobic metabolism, and the substrate itself is readily accessible to microorganisms and their extracellular enzymes. Small particles have more surface area per unit mass or volume than large particles, so if aeration is adequate, small particles will degrade more quickly.

Experiments have shown that the process of grinding compost materials can increase the decomposition rate by a factor of two. They again recommend a particle size of 1.3 to 7.6 cm (0.5 to 2 inches), with the lower end of this scale suitable for forced aeration or continuously mixed systems, and the upper end for windrow and other passively aerated systems. The smaller the size of the organic refuse particle, the more quickly it can be consumed by the microbes. Particle size also affects the availability of carbon and nitrogen. Large wood chips, for example, provide a good bulking agent that helps to ensure aeration through the pile, but they provide less available carbon per mass than they would in the form of wood shavings or sawdust.

2.6 Organisms Involved in Composting

Compostable materials normally contain a large number of many different types of bacteria, fungi, moulds and other living organisms. Research by Gotaas (1976) and Dindal (1971) have indicated that no supplementary inoculum is needed in a compost pile. More species of bacteria are involved in aerobic decomposition than anaerobic putrefaction. Many of the same organisms are no doubt as active in anaerobic composting such as sludge digestion. However, since environmental conditions of aerobic compost stacks, particularly moisture and nutritional materials differs greatly from that of sludge digestion tanks, the biological population is also expected to differ. Although many types of organisms are required to decompose different materials, the necessary variety is usually present and organisms thrive when environmental conditions are satisfactory. Some of the many species will multiply rapidly at first but will dwindle as the environment changes and other organisms are also able to thrive. Temperature and changes in the available food supply probably exert the greatest influence in determining the species of organisms comprising the population at any one time.

Soil invertebrates such as termites, worms, ants, etc. also have been reported as colonizing compost pile and contributing to the decomposition process. (Dindal, 1971).

Aerobic composting is a dynamic process in which the work is done by combined activities of a wide succession of mixed bacteria, actinomycetes, fungal and other biological populations. Since each is suited to a particular environment of relatively limited duration and each is most active in decomposition of some particular type of organic matter, the activities of one group complements those of another (Cole, 1995). The mixed populations parallel the complex environments afforded by the heterogeneous nature of the compostable material. Bacteria, actinomycetes and fungi are the most active microorganisms in aerobic composting (Gupta *et al.*, 1987). Mesophilic bacteria are characteristically predominant in the start of the process, soon given way to thermophilic bacteria which inhabits all parts of the stack where the temperature is satisfactory. Thermophilic fungi usually appear after 5 to 10 days and actinomycetes become conspicuous in the final stages when short duration, rapid composting is practiced (Finstein, 1975).

Table 3 Microbial Populations in Soil and Mature Yard Trimmings Compost

Material	**Bacteria**	**Fungi**
Fertile soil a	6 to 46	9 to 46
Recently reclaimed soil b	19 to 170	8 to 97
Mixture of silt and clay c	19	6
Mature compost d	417	155

Source: Cole, 1995

2.7 Compost odour

Odour is generally the most serious complaint from neighbours of compost facilities (Cole, 1995). The first and most important task is for the operator to determine what problematic odours are present and where they are being generated. Compost that is properly made under aerobic conditions will have an earthy aroma that is not offensive. However, partly decomposed feedstocks can generate problematic odours including ammonia, hydrogen sulphide (rotten egg smell), and volatile fatty acids (VFAs) (Dindall, 1971). While determining that there is an odour may seem simple, identifying the source and cause of odour at compost facility can be complex. It is essential to determine whether odours are generated by piles of incoming material that have not yet been incorporated or from a specific compost pile.

An ammonia smell is usually generated in a compost pile that contains too much nitrogen-rich material such as fresh grass. Ammonia can also be generated when carbon has been supplied to the piles in particles that are too large. An ammonia odour can also sometimes indicate a pH level that is too high. A smell of hydrogen sulphide (rotten egg) indicates that anaerobic conditions are present within the compost pile. This is either because the material is too wet or there is insufficient aeration. The occurrence of VFAs also indicates that anaerobic conditions are present within the compost pile.

2.8.0 Importance of Compost

Properly decomposed compost has a number of uses and advantages in agriculture. Compost provides economic and efficient ways to recycle organic matter.

2.8.1 Soil Amendment

Compost is used as an organic amendment to improve physical, chemical and biological properties in the soil. Adding compost will increase the moisture holding capacities of sandy soils, thereby reducing drought damage to plants. When added to heavy clay soils, it improves drainage and aeration and reduces watterlogging damage to plants. Compost increases the ability of the soil to hold and release essential nutrients. The activities of earthworms and soil microorganisms beneficial to plant growth are promoted with compost conditions (Gupta *et al*., 1987). Other benefits of adding compost includes improving seedlings emergence and water infiltration due to a reduction in soil crusting. Over time, regular addition of compost creates a desirable soil structure, making the soil mulch easier to work.

2.8.2 Prevention of Heavy Metals from Leaching

The composting process has also been shown to bind heavy metals and prevent them from migrating to water sources or being absorbed by plants (Barker and Bryson, 2002).

2.8.3 Mulch

Mulches used in agricultural lands suppress weeds, reduce soil erosion and modify the soil temperature. The soil environment beneath the mulch is favourable for promoting earthworms, which in turn are valuable for promoting aeration (Carter and Stewart, 1996).

2.9.0 Compostable Materials

Organic refuse materials such as leaves, grass clippings, straw and non-woody plant trimmings, and kitchen waste such as vegetable peelings, coffee grounds and eggshells are very suitable for compost formation (Brinton, 2000). Sawdust may be added in moderate amounts if additional nitrogen is applied. Approximately one pound of actual nitrogen is required for the breakdown of 100 pounds of actual sawdust (Grebus *et al.*, 1994). Wood ashes act as a lime source and if used, should be added only in small amounts. Ordinary waste paper can be composted; however, the nitrogen content is low and will consequently slow down the rate of decomposition. If paper is composted, it should not be more than 10% of the total weight of the material in the compost pile. Other organic materials used to add nutrients to the pile are blood and bone meal, livestock manure and lake plants. However, because of health hazards and nuisance, certain organic materials such as human or pet faeces, meat, bones, grease, whole eggs and daily products should not be used to make compost.

2.10 Paper Products

Papers can be added to compost heap, but in any quantity it should go for recycling into more paper. Cardboard, paper towels and other paper items can be scrunched up and composted. They are particularly useful where kitchen scraps make up a high proportion of the compost ingredients.

2.11 Sawdust and Wood Shavings

The species of tree from which sawdust and wood shavings are derived largely determines its quality and value for use in a growing media. Several sawdust, such as walnut and non-composted redwood, are known to have direct phytotoxic effects. However, the C: N of sawdust is such that it is not readily decomposed. The high cellulose and lignin content along with insufficient nitrogen supply creates depletion problems which can severely restrict plant growth.

2.12 Food Waste

Food waste is any food substances, raw or cooked, which is discarded, or required to be discarded. Food wastes are the organic residues generated by the handling, sale, and storage, preparation, cooking and serving of food. For effective and more efficient composting, it is recommended that only waste vegetables, fruits, eggshell and peels of uncooked food should be composted (Cole, 1995). The inclusion of cooked food, meat and other organic residues generates a lot of foul smelling.

2.13 Sewage Sludge

All around the world, people in rural and urban areas have been using human excreta for centuries to fertilize fields and fishponds and to maintain or replenish the soil organic fraction, i.e. the humus layer. Until today, in both agriculture and aquaculture this continues to be common. Reuse practices have led to a strong economic linkage between urban dwellers (food consumers as well as waste producers), and urban farmers (waste recyclers and food producers). Chinese peri-urban vegetable farmers have reported that customers prefer excreta-fertilized vegetables to chemically fertilized ones. Thus vegetables grown on excreta-conditioned soils yield higher sales prices.

Table 4 summarizes the approximate composition of the main nutrients in sewage sludge. Other trace nutrients are calcium, magnesium, sulphur, and sodium, boron, manganese, copper, molybdenum, and zinc (Webley, 1993). The substantial nitrogen (N) and phosphorus (P) concentrations in sludge are a useful fertilizer material and its organic constituents give it beneficial soil conditioning properties. Sludge application on land improves the nutrient status, organic matter content, and water-holding capacity of the soil (Snell, 1998).

The organic matter in sludge is a key component to its success as an amendment material. In general, it has been shown that the addition of sludge to agricultural land increases crop production. Epstein *et al*. (1997), reported that the increase of crop yield by sludge application often exceed that of well-managed fertilized controls.

Table 4 Approximate Nutrient Composition of Sewage Sludge

Parameter (Dry basis)	**Percentage**
Organic matter	88-97
Phosphorus	3.0-5.4
Nitrogen	5.0-7.0
Potassium	1.0-2.5
Carbon	40-55
Calcium (as CaO)	4-5

Source: Webley, 1993

2.14 Compost Quality

Gotaas (1976), lists ranges of the main constituents in final composts as reported in reviewed publications Table 5. The quality varies widely and depends on the initial mixture of the material to be composted.

Table 5 Range of Constituents in Finished Compost

Parameter (Dry basis)	**Range (% of dry matter)**
Organic matter	25-50
Carbon	8-50
Nitrogen (as N)	0.4-3.5
Phosphorus (as P_2O_5)	0.3-3.5
Potassium (as K_2O)	0.5-1.8

Source: Gotaas, 1976

2.15 Determining when Active Composting is finished

The understanding of organic matter transformation throughout the composting process and proper evaluation of compost stability and maturity are essential for successful utilization of composts. Stability refers to the level of biological activity of the compost and is dependent on the degree of degradation achieved during the composting process. Maturity refers to a lack of phytotoxicity when compost is used as a soil conditioner on vegetation (Poincelot *et al.,* 1999). Immature compost, when applied to soils, maintains high decomposition activity, which may retard plant growth due to nitrogen starvation, anaerobic conditions and phytotoxicity of ammonia and some organic acids (Geris and Regan, 1990). Therefore, compost maturity and stability are key factors during application of composting process.

The point at which the active composting stage should be stopped depends on the ultimate use of the compost, on how soon it will be used, and also on the available space at the compost site (Grebus *et al.*, 1994). These factors determine how stable the compost must be before it is used or cured. At a minimum the decomposition must have slowed enough to allow the compost to store indefinitely without overheating or generating odours.

A sustainable drop in temperature is perhaps the most reliable indication that active composting has been completed. In windrow composting, the failure of cooled compost to reheat after turning indicates that decomposition has slowed enough for compost to be cured. In the case of forced aeration, the compost is ready for curing when the temperature remains relatively low or falls gradually.

According to Cole (1995), characteristics dark brown colour and earthy odours of composting materials are not adequate criteria to determine that composting is completed. These qualities develop relatively early in the process long before stability is reached. Immature or unfinished composts may have detrimental or phytotoxic effects if applied to cropping soils too soon. It seems prudent to accept a final temperature drop as a guide for measuring the end of active decomposition and then to cure the compost for one month or longer prior to use. Generally, some of the underlisted parameters are used to determine compost maturity:

- physical parameters: temperature, odour, colour, particle size, water and air retention capacities (Dindal, 1971),
- chemical parameters: C/N ratio in solid and water phases, cation exchange capacities, elemental concentrations, organic matter level, water-soluble organic matter and humification indexes (Cole, 1995),
- spectroscopic analysis: NMR, FTIR and fluorescence (Tiquia *et al.*, 1996),
- biochemical parameters: total and specific enzyme activity (Grebus *et al.*,1994),
- microbiological parameters: oxygen and carbon dioxide (CO_2) respirometry, bioassay responses such as: germination index and plant growth bioassays (Grebus *et al.*,1994).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The project was conducted at Newmont Ghana Gold Ltd (NGGL) Ahafo Mine Site, at the compost shed located within the Integrated Waste Management Facility (IWMF) and on the trial plot of the mines between September 2010 and April 2011. The facility has other apartments for waste management which includes but not limited to; the hazardous waste shed, the volatilization pad, the scrap yard and the electronic waste container. The IWMF is located at the southern corridor of the mine with an average wind speed of 15 m/s and an annual rainfall of 1500 mm.

3.2 Feedstock Formulation and Determination of Appropriate Operational Choices

A wide variety of raw materials, or feedstocks, may be used for composting. Most often there is a primary raw material to be composted and other materials are added. Rarely will an organic material have all of the characteristics needed for efficient composting, so other materials (amendments or bulking agents) must be blended to achieve the desired characteristics. In this case the primary raw materials to be composted are the dewatered sewage sludge and food waste. Paper and/or wood shavings were added to achieve desired characteristics of the composting material. Based on the analysis of moisture content and C/N ratio of raw materials, formulations of composting recipes were made balancing moisture and C/N ratios of the different feedstock materials. These formulations are presented in Table 6 below.

Table 6 Feedstock formulations for the composting

Formulations (by weight)	Food waste	Dewatered Sludge	Wood shavings	Waste Paper
A	1	1	1	1
B	4	4	1	0
C	4	4	0	1

Three different formulations of co-compost heaps (piles) were prepared and named A, B and C with three replicates each (A1, A2, A3; B1, B2, B3 and C1, C2, C3); totalling nine heaps. The letters A, B and C denote compost formulations of different ratios of food waste: dewatered sewage sludge: wood shavings: waste papers (Table 6). The numbers 1, 2, and 3 denote turning frequencies of 3, 7 and 14 days, respectively. For example, A1 represents a compost formulation of ratio 1:1:1:1 by weight of the compost ingredients, food waste, dewatered sewage sludge, wood shavings and waste papers with a turning period of 3 days. B2 represents a compost formulation of ratio 4:4:1:0 by weight of the compost ingredients, food waste, dewatered sewage sludge, wood shavings and waste papers with a turning period of 7 days. C3 represents a compost formulation of ratio 4:4:0:1 by weight of the compost ingredients, food waste, dewatered sewage sludge, wood shavings and waste papers with a turning period of 14 days.

Plate 1 to 4 show the various materials used in the composting.

Plate 1 Vegetables waste

Plate 2 Dewatered Sewage Sludge

Plate 3 Waste papers

Plate 4 Wood Shavings and Sawdust

Plate 5 Some of the prepared compost heaps

3.3 Preparation of Samples for Laboratory Analysis

A representative sample of each pile was taken with the help of a hand trowel and placed in sample bags right after the preparation of the piles, kept in a refrigerator and sent to the laboratory for analysis. Samples were taken again on monthly basis following the same trend until a more stable and matured compost was obtained.

3.4 Temperature Measurement

A Reotemp long-stem (24 inches) thermometer was used for the determination of daily ambient and compost temperatures. Daily temperature of each compost pile was measured at three different stratified locations. This was done by inserting the thermometer at about 20, 30 and 40 cm from the base of the compost pile. The average reading was calculated and recorded.

3.5 Measurement of Volumetric Change of Compost Piles

The rate of degradation of materials was monitored by measuring the rate of material lost (reduction of heap volume) using a calibrated rod and a measuring tape**,** the height h and the circumference c of each heap was measured as illustrated in Figure 2

$$\text{The volume of the compost heap} = \frac{\pi r^2 h}{3},$$

where

$$r = \frac{c}{2\pi}, \text{ is the radius of the heap.}$$

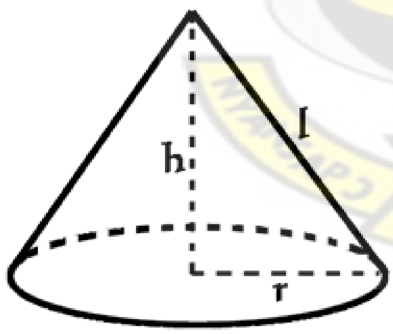


Figure 2 Schematic diagram for estimating the volume of the compost heaps

3.6 Determination of Moisture Content (MC)

The moisture content was determined by weighing representative samples of each pile using a weighing balance (W_1). The samples were then oven-dried at a temperature of 105^oC for 24 hours and reweighed (W_2). The difference in weight $(W_1 - W_2)$ represents the amount of moisture in the samples taken.

The percentage moisture content was then calculated using the formula:

$$\text{Percentage moisture content } MC = \frac{W_1 - W_2}{W_1} \times 100$$

3.7 Determination of Organic Matter (OM)

The organic matter was determined by oven drying a weighted representative sample of each pile at 105^oC for 24 hours to obtain a constant weight. The dried samples were burnt in an ignition furnace for one hour at a temperature of 550^oC. The resulting ash was then weighed to obtain the ash content (AC).

Percentage organic matter of each sample was determined using the formula:

$$\%\text{ organic matter (OM)} = \frac{(\text{weight of oven dried sample - ash content}) \times 100}{\text{weight of oven dried sample}}$$

3.8 Determination of Total Organic Carbon (TOC)

The total organic carbon (TOC) was determined from organic matter (OM) using the formula:

$$\%TOC = 0.51 \times \%OM + 0.48$$

3.9 Determination of Carbon-Nitrogen Ratio

The Carbon-Nitrogen (C/N) ratio was obtained by the relation:

$$(\mathrm{C/N})\mathrm{Ratio} = \frac{\%\mathrm{TOC}}{\%\mathrm{TN}}$$

3.10 Determination of pH

The pH was determined by using pH meter. This was done by inserting the pH meter in the compost sample at three different positions. The average reading was then calculated and recorded.

3.11 Determination of Heavy Metals and other Macro-Nutrients

The following heavy metals and macro-nutrients were determined using Atomic Absorption Spectroscopy (AAS): Nickel, Cadmium, Chromium, Mercury, Copper, Zinc Phosphorus, Potassium, Nitrogen and Magnesium. AAS is a spectro-analytical procedure for the qualitative and quantitative determination of chemical elements employing the absorption of optical radiation by free atoms. The concentrations of elements of prepared samples were assessed by promoting their electrons into a higher orbital for a short period of time by absorbing a defined quantity of energy (radiation of a given wavelength). This amount of wavelength is specific to a particular electron transition in a particular element. Each wavelength corresponds to only one element which gives the technique its elemental selectivity. The radiation then passes through a monochromator in order to separate the element specific radiation from any other radiation emitted by the radiation source which is finally measured by a detector.

3.12 Coliform and Helminth Eggs Determination

Coliform is a group of closely related bacteria that are generally harmless which can be used as an indicator of pollution. Prepared samples were allowed to pass through a filter disc of about 150 microns thick with pores of 0.45 micron diameter with 80% area perforation. All the bacteria present in the samples were retained directly on the filter surface. The membrane filter was then placed on an absorbent pad saturated with liquid nutrient medium and incubated for 24 hours. The organisms on the filter then formed colonies and were counted under a microscope. *E coli* were the most common isolated species followed by *Enterobacter agglomerans*, *Klebsella pneumonia* among others.

The specific gravities of helminth eggs within the samples were determined using sucrose density gradient centrifugation. The samples were layered over a 3 to 54% sucrose density gradient. The gradient was then centrifuged at 800 g for 20 min, allowing 5 min for acceleration and 5 for deceleration. Bands formed were identified and measured. Refractive index was measured at the middle of narrow bands, or at the level at which the concentration of eggs was highest. The specific gravity corresponding to this refractive index was taken as the number of helminth eggs present in the samples.

CHAPTER FOUR

4.0 RESULTS

4.1 Initial Analysis of Samples of Proposed Compost Ingredients

Results of the initial analysis of samples taken from the various compost Ingredients are presented in Table 7. The values of these parameters were within the range recommended by the Standards Association of Australia (1999).

Table 7 Initial parameters of the materials used for the compost formulations.

Parameter	Sawdust	Sludge	Paper	Food waste
MC (% wb)	9.6	82.1	2.9	92.6
%C (%,DM)	50.69	29.2	39.2	35.76
%N (%,DM)	0.53	5.58	0.86	1.32
C:N	442:1	16:1	398:1	15:1
OM (%,DM)	13	90	30.9	60.3
P (%,DM)	3.2	3.1	1.5	0.9
K (%,DM)	3.0	1.5	2.9	6.7
AC (%,DM)	53.03	40.20	46.50	39.90
pH	7.7	6.7	7.7	6.0
Total Coliform	0000	5000	0000	15400
Faecal Coliform	0000	5000	0000	0000

4.2 Soil Nutrient Test

Initial nutrient contents and some physicochemical parameters of soil samples taken from the test plot used for the cultivation of tomatoes are presented in Table 8.

Table 8 Initial nutrient contents and some physicochemical parameters of soil samples taken from the test plot.

Parameter	
MC (% wb)	90.3
OM (%,DM)	20.5
%C (%,DM)	30.9
%N (%,DM)	1.9
Mg (%,DM)	6.3
Ca (%,D)	3.5
P (%,DM)	5.0
K (%,DM)	7.2
AC (%,DM)	50.0
pH	6.9

4.3 Physical and Chemical parameters of the compost heaps

Table 9 shows some physicochemical parameters and nutrient contents of the various compost heaps at the start of composting while the respective values of the final compost heaps are shown in Table 10. The pH, moisture content, organic matter, carbon, nitrogen, phosphorus and potassium contents decreased consistently for all the heaps as composting progressed. However, there was an increase in ash content as the process progressed. The carbon/nitrogen ratio remained almost the same throughout the composting process.

Table 9 Concentrations of some physical and chemical parameters of the compost heaps at the beginning of composting

Parameter	Units	US Standard	Piles								
			A1	A2	A3	B1	B2	B3	C1	C2	C3
pH	-	**5.5-8.5**	7.85	7.78	7.99	8.51	8.43	8.50	8.43	8.48	8.85
Moisture content	**%, wb**	***<50***	74.88	76.38	73.74	78.17	75.72	77.97	72.09	77.60	77.62
Ash Content	**%,DM**	-	42.62	45.57	44.71	40.90	40.71	45.15	39.33	38.00	43.33
Organic Matter	**%,DM**	***≥30***	60.38	51.00	54.19	59.07	53.18	57.40	61.67	58.79	57.70
Total Carbon	**%,DM**	-	28.14	30.68	29.00	29.18	27.05	30.30	28.30	28.82	27.10
Total Nitrogen	**%,DM**	***>0.5***	1.84	1.91	1.99	2.94	3.00	2.98	2.23	3.00	3.05
Carbon/Nitrogen	**-**	***10-20***	12.96	15.43	13.35	18.57	14.46	17.85	11.32	10 .91	12.58
Phosphorus	**%,DM**	-	1.85	1.63	1.88	1.90	1.27	1.88	1.93	1.80	1.88
Potassium	**%,DM**	-	0.55	0.53	0.39	0.55	0.66	0.69	0.52	0.60	0.59
Magnesium	**%DM**	-	0.12	0.08	0.08	0.15	0.14	0.08	0.09	0.10	0.08
Nickel	**Mg/kg**	***420***	10.45	19.25	13.20	11.33	14.85	10.70	16.80	15.80	17.60
Cadmium	**Mg/kg**	***35***	1.40	1.25	1.10	1.40	1.30	1.10	1.20	1.40	1.15
Chromium	**Mg/kg**	***1200***	35.40	96.75	58.10	44.75	38.65	35.00	66.35	13.85	77.05
Mercury	**Mg/kg**	***17***	2.70	2.95	2.15	3.20	1.90	3.40	3.15	3.35	3.45
Copper	**Mg/kg**	***1500***	23.60	23.80	26.50	26.15	25.70	22.70	24.10	30.60	45.70
Zinc	**Mg/kg**	***2800***	69.65	43.75	54.95	95.75	78.45	57.60	71.55	82.50	65.75
Lead	**Mg/kg**	***300***	7.40	21.60	16.50	20.90	21.60	19.95	21.70	17.40	18.85

Table 10 Concentrations of some physical and chemical parameters of the final compost heaps

Parameter	Units	US Standard	Piles								
			A1	A2	A3	B1	B2	B3	C1	C2	C3
pH	**-**	**5.5-8.5**	6.21	6.35	6.30	6.51	6.48	6.50	6.55	6.55	6.52
Moisture content	**%, wb**	***<50***	54.88	56.38	53.74	58.17	55.72	57.97	52.09	47.60	47.02
Ash Content	**%,DM**	**-**	51.62	58.91	54.71	50.93	49.71	51.25	48.33	46.03	50.37
Organic Matter	**%,DM**	***≥30***	42.30	43.09	41.95	45.00	40.26	44.61	42.67	43.79	44.50
Dry Matter	**%, wb**	***>50***	45.12	47.62	46.26	41.83	44.28	42.03	47.91	53.40	42.38
Total Carbon	**%,DM**	-	23.14	25.68	26.56	24.88	24.30	25.24	21.30	25 .80	23.20
Total Nitrogen	**%,DM**	***>0.5***	0.32	0.58	0.50	0.88	0.98	0.63	0.88	0.98	0.79
Carbon/Nitrogen	**-**	***10-20***	12.15	13.80	12.00	17.57	13.46	16.01	10.21	7.91	9.96
Phosphorus	**%,DM**	-	0.85	0.63	0.88	1.09	0.87	0.88	0.93	1.00	0.88
Potassium	**%,DM**	-	0.48	0.50	0.30	0.48	0.55	0.60	0.50	0.55	0.50
Magnesium	**%,DM**	-	0.12	0.08	0.08	0.15	0.14	0.09	0.08	0.10	0.08
Nickel	**mg/kg**	**420**	10.45	19.25	13.20	11.33	14.85	10.70	16.80	15.80	17.60
Cadmium	**mg/kg**	**35**	1.40	1`.25	1.10	1.40	1.30	1.10	1.20	1.40	1.15
Chromium	**mg/kg**	**1200**	35.40	96.75	58.10	44.75	38.65	35.00	66.35	13.85	77.05
Mercury	**mg/kg**	**17**	2.70	2.95	2.15	3.20	1.90	3.40	3.15	3.35	3.45
Copper	**mg/kg**	**1500**	23.60	23.80	26.50	26.15	25.70	22.70	24.10	30.60	45.70
Zinc	**mg/kg**	**2800**	69.65	43.75	54.95	95.75	78.45	57.60	71.55	82.50	65.75
Lead	**mg/kg**	**300**	7.40	21.60	16.50	20.90	21.60	19.95	21.70	17.40	18.85

4.4 Biological Parameters of Compost Heaps

Total coliforms, faecal coliforms and helminth eggs in the various formulations at the beginning of composting are shown in Table 11.

Table 12 presents coliform counts and helminth eggs in the final compost. Helminth eggs were almost completely undetectable in all the final compost heaps. Total coliforms ranged from (4.0 – 4.85) $\times 10^4$ MPN at the start of composting (Table 11) and (1.95 – 2.92) $\times 10^4$ MPN in the final compost heaps (Table 12). Similarly, faecal coliforms were in the range of (2.2 – 4.2) $\times 10^4$ MPN at the start of composting and (0 – 1) $\times 10^4$ MPN in the final composts.

Table 11 Coliform numbers and helminth eggs in the compost heaps at the start of composting

Parameter	Unit ($\log_{10}$)	US Standard	Piles (MPN $\times 10^4$)								
			A1	A2	A3	B1	B2	B3	C1	C2	C3
Total coliform	**MPN**	-	4.27	4.49	4.29	4.85	4.59	4.11	4.67	4.00	4.51
Faecal Coliform	**MPN**	3.00	3.90	3.80	4.20	2.40	2.70	3.50	2.20	2.60	2.89
Helminth eggs			2.00	2.00	1.50	1.00	1.00	2.00	1.50	1.00	2.00

Table 12 Coliform numbers and helminth eggs in the compost heaps at the end of composting

Parameter	Unit ($\log_{10}$)	US Standard	Piles (MPN $\times 10^4$)								
			A1	A2	A3	B1	B2	B3	C1	C2	C3
Total coliform	**MPN**	-	2.27	2.89	2.29	2.50	2.75	2.20	1.95	2.00	2.00
Faecal Coliform	**MPN**	3.00	1.00	1.00	1.00	1.00	1.00	1.00	0	0	0
Helminth eggs			1.00	1.00	0	0	1.00	0	0	0	0

4.5 Analysis of Tomato Yield

Yield of tomato planted on the trial plot amended with the various mature compost formulations ranged from 0.85 kg on the plot amended with compost formulation 4:4:1:0, to 1.40 on the plot amended with a chemical fertilizer (Table 13). In terms of yield, the chemical fertilizer did better than all the amendments even though amendment C gave a yield that was close to the chemical fertilizer. The soil without any amendment (control) gave a yield of 0.75 kg, indicating a lower yield than the soil amended with the compost. The compost amended soil also did better in terms of faecal coliform numbers than the control. Faecal coliform and helminth eggs were not detected in any of the yields upon analysis. However, the control did better than the compost amended soil in terms of total coliform numbers. Nonetheless, the total coliform levels were below the recommended levels as set by compost council of Canada (30000 MPN) as being safe for human consumption.

Table 13 Tomato yield, coliform numbers and helminth eggs on tomato fruits

PARAMETER	Unit	A1	A2	A3	B1	B2	B3	C1	C2	C3	Chemical fertilizer	control
Total coliform	MPN	20000	21500	19500	17900	17000	17800	13500	13500	13800	3500	3650
Faecal coliform	MPN	00000	00000	00000	00000	00000	00000	00000	00000	00000	00000	10000
Helminth eggs		00000	00000	00000	00000	00000	00000	00000	00000	00000	00000	00000
Fresh weight(average)	Kg	1.00	0.90	0.90	1.00	0.85	1.00	1.10	1.30	1.20	1.40	0.75

4.6 Effects of turning rates on compost temperature

Compost temperatures rose rapidly in all the formulations during the first 15 days and became relatively stable till the middle of the second month (Figures 3-5).

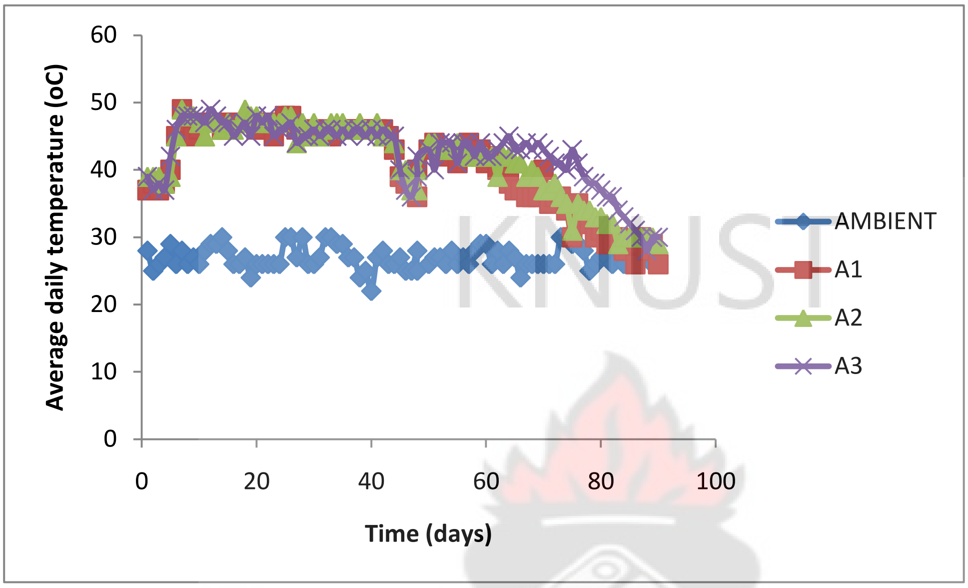


Figure 3 Variation of temperature with turning rates for the formulation ratio, food:dewatered sludge:wood shavings:paper (formulation A = 1:1:1:1)

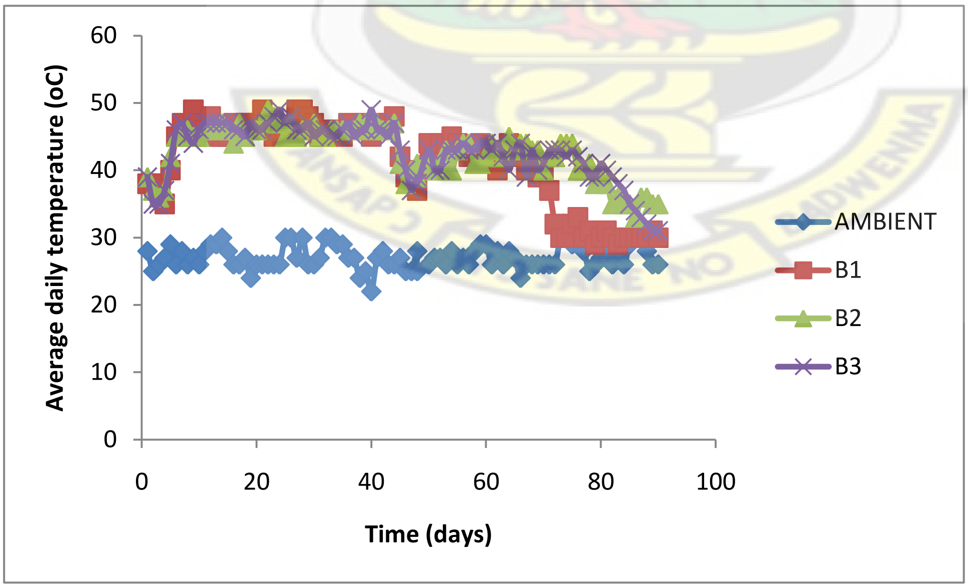


Figure 4 Variation of temperature with turning rates for the formulation ratio food:dewatered sludge:wood shavings:paper (Formulation B = 4:4:1:0)

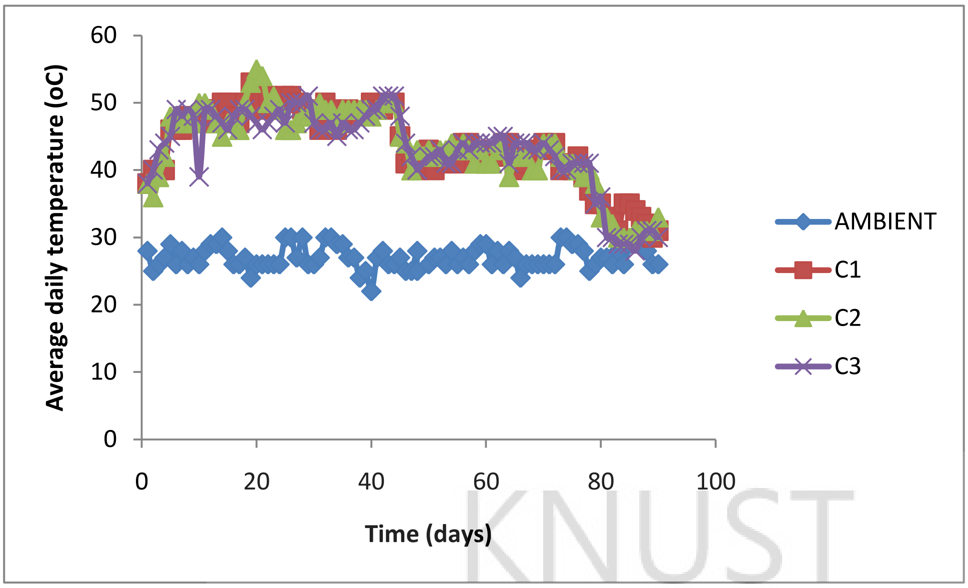


Figure 5 Variation of temperature with turning rates for the formulation ratio food:dewatered sludge:wood shavings:paper (Formulation C = 4:4:0:1)

4.7 Effects of the different formulations on compost temperature

The different compost formulations (replicates) had little effect with regards to temperature (Figures 6-8). Temperatures recorded during the first month of composting were almost the same for all the replicates irrespective of the formulation (appendix A). Temperature became relatively consistent during the second month until it started declining at the maturation stage.

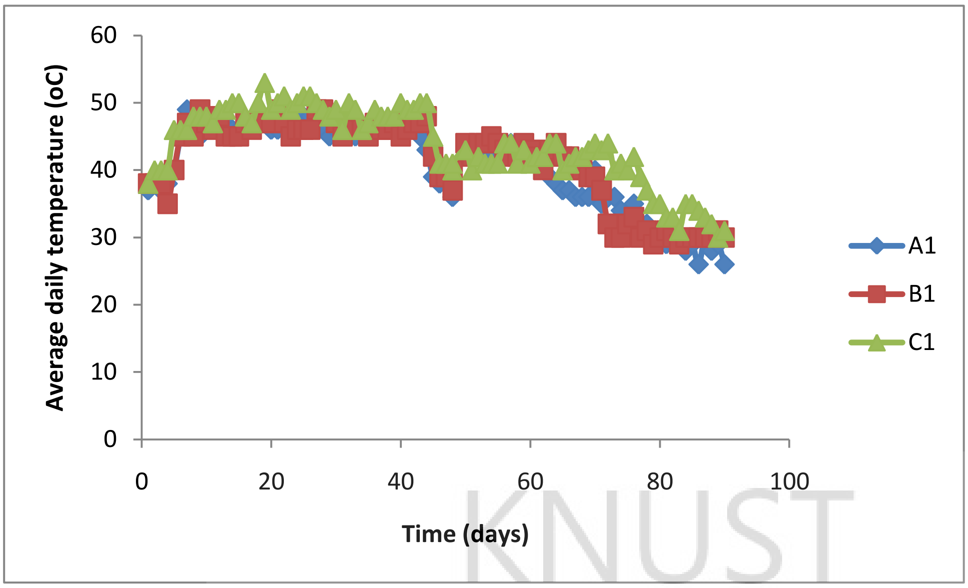


Figure 6 A comparison of temperature of the different compost formulations at 3 days turning period

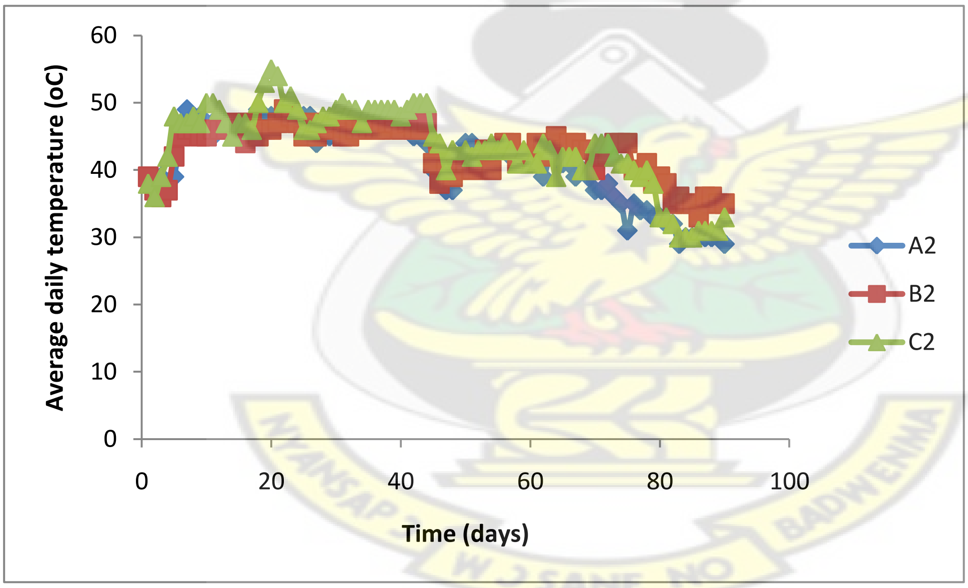


Figure 7 A comparison of temperature of the different compost formulations at 7 days turning period

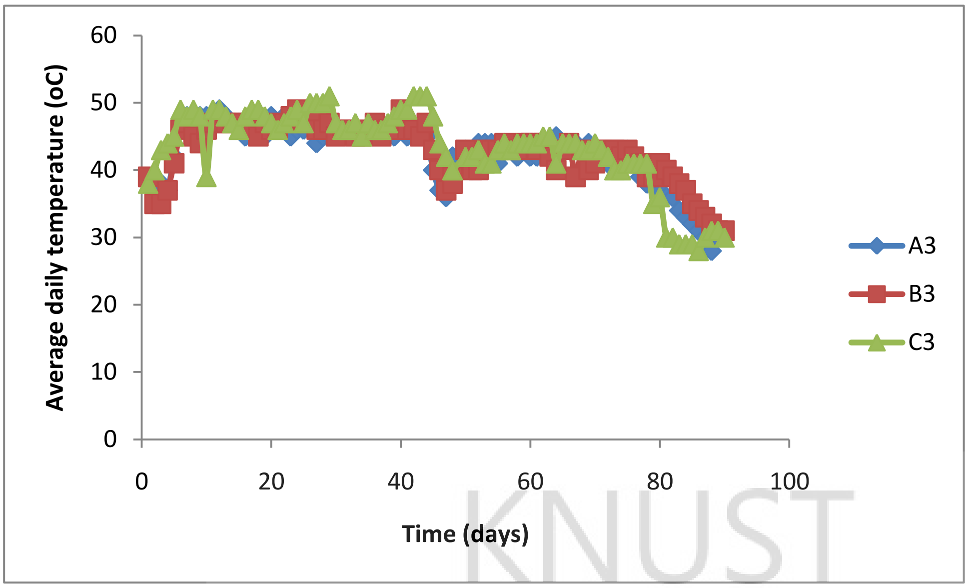


Figure 8 A comparison of temperature of the different compost formulations at 14 days turning period

4.8 Rate of degradation of compost piles

The rate of degradation of the various compost formulations at the different turning rates showed little variation between the various replicates from the beginning to the end of active composting (Figure 9-11). The rate of degradation was highest during the first month of composting for all the formulations (appendix A), but the rate got reducing as the more readily decomposable organic materials got used up.

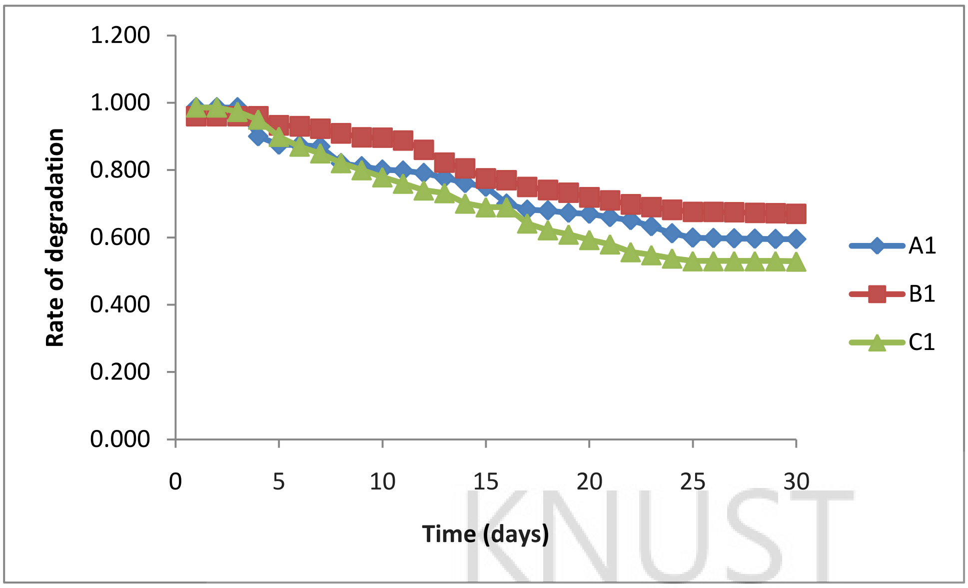


Figure 9 Rate of degradation of compost piles at three days turning period

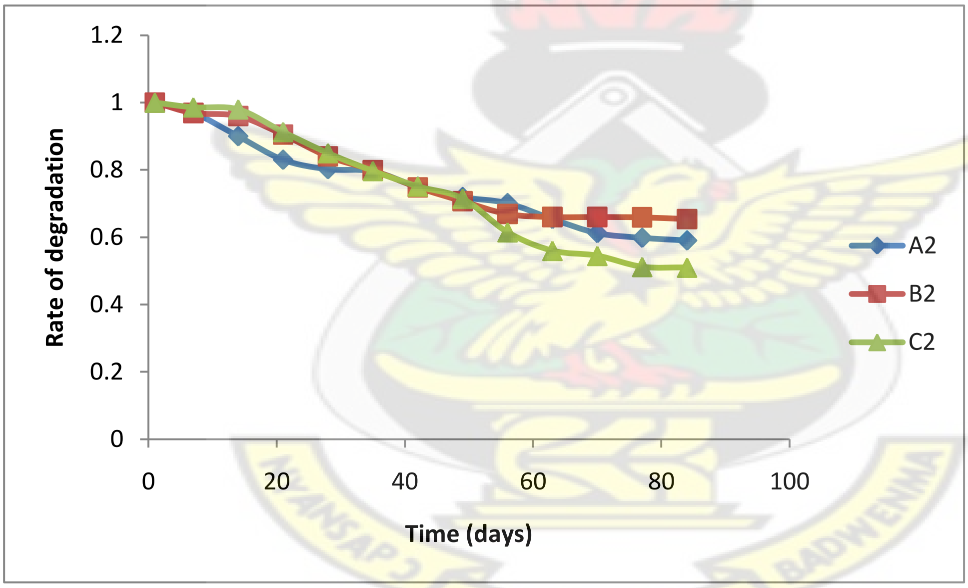


Figure 10 Rate of degradation of compost piles at seven days turning period

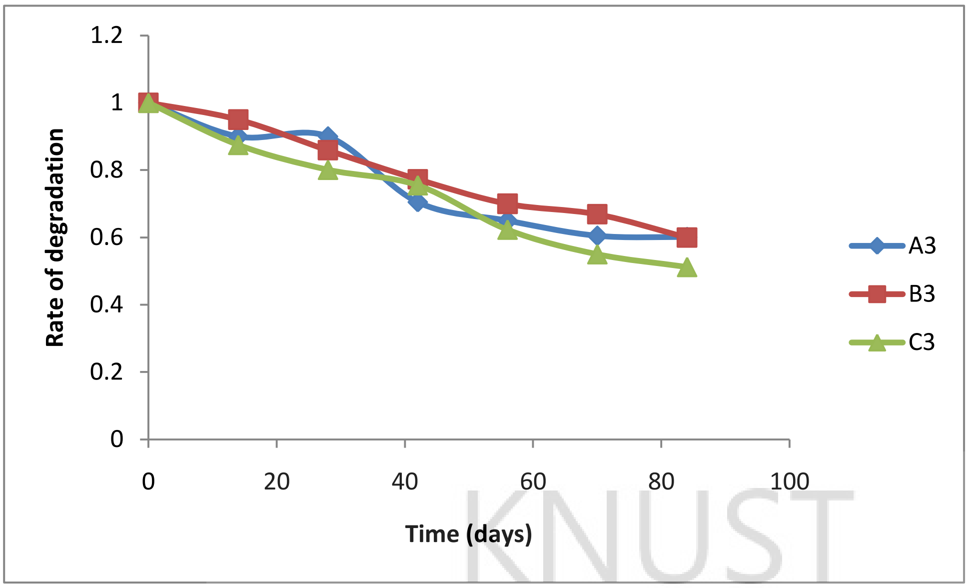


Figure 11 Rate of degradation of compost piles at fourteen days turning period

CHAPTER FIVE

5.0 DISCUSSION

5.1 Temperature

By the standard of best practice for temperature of a formulated compost pile, it is recommended that pile be managed to achieve an average temperature ≥ 65^{o}C for at least 3-7 days or ≥ 55^{o}C for at least 14 days if the system of composting is an out-door (with or without a shed) windrow system. Although none of the piles achieved a temperature ≥ 65^{o}C, almost all the piles achieved temperatures ranging between 45-55^{o}C for the first 30 days of composting. For example, in pile C2, temperature first reached 48^{o}C on day 5, and lasted above the 48^{o}C for the thermophilic phase for almost two weeks and recorded a temperature of 55^{o}C on day 20. The temperatures achieved so far are in line with the best practices in compost management. Generally, elevated temperatures (greater than 60^{o}C) are effective in the destruction of pathogens, but lead to increasingly rapid thermal inactivation of mesophilic microorganisms (Cole, 1995). It is now generally agreed that the temperature of the composting process should not exceed 60°C to avoid rapid thermal inactivation of the desired microbial community (Bach *et al*., 1993). Achieving the desired temperature of > 55^{o}C lasting for about 1-2 weeks becomes even more difficult because of the size of the piles and the cooling effect of the outdoor environment.

5.2 Heavy Metals

Analysis of heavy metals in the compost heaps showed levels far less than the USEPA standards from the beginning to the end of the composting process. This might have been due to the fact that most of the chemical elements (heavy metals) used in the process plant are all channelled to the tailings dam with little or none of the heavy metals getting into the main site or the sewage treatment plant.

5.3 Compost Volume

At the end of the three months of active composting, there were massive reductions in heap volume by more than half in all the composting heaps. This is in line with the observation by Obeng and Wright (1992) when they composted manure and attained volume reductions of more than 50%. The rate of volume reduction was highest during the first month of composting for all the formulations (appendix A), but the rate got reducing as the more readily decomposable organic materials got used up. This could be due to the fact that more energy was available to microbes involved in the decomposition at the initial stage as more carbon was readily available but the process of decomposition slowed down as the carbon began to deplete since it served as a source of energy for the microbes.

5.4 The pH

There was a slight reduction in pH after the three months of composting. The pH values remained almost the same (slightly acidic) for most of the replicates during the composting period in all the heaps owing to the high buffer capacity of the sewage sludge components. At the end of the composting, the pH range was around 6.55, 6.48, 6.35 and 6.21 in the various formulations showing a significant difference ($P < 0.05$) (appendix A). These values were within the optimal pH range for most biological reactions in composting which is between 5.5 and 8.0. In comparison, Finstein (1975) measured a pH of 6.2 in final compost of activated sludge. This implies that the pH values depended on the formulations since the results of the initial analysis of samples of compost ingredients with regards to pH showed different variations (Table 9).

5.5 Organic Matter

The organic matter content in the various heaps kept decreasing from the onset of composting to the end. Nevertheless, the rate of reduction slowed as the process progressed. Organic matter is decomposed and transformed to stable humic compounds (Finstein, 1975). The extent of organic matter decomposition at any particular time is related to the temperature at which composting takes place and the chemical composition of the organic substrate undergoing composting (Webley, 1993). The compost heaps reached their highest temperatures within the first five days of composting and maintained temperatures above 45^{o}C for almost four weeks. Decomposition was also observed to be highest at those high temperatures. The high temperatures were attained due to the presence of readily degradable carbon compounds (organic matter), most of which initially decomposed rapidly as in the case of formulation C. Thereafter, decomposition slowed because of the greater resistance of the remaining carbon compounds (lignin and cellulose) to decomposers. Generally, the higher the lignin and polyphenolic content of organic materials, the slower their decomposition (Carter and Stewart, 1996). The rate of organic matter decomposition was found to be almost the same in all the formulations and was therefore statistically not significant ($p > 0.05$, Appendix A) and implies that, the different ratios of sawdust to sludge was minute and could not exert major difference in their respective final compost.

5.6 Ash Content

The difference in ash levels in all the final compost produced was statistically not significant ($p = 0.087$, Appendix A). It was detected that, the ash content kept increasing in all the different compost heaps as the process progressed. The ash content (also called mineral matter), is a measure of non combustible component of organic matter and increases as organic matter decomposed. The increase was rapid within the first two months and decreased steadily towards the end of active composting. This was due to the high temperature attained during the first two months which resulted in the decomposition of the organic matter.

5.7 Moisture Content and Total Solids of Compost

Water was extensively utilized and there was generally, a gradual reduction in the moisture content in all the various heaps from the beginning to the end of composting. Formulation C was much reduced followed by B and A and could be as a result of moisture loss through evaporation, as temperature was slightly higher in C followed by B and then A. Finstein (1975), states that during composting of organic matter, heat is built up in the heap which is enough to vaporize moisture from the heaps and as temperature increases, more heat is lost. The mean difference in the moisture content in all the final composts produced was statistically significant ($p = 0.004$, Appendix A). This is in line with a study carried out by Richards *et al*. (2002) which indicates that, there is a gradual loss in moisture through evaporation during composting process as a result of high temperatures as water provides a medium for the transportation of dissolved nutrients required for metabolic and physiological activities of organisms.

5.8 Carbon, Nitrogen and Carbon-Nitrogen ratio

The process of decomposition of organic matter is affected by the presence of carbon and nitrogen. The total organic carbon in all piles gradually decreased over the entire composting period. The gradual decreases in total organic carbon content especially formulations A and B could be due to the high content of lignin and cellulose usually present in sawdust. The lignin and cellulose affect the degree of organic carbon loss during the decomposition process (Tiquia *et al.,* 1996). The monthly and the final reductions of organic carbon in all the heaps were statistically insignificant ($p > 0.05$). These decrease in total organic carbon concentration resulted from the oxidation of carbon to carbon dioxide by microorganisms (Tiquia *et al.*, 1996). The carbon provides both an energy source and the basic building block making up about 50 percent of the mass of microbial cells.

Nitrogen almost got lost from all the heaps during the composting process. These losses were not substantial as compared to carbon losses. This reduction could be due to the utilization of inorganic nitrogen by bacteria in the composting process and the conversion of nitrogen into bacterial proteins (Schultze, 1995). Again, nitrogen loss could be attributed to organic nitrogen (N) being mineralized (converted to nitrate-nitrogen, a form that plants use) by microbial activity during decomposition. The mineralization rate slowed as the process progressed. In addition, nitrogen could be lost through volatilization of gaseous ammonia during mixing and processing of the compost heaps. For example, nitrogen losses ranging from 9 to 68% have been reported during the composting of cattle manure (Geris and Regan, 1990). There was a significant difference ($p < 0.05$) in the nitrogen content in the final compost produced. These differences could be related to the nitrogen content of their respective mixtures before composting. This is because, the highest nitrogen content in the initial compost mixture was found in formulation C, followed by B and then A. At the end of composting, the nitrogen content followed the same trend in the composts produced.

There was also a slight decrease in the carbon-nitrogen ratio in the entire heap. A significant negative correlation between temperature and carbon-nitrogen ratio was noted during the composting process. This indicates that a large temperature increase is of crucial importance for efficient mineralization, which in turn results in reduced C/N values. This explains why C/N ratio saw the highest reduction in formulation C.

5.9 Phosphorus, Potassium and Magnesium Content in the Compost

The phosphorus, potassium and magnesium levels in the compost heaps were low and decreased gradually from the onset of composting to the end. These findings are explained by Gotaas (1976). For effective composting, phosphorus is utilized in the energy transfer process of cells and potassium, helping to regulate the osmotic pressure of cells. The differences in phosphorus, potassium and magnesium contents in the final compost produced from all the formulations were observed to be statistically insignificant ($p > 0.05$, Appendix A). According to FAO report (1975), in China, for instance, because of the low level of phosphorus in night soil compost, phosphate fertilizers are added before composting to improve the phosphorus content of the final compost.

5.10 Coliform numbers and Helminth eggs in Compost

Total and faecal coliforms decreased significantly at the end of the composting period in all the different composting heaps. Faecal coliform was almost completely undetectable in all the different compost heaps. On the other hand, total coliforms had been reduced to below the standard of less than 3.00 Log10 MPN set by the Canadian Compost Council (1999) as being ‘A class’ standard for its application in agricultural lands.

USEPA (1995) states that a temperature higher than 40^{o}C for 5 days is sufficient to reduce pathogens. In addition, lack of nutrients, caused by high population of indigenous microorganisms in manure compost or the production of compounds detrimental to coliforms may also play a role in the decline of pathogens during composting (De Bertoidi, 1982).

There was a significant reduction in the helminth eggs levels in all the different compost heaps over the composting period. Helminth eggs died-off during the co-composting process and were mainly due to the heat that was generated inside the composting heaps. Feachem (1983) gives a theoretical time-temperature relationship leading to the die-off of excreted pathogens. For example, inactivation of all ascaris eggs should take place if the temperature of the compost heaps exceeds 45^{o}C for at least 5 days and 8 days at 43^{o}C. In all the different ratios of compost heaps, temperatures attained were above 43^{o}C and got sustained over more than 8 days and ensured a drastic reduction in helminth eggs levels in all the heaps. Meanwhile, there was no complete eradication of helminth eggs in some of the heaps even though the heaps were turned regularly for all parts to reach the die-off temperature. The mean difference in helminth eggs in the final compost produced was statistically not significant (p=0.643, Appendix A).

5.11 Levels of Coliforms, Helminth eggs and the Yield of Tomatoes cultivated on compost-amended soil

The matured composts and a chemical fertilizer were applied on the soil to cultivate tomatoes on a trial plot. Tests for total coliforms, faecal coliforms and helminth eggs levels on the tomatoes upon harvesting proved to be lower than their levels in the compost before application on the soil. Faecal coliforms and helminth eggs were completely undetectable in all the tomatoes harvested. Total coliform was reduced far below the levels detected in the final compost before their application on the soil.

Tomatoes cultivated with the chemical fertilizer produced the maximum yield (fresh weight) compared to those cultivated with the various compost formulations.

A control experiment where no treatment (neither compost nor chemical fertilizer) was applied to the soil for cultivation produced a yield which was lower than those in which compost was applied (Table 13).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study showed that co-composting of dewatered sewage sludge, food waste, waste papers and sawdust/wood shavings is an effective means of reducing the pathogen in sewage sludge for agriculture use as an organic fertilizer and / or soil conditioner. However, the level of nutrients especially that of nitrogen, phosphorus and potassium produced from the different compost was found to be very low. Compost obtained this way cannot be compared with the chemical fertilizers in the market, which have been found to contain about 15% each of these nutrients. Such compost cannot therefore serve as an improved alternative to these chemical fertilizers. However, such compost has a better ability of fertilizing and conditioning the soil. Furthermore, the application of these composts has relative advantage of being environmentally friendly, if we reflect on the fact that these chemical fertilizers pollute aquifers and other subterranean water bodies by increasing the nitrite levels and thereby causing eutrophication.

There was no significant difference in the quality of compost produced, whether the compost was from formulation A, B or C in terms of the various parameters measured. However, compost from formulation C (food waste : dewatered sewage sludge : waste papers : wood shavings = 4:4:1:0) gave a higher yield than the other combinations.

Composting of dewatered sewage sludge, food waste, waste papers and sawdust has been shown to be an economical way of reducing the volume of waste since the piles were reduced by more than 50% of their original volume after the 12 weeks of composting. This method can be adopted as a means of disposing off the huge volumes of waste which is generated on the mine site on daily basis.

6.2 Recommendations

The smaller size of the initial compost volume of about one cubic metre, might have led to the highest temperature recorded to be 55^{o}C. The low level of temperature attained might have contributed to the incomplete elimination of helminth eggs from the compost. To ensure the complete eradication of helminth eggs, initial volume of compost piles for the company's operations should be set around five cubic metres and thoroughly mixed to achieve a temperature of more than 55^{o}C.

Again, due to the fact that the final compost produced showed no significant difference between the various compost formulations with regards to the various parameters tested for as well as the turning frequency and the yield after harvesting, and considering the availability of compost ingredients and labour strength, I recommend that both formulations B and C should be adhered to with either one week or two weeks turning frequency.

It is further recommended that matured compost of about 90-days should be allowed to cure (heaping to allow for dryness) for about a month before use. This would tremendously reduce faecal coliform below the 3.00 logarithmic value mark recommended by the USEPA.

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APPENDIX A1

Average daily temperatures for the various piles for the first thirty days of composting

DAYS	AMBIENT	A1	A2	A3	B1	B2	B3	C1	C2	C3
1	28	37	39	39	38	39	39	38	38	38
2	25	38	39	37	38	37	35	40	36	40
3	26	37	39	38	38	36	35	40	39	43
4	27	38	38	37	35	37	37	40	42	44
5	29	40	39	42	40	42	41	46	48	45
6	26	45	45	46	45	45	46	46	47	49
7	28	49	49	48	47	46	47	46	47	48
8	26	47	48	48	45	46	45	48	48	49
9	27	45	48	48	49	45	44	48	47	48
10	26	46	47	48	47	45	46	48	50	39
11	28	47	45	47	46	46	47	47	50	49
12	29	47	48	49	48	46	47	49	49	49
13	29	47	47	48	45	46	47	49	47	48
14	30	46	46	47	45	47	47	50	45	47

15	28	46	47	47	45	46	47	50	47	46
16	26	47	46	45	47	44	46	48	47	48
17	26	47	47	46	46	47	46	47	46	49
18	27	47	49	47	47	45	45	50	50	49
19	24	47	48	45	47	46	47	53	53	48
20	26	46	48	48	47	46	46	49	55	47
21	26	46	47	47	49	47	46	50	54	46
22	26	47	47	48	47	49	47	51	50	47
23	26	45	47	45	45	48	48	49	51	48
24	26	47	47	46	46	47	49	50	49	49
25	30	48	48	46	46	45	47	51	46	47
26	30	48	48	47	46	47	48	51	46	50
27	27	46	44	44	49	45	46	50	47	50
28	30	46	47	45	49	46	46	49	48	50
29	26	45	45	45	48	46	47	48	48	51
30	26	46	47	46	47	47	45	49	49	47

Average daily temperatures for the various piles for the second month of composting

DAYS	AMBIENT	A1	A2	A3	B1	B2	B3	C1	C2	C3
1	27	46	45	45	45	45	46	46	50	46
2	30	45	46	46	46	45	46	50	49	46
3	30	45	47	46	46	46	45	49	49	47
4	29	46	47	45	46	46	45	46	47	45
5	29	46	47	46	45	46	46	47	49	47
6	27	46	46	45	47	46	47	49	49	46
7	27	46	46	46	46	46	45	48	49	46
8	24	46	47	46	46	47	46	48	49	47
9	25	46	46	45	47	47	46	48	49	48
10	22	46	46	46	45	46	49	50	48	49
11	27	46	47	45	46	47	46	49	49	49
12	28	46	45	46	47	46	46	49	50	51
13	26	45	45	45	47	46	45	50	50	51
14	26	43	44	45	48	47	47	50	50	51

15	27	39	40	40	42	41	43	45	45	48
16	25	38	40	37	39	38	40	41	44	44
17	25	38	37	36	39	40	37	41	40	42
18	28	36	37	39	37	39	39	40	43	40
19	25	40	40	42	40	41	38	41	43	40
20	26	43	44	43	44	41	43	43	43	42
21	27	44	44	40	42	40	40	40	42	42
22	27	43	43	44	44	41	40	42	43	43
23	26	42	43	44	44	43	43	41	43	41
24	28	42	43	44	45	40	43	41	44	41
25	26	41	44	41	44	43	43	41	43	43
26	27	43	43	44	43	44	44	44	44	44
27	26	44	42	44	42	44	43	44	43	43
28	28	43	42	42	42	41	43	41	41	44
29	29	43	42	44	44	41	44	43	43	44
30	29	41	42	42	43	42	44	41	41	44

Average daily temperatures for the various piles for the third month of composting

DAYS	AMBIENT	A1	A2	A3	B1	B2	B3	C1	C2	C3
1	26	42	42	42	42	44	43	42	41	44
2	28	40	39	43	40	43	44	42	44	45
3	26	39	42	44	43	42	42	44	43	45
4	28	38	42	45	44	45	40	44	39	41
5	27	37	41	43	42	43	43	40	42	44
6	24	37	41	43	42	44	44	41	42	44
7	26	36	39	44	40	44	39	42	42	44
8	26	36	40	43	40	43	43	42	40	43
9	26	36	39	44	39	43	40	43	40	43
10	26	40	37	43	39	40	41	44	44	44
11	26	35	37	42	37	42	43	43	44	43
12	26	36	38	41	32	42	43	44	44	42
13	30	36	36	41	30	44	43	40	42	40
14	30	34	35	40	30	44	42	41	41	40
15	29	30	31	43	32	44	43	40	41	41

16	29	35	35	41	33	40	42	42	40	41
17	28	32	34	39	30	40	41	39	39	41
18	25	32	34	38	31	41	39	37	40	41
19	26	30	33	38	29	38	39	35	38	35
20	27	31	33	37	30	39	41	35	33	36
21	27	29	32	36	31	38	40	33	33	30
22	26	29	32	36	30	35	39	33	32	30
23	28	30	29	34	29	36	38	31	30	29
24	26	28	30	33	30	35	37	35	30	29
25	29	29	30	32	30	35	35	35	30	29
26	30	26	30	31	30	33	34	34	31	28
27	30	30	30	30	30	36	33	33	31	30
28	28	28	30	28	30	36	32	32	31	31
29	26	29	30	30	31	35	31	30	31	31
30	26	26	29	30	30	35	31	31	33	30

APPENDIX A2

Rate of degradation of piles with three days turning period

DAYS	A1	B1	C1
1	0.986	0.960	0.986
2	0.986	0.960	0.986
3	0.986	0.960	0.973
4	0.900	0.960	0.950
5	0.875	0.933	0.899
6	0.874	0.930	0.870
7	0.870	0.923	0.850
8	0.820	0.909	0.821
9	0.811	0.897	0.800
10	0.801	0.896	0.779
11	0.798	0.888	0.760
12	0.791	0.860	0.740
13	0.777	0.822	0.732
14	0.761	0.805	0.701

15	0.750	0.775	0.690
16	0.700	0.770	0.690
17	0.682	0.750	0.642
18	0.680	0.741	0.622
19	0.673	0.733	0.609
20	0.670	0.719	0.593
21	0.660	0.710	0.580
22	0.651	0.698	0.557
23	0.633	0.690	0.548
24	0.612	0.682	0.538
25	0.599	0.676	0.530
26	0.598	0.676	0.530
27	0.597	0.675	0.530
28	0.596	0.673	0.530
29	0.595	0.672	0.530
30	0.595	0.670	0.529

Rate of degradation of piles with one week turning period

WEEKS	A2	B2	C2
1	0.970	0.969	0.986
2	0.900	0.960	0.980
3	0.830	0.905	0.913
4	0.802	0.840	0.850
5	0.796	0.799	0.797
6	0.750	0.748	0.751
7	0.719	0.707	0.715
8	0.701	0.669	0.615
9	0.654	0.660	0.560
10	0.612	0.660	0.545
11	0.598	0.659	0.512
12	0.590	0.654	0.510

Rate of degradation of piles with two weeks turning period

WEEKS	A3	B3	C3
1	0.900	0.950	0.875
2	0.900	0.859	0.801
3	0.705	0.773	0.755
4	0.650	0.700	0.623
5	0.605	0.669	0.550
6	0.601	0.600	0.512

APPENDIX A3

A SUMMARY OF ANOVA FOR THE VARIOUS PARAMETERS

Parameter	F	P-value (α)=0.05	F-critical
PHYSICOCHEMICAL PARAMETERS OF PREPARED COMPOST HEAPS (INITIAL)			
pH	20.19808	0.002163	5.143253
Moisture content	0.885335	0.46034	5.143253
Ash Content	8.6886	0.016907	5.143253
Organic Matter	1.140847	0.380274	5.143253
Total Carbon	0.643126	0.558394	5.143253
Total Nitrogen	12.9847	0.006611	5.143253
Carbon/Nitrogen	8.853952	0.01621	5.143253
Phosphorus	0.520617	0.618739	5.143253
Potassium	3.109375	0.118406	5.143253
Nickel	1.705825	0.259093	5.143253
Cadmium	0.013158	0.986957	5.143253
Chromium	0.60709	0.575298	5.143253
Mercury	1.407805	0.31528	5.143253
Copper	1.771949	0.248471	5.143253
Zinc	1.874926	0.233056	5.143253
Lead	1.347418	0.328602	5.143253
BIOLOGICAL PARAMETERS (Coliforms and Helminth eggs) (INITIAL)			

Total coliform	0.241941	0.792407	5.143253
Faecal Coliform	10.08225	0.012059	5.143253
Helminth eggs	0.875	0.464033	5.143253
PHYSICOCHEMICAL PARAMETERS (MEDDLE)			
pH	6.885559	0.027949	5.143253
Moisture content	33.66673	0.000548	5.143253
Ash Content	6.018496	0.03681	5.143253
Organic Matter	3.705413	0.089554	5.143253
Dry Matter	1.883587	0.231818	5.143253
Total Carbon	0.961346	0.434346	5.143253
Total Nitrogen	20.33683	0.002124	5.143253
Carbon/Nitrogen	8.485781	0.017819	5.143253
Phosphorus	0.031579	0.969074	5.143253
Potassium	2.166667	0.195764	5.143253
Magnesium	2.431373	0.168514	5.143253
Nickel	1.705825	0.259093	5.143253
Cadmium	0.013158	0.986957	5.143253
Chromium	0.60709	0.575298	5.143253
Mercury	1.407805	0.31528	5.143253
Copper	1.771949	0.248471	5.143253
Zinc	1.874926	0.233056	5.143253
Lead	1.347418	0.328602	5.143253
BIOLOGICAL PARAMETERS (Coliforms and Helminth eggs) (MEDDLE)			

Total coliform	1.427532	0.311085	5.143253
Faecal Coliform	1.3125	0.336648	5.143253
Helminth eggs	1.0000	0.421875	5.143253
PHYSICOCHEMICAL PARAMETERS (FINAL)			
pH	29.68263	0.000773	5.143253
Moisture content	14.95071	0.004668	5.143253
Ash Content	3.747169	0.087902	5.143253
Organic Matter	3.982354	0.079316	5.143253
Dry Matter	1.883587	0.231818	5.143253
Total Carbon	0.858728	0.469928	5.143253
Total Nitrogen	3.136775	0.016827	5.143253
Carbon/Nitrogen	13.75319	0.005742	5.143253
Phosphorus	1.917772	0.227017	5.143253
Potassium	2.026104	0.212652	5.143253
Magnesium	2.431373	0.168514	5.143253
Nickel	1.705825	0.259093	5.143253
Cadmium	0.013158	0.986957	5.143253
Chromium	0.60709	0.575298	5.143253
Mercury	1.407805	0.31528	5.143253
Copper	1.771949	0.248471	5.143253
Zinc	1.874926	0.233056	5.143253
Lead	1.347418	0.328602	5.143253
BIOLOGICAL PARAMETERS (Coliforms and Helminth eggs) (FINAL)			

Total coliform			
Faecal Coliform	65535	?	7.708647
Helminth eggs	0.25	0.64333	7.708647

H_0: the set factors A, B and C do not interact to affect the mean values of the parameters

H_1: the set factors A, B and C do interact to affect the mean values of the parameters

A significant level of $\alpha = 0.05$ was used.

We reject H_0 and accept H_1 if $F > F_{Critical}$ from the table

NB: P- value < 0.01 implies there is overwhelming evidence to infer that the alternative hypothesis is true. We also say the test (difference) is highly significant.

P- value between 0.01-0.05 implies there is strong evidence to infer that the alternative hypothesis is true. We also say the test (difference) is deemed significant.

APPENDIX B

ANOVA FOR THE VARIOUS PARAMETERS

A	B		
10000	0		HEMINTH EGGS
10000	10000		
0	20000		

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	20000	6666.667	33333333
Column 2	3	30000	10000	1E+08

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16666667	1	16666667	0.25	0.64333	7.708647
Within Groups	2.67E+08	4	66666667			
Total	2.83E+08	5				

A	B	C	
19000	10000	12000	FAECAL COLIFORM
15000	17000	10000	
10000	20000	10000	

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	44000	14666.67	20333333
Column 2	3	47000	15666.67	26333333
Column 3	3	32000	10666.67	1333333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	42000000	2	21000000	1.3125	0.336648	5.143253
Within Groups	96000000	6	16000000			
Total	1.38E+08	8				

A	B	C	
7.4	20.9	21.7	LEAD
21.6	21.6	17.4	
16.5	19.95	18.85	

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	45.5	15.16667	51.74333
Column 2	3	62.45	20.81667	0.685833
Column 3	3	57.95	19.31667	4.785833

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	51.395	2	25.6975	1.347418	0.328602	5.143253

Within Groups	114.43	6	19.07167

A	B	C	
2.7	3.2	3.15	MERCURY
2.95	1.9	3.35	
2.15	3.4	3.45	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	7.8	2.6	0.1675
Column 2	3	8.5	2.833333	0.663333
Column 3	3	9.95	3.316667	0.023333

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.801667	2	0.400833	1.407805	0.31528	5.143253
Within Groups	1.708333	6	0.284722			
Total	2.51	8				

A	B	C	
10.45	11.33	16.8	NICKEL
19.25	14.85	15.8	
13.2	10.7	17.6	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	42.9	14.3	20.2675
Column 2	3	36.88	12.29333	5.001633
Column 3	3	50.2	16.73333	0.813333

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	29.66142	2	14.83071	1.705825	0.259093	5.143253
Within Groups	52.16493	6	8.694156			
Total	81.82636	8				

A	B	C	
0.85	1.09	0.93	PHOSPHORUS
0.63	0.87	1	
0.88	0.88	0.88	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	2.36	0.786667	0.018633
Column 2	3	2.84	0.946667	0.015433
Column 3	3	2.81	0.936667	0.003633

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between	0.0482	2	0.0241	1.917772	0.227017	5.143253

Groups			
Within Groups	0.0754	6	0.012567
Total	0.1236	8	

A	B	C	
23.14	24.88	21.3	TOTAL CARBON
25.68	24.3	25.8	
26.56	25.24	23.2	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	75.38	25.12667	3.153733
Column 2	3	74.42	24.80667	0.224933
Column 3	3	70.3	23.43333	5.103333

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.855822	2	2.427911	0.858728	0.469928	5.143253
Within Groups	16.964	6	2.827333			
Total	21.81982	8				

A	B	C	
6.21	6.51	6.55	PH
6.35	6.48	6.55	
6.3	6.5	6.52	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	18.86	6.286667	0.005033
Column 2	3	19.49	6.496667	0.000233
Column 3	3	19.62	6.54	0.0003

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.110156	2	0.055078	29.68263	0.000773	5.143253
Within Groups	0.011133	6	0.001856			
Total	0.121289	8				

A	B	C	
51.62	50.93	48.33	ASH CONTENT
58.91	49.71	46.03	
54.71	51.25	52.37	

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	165.24	55.08	13.3887
Column 2	3	151.89	50.63	0.6604
Column 3	3	146.73	48.91	10.3012

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	60.8298	2	30.4149	3.747169	0.087902	5.143253
Within Groups	48.7006	6	8.116767			
Total	109.5304	8				

A		B	C	
	23.6	26.15	24.1	COPPER
	23.8	25.7	30.6	
	26.5	22.7	45.7	

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	73.9	24.63333	2.623333
Column 2	3	74.55	24.85	3.5175
Column 3	3	100.4	33.46667	122.8033

Source of Variation	SS	Df	MS	F	P-value	F crit
	152.3217	2	76.16083	1.771949	0.248471	5.143253
Within Groups	257.8883	6	42.98139			
Total	410.21					

APPENDIX C

A Cross Section of the Tomatoes Cultivated with the various Compost