COMPOSTING OF ABATTOIR WASTE AND RIVER REED: EFFECT OF FEEDSTOCK AND AERATION MECHANISM ON PROCESS EFFICIENCY

BY

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DECLARATION

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

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ABSTRACT

Few successful composting facilities exist in Ghana and there is limited information and experience in composting abattoir waste and river reed. These wastes are deemed to be potentially suitable for composting but not much has been reported on the composting dynamics when they are composted with different amendment materials and aeration mechanisms. Therefore, this research sought to investigate opportunities that exist for composting in Ghana based on experiences of currently and previously operational composting facilities in Ghana and evaluate the effect of feedstock formulation, turning frequency, and aeration mechanisms on process efficiency and nutrient quality during windrow composting of abattoir waste and river reed. The state of composting facilities in Ghana was assessed through questionnaires and interviews with managers of such facilities. Two composting experiments were undertaken. The first one was conducted utilizing abattoir waste as the common substrate with source separated market/commercial waste, cocoa pod husk, corn cob and straw, yard trimming and sawmill wood shavings waste as other feedstock materials in the formulation of different composting piles. The second experiment was conducted to assess the effect of four aeration mechanisms on the composting process under an already existing formulated feedstock compositions using river reed (as main substrate), cocoa seed husk, poultry manure, clay soil, cow dung and banana waste. Parameters monitored in the piles include: Temperature, Moisture Content, Organic Matter, pH, Electrical Conductivity, Total Carbon and Total Nitrogen, Macro-nutrients (N, P, K, Mg and Ca) and heavy metals (Pb, Cd, Cu, Zn, Ni, and Cr). It was found that private agro-based facilities were the only operational composting facilities at the time of the study. Opportunities exist for investigating passive aeration mechanisms in some of

these facilities to reduce the cost mainly due to the use of mechanical turning equipment. Analyses of physicochemical parameters confirm that feedstock composition or turning frequency had significant effect on physicochemical parameters studied. Final C/N ratio of the abattoir waste compost ranged from 17.03 - 20.09, with no significant difference between the treatments and the interaction of feedstock and turning frequency. Organic matter degradation was influenced by both feedstock composition and turning frequency; difference in degradation data was also observed when fitted to a first or zero order kinetics, with co-efficient of correlation (r) > 0.918. Analysis on composting of river reed, however, revealed that the kinetics of degradation could be represented by a first order rate equation. Also, findings from the study suggest that compost maturity should be assessed by measuring two or more compost parameters, and that parameters of compost maturity need to satisfy the following threshold values: NH_4^+/NO_3^- ratio < 3.5, C/N ratio < 15; stable OM Loss, Temperature < 50^0C). Passive composting showed comparable characteristics with mechanically aerated systems from this study. Multi-regression equations were produced to predict nutrient (T, P, K) levels during composting using physicochemical parameters that are easy to measure.

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LIST OF ACRONYMS AND SYMBOLS

ACC	Abattoir Waste, Cocoa Pod Husk, Corn Cobs And Husks
ACS	Abattoir Waste, Cocoa Pod Husk, Sawmill Waste
AKCPP	Ashiedu Keteke Community Participation Project
AMA	Accra Metropolitan Assembly
AMYC	Abattoir Waste, Market Waste, Yard Waste, Corn Cobs And Husks
ANOVA	Analysis of Variance
AW	Abattoir Waste
BMSW	Biodegradable Municipal Solid Waste
BW	Banana Waste
C	Carbon
Ca	Calcium
Cd	Cadmium
CH_4	Methane
CM	Cow Manure
CO_2	Carbon Dioxide
Cr	Chromium
CSH	Cocoa Seed Husk
Cu	Copper
DAT	Dome Aerated Technology
DM	Dry Matter
EAWAG	Swiss Federal Institute For Environmental Science And Technology
EC	Electrical Conductivity

EU	European Union
FA	Forced Aerated
FS	Faecal Sludge
Hg	Mercury
HV	Horizontal-Vertical
H_2O	Water
IWMI	International Water Management Institute
K	Potassium
KACL	Kumasi Abattoir Company Limited
KMA	Kumasi Metropolitan Assembly
KNUST	Kwame Nkrumah University of Science And Technology
LSD	Least Significant Difference
MC	Moisture Content
Mg	Magnesium
MMDAs	Metropolitan, Municipal And District Assemblies
MSW	Municipal Solid Waste
N	Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium Ion
Ni	Nickel
NO_3^-	Nitrate Ion
N_xO	Nitrous Oxides
O_2	Oxygen
OFMSW	Organic Fraction of Municipal Solid Waste
OM/OML	Organic Matter/ Organic Matter Loss

P	Phosphorous
Pb	Lead
pH	Hydrogen Ion Concentration
PM	Poultry Manure
PPP	Private Public Partnerships
RH	Rice Husks
RR	River Reed
SANDEC	Department of Water & Sanitation in Developing Countries
SOM	Soil Organic Matter
TC	Total Carbon
TN/TKN	Total Nitrogen/Total Kjeldhal Nitrogen
TW	Turned Windrow
VREL	Volta River Estate Limited
WMD	Waste Management Department
Zn	Zinc

CHAPTER 1 : INTRODUCTION

1.1 Background and Conceptual framework

Biodegradable or organic wastes are mostly by-products of human, animal, agricultural and industrial establishments and their associated activities. Waste generated in Ghana is highly putrescent and are mostly from organic fractions of Municipal Solid Waste (OFMSW) and Agro-processing industries (agro-waste such as, cocoa pod husk, palm bunch and fibre, animal or poultry manure, slaughterhouse waste, brewing waste, etc.). Existing waste management strategies and the inappropriate management of the organic components of MSW create potential environmental problems such as; dispersal of foul odour, creating an awful aesthetics, formation of breeding grounds for most pathogenic micro-organisms, difficulties for recycling and use of vast valuable land resources for their disposal.

Biodegradable materials could be converted into valuable products such as biofertilizers, soil amendment substances and biofuels using sound proven technologies notably aerobic composting, anaerobic digestion and incineration/pyrolysis. The main available disposal methods that have been widely applied are composting, landfilling and incineration. Landfill has the potential for groundwater contamination through leaching and the release of greenhouse gases with potential consequence of global warming. It is often difficult to find suitable, stable locations for landfills. Incineration can contribute to air pollution and therefore may require expensive treatment techniques to control emissions.

Composting is one such technology widely used to aerobically convert biodegradable materials into stable, useful and saleable compost product by the action of microorganisms. Indeed, composting is viewed as a more flexible technology than co-anaerobic digestion and incineration/ pyrolysis in terms of size, time frame for planning and construction, and pay-back period for investment (Sundberg, 2005; Aye and Widjaya 2006; Danso *et al*., 2006). Ultimately, composting has the potential to reduce the import cost of inorganic fertilizers, which cannot be used as the sole source of crop nutrient supply because of the stress it unleashes on the foreign exchange reserve on the Ghanaian economy. This experience is more pronounced in developing country like Ghana, where food production is of critical national interest and soil organic matter levels are general low. Indeed, compost provides the unique soil property with adequate organic matter and plant nutrient; and has the advantage of a high water and nutrient holding capacity. Thus, compost has the capacity to reduce nutrient leaching in soil and conserving mineral fertilizer nutrients applied to agricultural soils.

Composting of highly nitrogenous or high moisture content materials, such as slaughterhouse waste, biodegradable fractions of market waste, poultry and cow dung requires appropriate amendment with bulking agent for effective composting (Lau *et al*., 1992; Haug, 1993; Paredes *et al*., 1996; Parkinson *et al*., 2004; Guardia *et al*., 2008). This ensures a suitable Carbon-Nitrogen (C/N) ratio, increases moisture absorption, increases porosity and odour control (Haug, 1993; Aye and Widjaya, 2006). Hence, determining the right combination of feedstock material is critical to achieving optimal performance of an entire composting operation with regards to the quality of the finished product. Thus, monitoring changes in indicative parameters during composting can improve the process performance, efficiency and the optimization of design parameters (Haug, 1993; Mason and Milke, 2005; Sundberg, 2005). The main controlling parameters to ensuring process efficiency are: Feedstock nutrient balance (C/N ratio), temperature, pH, moisture, oxygen content and organic matter loss.

1.2 Problem Statement

Various forms and substantial quantities of biodegradable wastes are generated in Ghana varying from farm waste, agro-processing waste, market waste, organic fractions of household waste and forestry waste; apart from faecal sludge (FS)). The quanta of these wastes have in the past attracted interest to establish composting systems to manage them. Consequently, selecting and designing an appropriate and sustainable composting technology for Metropolitan, Municipal and District Assemblies (MMDA's), Agro-processing industries and commercial farms in Ghana has become an important issue considering the high amount of waste stream ending up at landfill or dumpsites from these sources. Very few less than ten (10), composting facilities exist in Ghana, and barely operate to their designed capacity (<50% of designed capacity). Previous studies on composting in Ghana focused on MSW (Drechsel *et al.*, 2004; Asomani-Boateng & Haight, 1999; Asomani-Boateng & Furedy, 1996) and faecal sludge (Mensah *et al.*, 2003). There is a need to investigate the opportunities that exist for composting in Ghana based on the experiences of identified currently operational and previously operational plants in the country considering MSW, agriculture and industrial waste.

Abattoir waste, consisting of rumen, stomach and intestinal content, poses a disposal challenge to abattoirs in Ghana. It was estimated from the Kumasi Abattoir in 2006 that, more than 9 tonnes bulk solid/slurry waste was produced daily (from rumen, stomach and intestinal content of cattle alone). This accumulates to an annual biodegradable waste generation of more than 3200 tonnes, excluding the wastewater after processing the livestock (Rockson & Aklaku, 2006). This organic waste (solids) and other waste materials (hoofs, horns, foetus, etc) end up at the landfill sites or are indiscriminately disposed of at the plant site to decompose. The solid fraction of the abattoir waste could be subjected to composting onsite or close by the abattoir to reduce disposal cost. However, not much information on the process dynamics of composting of this feedstock has been reported. León *et al.* (2004) have reported on the stability and maturity of composting commercial slaughterhouse waste with yard waste as bulking agent on experimental basis. Evaluation is needed to assess the effect of composting of abattoir waste with locally available organic waste in order to generate the ideal conditions for the composting process and the improve quality of the final compost produced.

River reed has been a major source of trouble affecting the livelihoods of the communities living along rivers in Ghana. The Mechanical harvesting of these weeds is suggested as the preferred method of their control. Composting has been proposed as a viable method of utilizing the harvested weeds that could be beneficial to nearby farmers (Sackey & Annang, 2009). Some organizations like the Volta River Estate Limited (VREL) are already composting these weeds (van Lersel and Maas, 2002; Annang, 2008). The challenge remains on how to reduce the cost of utilizing mechanical turning equipment for aerating windrow piles and how the process dynamics affects the quality of the final product. Also, there is the challenge for rapid determination of nutrient content of compost piles to avoid huge laboratory costs and time if quality control on-farm or medium-large scale composting are to be sustainable in Ghana.

Feedstock or substrates (abattoir waste and river reed) considered are noted as one of the difficult material to compost or have very little literature reported on them. Few systematic studies have been done to compare the effects of turning frequency, aeration technology of abattoir waste and river reed on the rate of compost decomposition or the properties of finished compost. This research work examines different feedstock materials formulations and aeration mechanisms on temperature and nutrient evolution; whiles seeking to reduce the dependency of mechanical or electrical energy in the operations of composting plants.

1.3 Goal and Objectives of this research

The study aims at evaluating the effect of feedstock formulation, turning frequency, and aeration mechanisms on process efficiency (rate of decomposition, nutrient conservation or compost quality, and sanitizing potential) of windrow composting of abattoir waste and river reed respectively.

1.3.1 *Specific Objectives*

1) To evaluate effect of feedstock composition on the process efficiency of windrow composting of abattoir waste.
2) To evaluate the effect of turning frequency on the process efficiency of windrow composting of abattoir waste.
3) To evaluate the interactive effect of feedstock composition and turning frequency on the process efficiency of windrow composting of abattoir waste.
4) To evaluate the effect of aeration mechanism on physicochemical process the process efficiency of composting of river reed.
5) To evaluate the feasibility of estimating nutrient content during composting using physicochemical parameters.

1.4 Research Questions

The following research questions are addressed in this study:

a. Does feedstock formulation significantly affect the process efficiency during the windrow composting of abattoir waste?

b. Does turning frequency significantly affect the process efficiency during the windrow composting of abattoir waste?

c. Does the interactive effect of feedstock formulation and turning frequency have any significant effect on process efficiency during the windrow composting of abattoir waste?

d. Does the mechanism of aeration of river reed compost pile have any significant effect on the process efficiency?

e. To what extent can physicochemical parameters be used to estimate nutrient content of piles during composting?

1.5 Scope of Research

The research investigates effect of feedstock mixture and aeration mechanisms on composting to assess their suitability for sustainable on-farm or medium-large scale composting practices. Hence, all experimental set-ups were devised to demonstrate a pilot scale or farm scale condition. The study does not investigate the dynamics of application of compost produced to agricultural soils.

1.6 Structure of the Thesis

This thesis is organized into five Chapters. The preceding Chapter presented the background information to this research work; justifying the need to investigate feedstock, turning frequency, and aeration technology in composting under local condition. Chapter Two presents relevant literature that was reviewed to support the discussion of the evolution composting parameters and aspects related to the objectives of the study. It also defines and discusses issues on organic biodegradable MSW recovery and composting facilities in Ghana. Chapter Three describes the methods employed in data collection, treatments studied, laboratory analysis and data management. Chapter Four presents the results and discussion whilst Chapter Five presents the conclusions of the study, recommendations and suggestions for future studies.

CHAPTER 2 : LITERATURE REVIEW

2.1 Definition of Composting

Composting is defined as an aerobic microbiological decomposition of organic matter, to produce a stable, sanitized product that is beneficial to soil and plants (Haug, 1993; Gomes and Pereira, 2008). Haug (1993), on the other hand defines it as, "the biological decomposition and stabilization of organic substrate, under conditions that allow development of thermophilic temperature as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be applied to the land".

2.1.1 *The Mechanism of Composting and the Benefits of Composting*

During composting unstable organic matter and nutrient from organic or biodegradable solid waste are degraded and transformed due to the presence of oxygen, water, nutrients, and microorganism to produce a stable organic matter and nutrients; while releasing carbon dioxide (CO_2), water and heat into the atmosphere (Fig. 2.1). Thus, compost is a solid mature product resulting from composting, which is a managed process of bio-oxidation of a solid heterogeneous organic substrate including a thermophilic phase (CCC, 2008). The agricultural and environmental benefits of compost usage have received a considerable attention by several researchers. These include disease suppression (Noble and Coventry, 2005; Termorshuizen *et al*., 2006, Cayuela *et al*., 2009), adsorption and transport of heavy metals (Kaschl *et al*., 2002; DeVolder *et al*., 2003), the potential to adsorb or transform hazardous organic pollutants and persistent biological molecules (Moeller and Reeh, 2003; Löser *et al*., 2004) and increasing soil water holding capacity (Eklund, 1996; Pinamonti *et al*.,1997) have been extensively studied in literature.

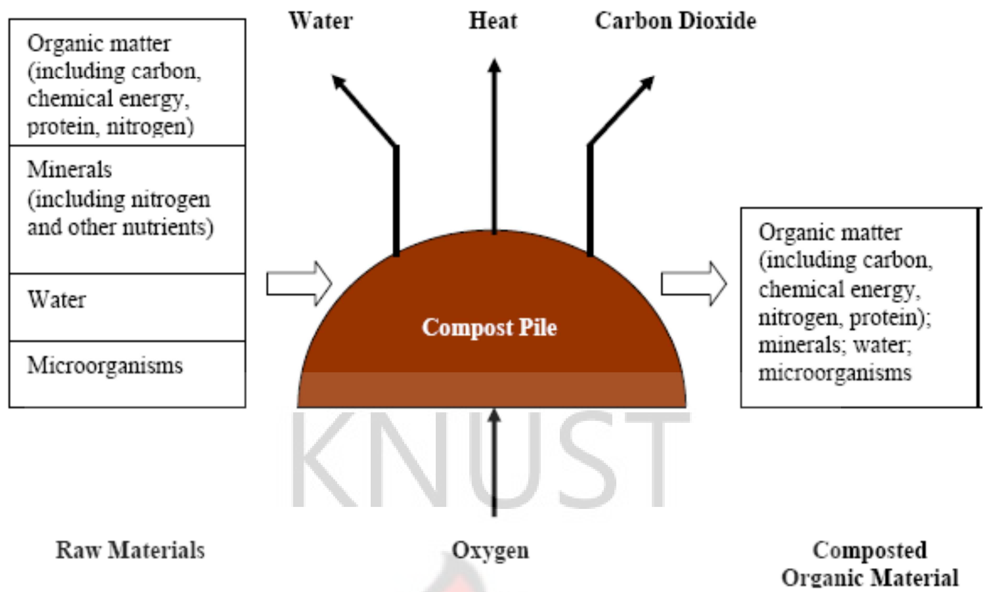


Figure 2.1: Composting process schematic diagram (from NRAES, 1992)

2.1.2 *Components of the Composting Mixture*

Prepared feedstock mixtures for composting would typically contain the following material groupings (Haug, 1993; Epstein, 1997; Mason, 2007):

a. a substrate (i.e. the material to be stabilized, mostly with a high moisture content),

b. an amendment (i.e. a partly biodegradable material used to adjust the nutrient, moisture, and/or physical structure),

c. a bulking agent (i.e. typically slow biodegradable or non-biodegradable materials are used primarily to adjust the physical structure in order to increase its porosity and to influence its water holding potential).

These materials are put together to ensure a balanced mixture with adequate moisture and oxygen supply for microbial growth and more rapidly biodegradation process.

2.1.3 ***The Phases of a Composting Process***

The composting process is divided into two main sequential phases: active and curing. The active phase is defined as a function of microbiological activity, which is measured as heat released, by oxygen uptake or carbon-dioxide production (Wu *et al*., 2000). The primary concern in industrial composting is the active phase, during which decomposition of easily biodegradable substances occurs (Seki, 2000; Sundberg, 2005; Mason, 2007). In most windrow systems, where continuous aeration is not pursued, a passive aeration phenomenon is traceable. The curing phase is when compost maturity and the decomposition and stabilization of phytotoxic organic substances produced during the active composting stage occur (Wu *et al*., 2000). The curing phase, passive in nature, produces humus (Seki, 2000).

2.1.4 ***Process Efficiency***

A measure of composting process efficiency is usually indicated by temperature phase characteristics and the organic matter loss (Keener *et al*., 1993; Liao *et al*., 1995; Ekinci *et al*., 2004; Sundberg, 2005). As explained by Sundberg (2005), the rate of organic matter turnover is a measure of compost process efficiency. This is evaluated as the measure of the mass loss of organic matter or carbon dioxide emission. The main controlled conditions to ensure process efficiency are feedstock, temperature, pH, moisture and aeration (Pace *et al*., 1995; Bueno *et al*., 2008). The moisture and aeration conditions present operational concerns in the management of composting processes. Failure to manage these can lead to the production of odour and the release of unstable leachate (Epstein, 1997; Granville and Trampel, 1997). This is resolved either by the use of bulking materials (biofilters) to adjust C/N ratio or control aeration in the pile.

2.2 Monitoring and Characterization of Composting Process

Although composting occurs naturally, efficient composting requires the control of a number of factors to avoid nuisances such as odours, leachates and dust (Sundberg, 2005; Bernal *et al*., 2009); as well as for obtaining a quality agricultural product. The composting process is influenced by a number of factors such as temperature, Moisture Content (MC), C/N ratio, carbon dioxide or oxygen concentration levels, aeration, pH value, and the physical structure of the feedstock material (Sundberg *et al*., 2004; Ekinci *et al*., 2006; Liang *et al*., 2006; Bueno *et al*., 2008; Xiujin *et al*., 2008).

2.2.1 *Temperature Characterization*

The temperature of compost is an easily measured indicator of biological activity because it changes in direct response to heat production. Temperature is considered the most important and easiest indicator of the efficiency of the composting process (NRAES, 1992; Imbeah, 1998, Yu *et al*., 2008). The optimal temperature for composting reflects a compromise between minimizing nutrient loss and maximizing the inactivation of pathogens and seeds (Larney *et al*., 2003; Cekmecelioglu *et al*., 2005; Zhang and He, 2006; Larney and Hao, 2007). Temperature can, thus, be used to assess the progress of decomposition, sanitization of the compost pathogens and thus the performance of a composting system (NRAES-54, 1992; Haug, 1993; Mason, 2007; Yu *et al*., 2008). Indeed, the temperature rise in the compost piles indicates the rate of metabolism and the extent of metabolism by the microorganisms (Haug, 1993; McKinney, 2004; Epstein, 1997).

Consequently, the process of composting is generally characterized into three main phases (Fig. 2.2): (1) the mesophilic phase (moderate temperature phase), with a duration of a couple of days or less and typically below 40 or 45^0C; (2) the thermophilic phase (high temperature phase), with duration from some, days until several months; and finally (3) a several-months cooling or maturation phase. However, thermophilic temperatures are desirable for any composting life cycle, because they destroy pathogens, weed seeds, and fly larvae in the composting manure (Haug, 1993; Jenkins, 1999; Cekmecelioglu *et al.*, 2005). Since temperature is a crucial parameter in composting, because it determines the potential termination of pathogen in compost prior to its application to soil, the evolution of this parameter requires a critical study. In general, international requirements on compost sanitization are based on a combination of temperature- time conditions that must be guaranteed (European Commission, 2001; USEPA, 1995).

In most situations the temperature of a composting pile is managed by aeration and moisture adjustment. Excessively high temperatures, however, could inhibit growth of most microorganisms, thus slowing decomposition of feedstock (Table 2.1). When the temperature rises beyond approximately 65^0C to 70^0C, the tendency is for spore formers (e.g., *Bacillus* and *Clostridium*) to convert into spores (Haug, 1993). Moreover, microbes incapable of forming spores are strongly inhibited or killed at those temperatures. Consequently, the maximum temperature should be kept at about 65^0C (Keener *et al*., 1993; Ekinci *et al*., 2004; Sundberg, 2005)

The temperature distribution within a composting mass is affected by the surrounding climatic conditions, pile dimensions and by the method of aeration (Haug, 1993; Ekinci *et al*., 2004; Mason and Milke, 2005; Sundberg, 2005). In static piles (Fig. 2.3), the highest temperatures develop at the centre of the mass and the lowest temperatures occur at the edges of the pile. Notably, temperature gradients promote a small degree of convection (i.e., natural airflow). Pichtel (2005) related the degree of air movement as a function of ambient conditions as well as porosity of the composting mass. Thus, effective temperature control in intensive degradation systems is best solved by either periodically turning (with moisture adjustment) the pile or using forced ventilation throughout the process in active composting system (Haug, 1993; Epstein, 1997; Richard *et al*., 2002; Pichtel, 2005). However, caution must be taken when turning or aerating a pile, since a desire to increase the rate of degradation may lead to a premature dryness in the pile (Nelson *et al*., 2006; Szanto *et al*., 2007).

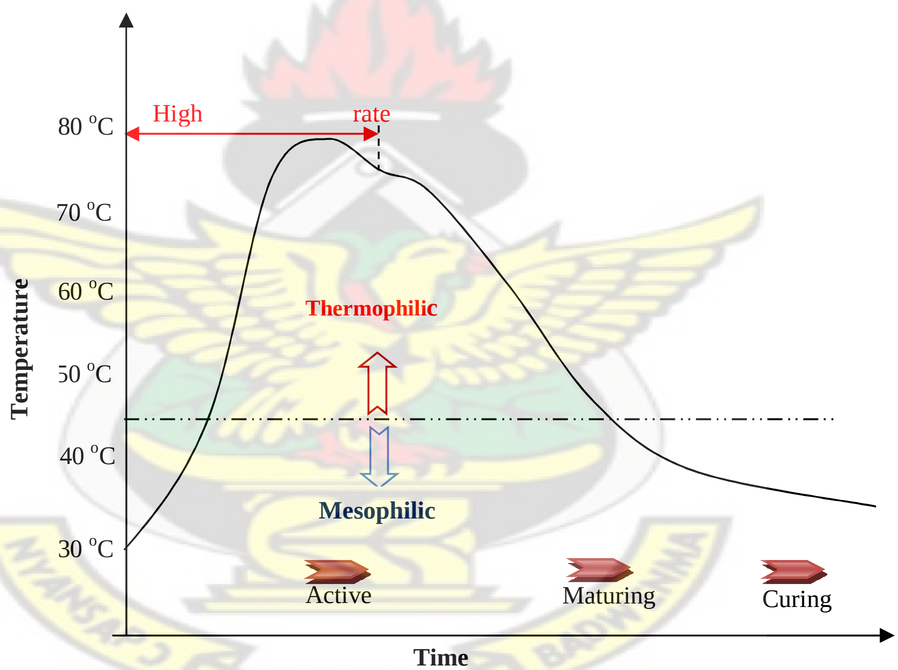


Figure 2.2: Temperature variation during composting process

Table 2.1: Temperature inactivation of pathogens in composting processes in some selected countries

Country	Temperature	Time required	Mode of Aeration	Reference
USA	>55°C	15 d	turning	Dorau, 1992;
			every 3d	Droffner *et al.*, 1995
Switzerland	>55°C	21d	-	Cekmecelioglu *et al.*, 2005; Brinton, 2000
	>60°C	7 d	-	
Denmark	>70°C	>1h	-	Tønner-Klank *et al.,* 2007
Japan	65°C	2d	In-vessel	Tateda *et al.*, 2002
EU/ Germany	>60°C	7d	In-vessel	Cekmecelioglu et al, 2005; Brinton (2000); European Commission (2001).
	>55°C	14d	Windrow (5x)	
	>65°C	7d	Windrow (2x)	

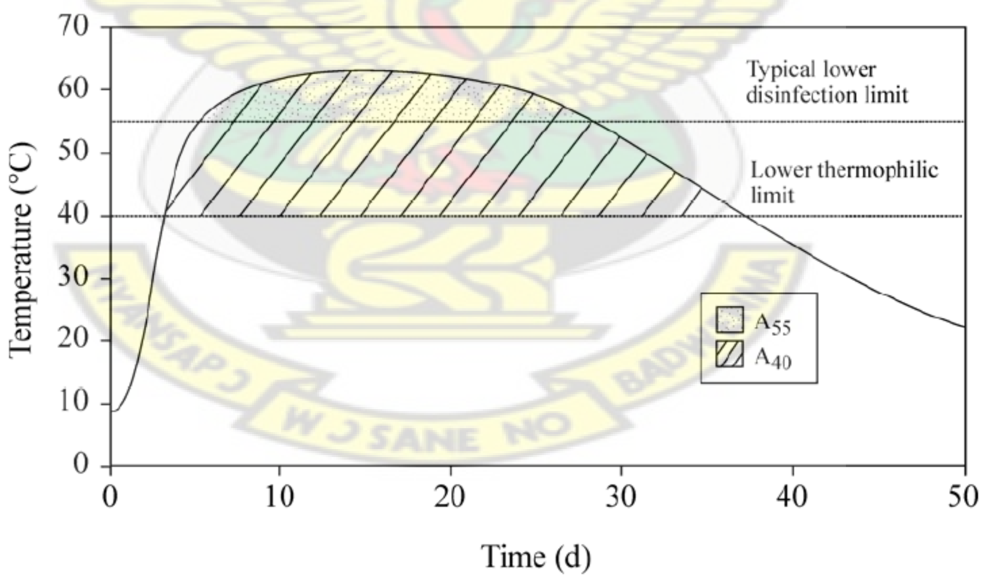


Figure 2.3: Generic composting process temperature profile

Mason (2007) proposed for the evaluation of reactor or windrow pile simulation performance, the following quantitative assessment of a temperature-time profile depicted in Fig. 2.3 and Fig. 2.4:

(i) the area bounded by the temperature curve and selected baselines (40^0C and 55^0C);

(ii) the time for which baseline temperatures are equalled or exceeded (t_{40} and t_{55}); and

(iii) the times taken to reach peak temperatures. Both 40^0C and 55^0C are useful reference temperatures, indicating the extent of thermophilic activity, and exposure of material to recommended disinfection conditions, respectively.

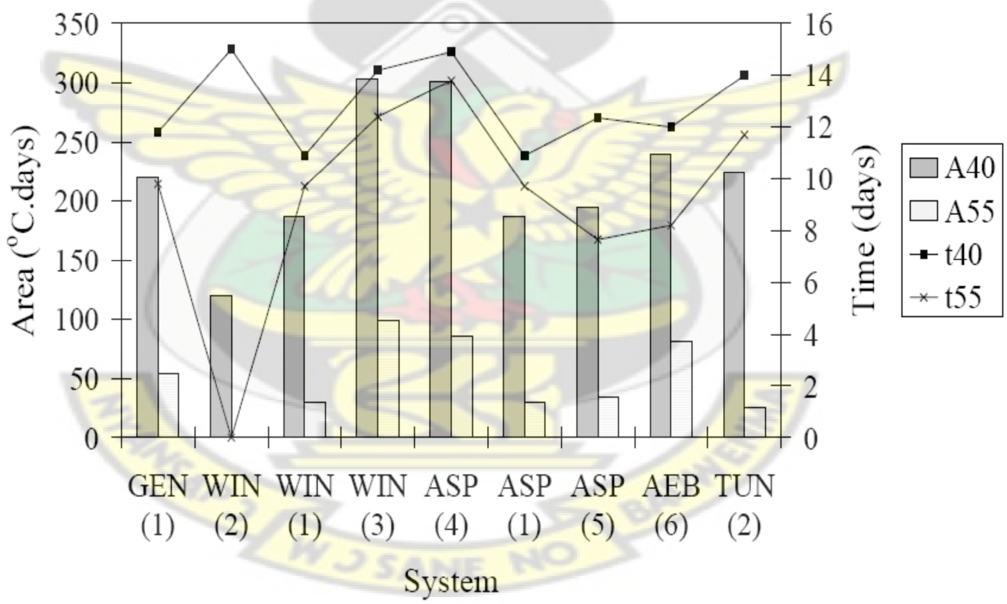


Figure 2.4: Area and time parameters for full-scale composting systems at 15 days (Mason, 2007)

Key as in found Mason (2007): GEN – generic profile; WIN - windrow; ASP – aerated static pile; AEB – aerated bin; TUN –tunnel reactor; 1 – NRAES(1992); 2 – Plana *et al*. (2001); 3 – Keener *et al*. (2001); 4 – Liao *et al*. (1995); 5 – Sundberg and Jonsson (2003)

Given identical raw material and operating conditions (e.g., moisture addition, mixing), these parameters may be used, in combination with the general shape characteristics, to evaluate the extent to which laboratory- and pilot-scale temperature data provide a good simulation of full-scale profiles. These cardinal temperatures (40^0C and 55^0C), reflect the bacterial activity as (NRAES, 1992; Sundberg, 2005; Mason, 2007; Yu *et al.*, 2008; Yu *et al.*, 2009):

i. mesophilic bacteria active: from about 10^0C to 55^0C,

ii. thermophilic bacteria: active from about 40^0C to 75^0C,

As described by Mason (2007), the temperature-time (^{0}C·days) profile analyses of composting piles enable a comparison of the scale of a set-up (in classifying set-ups as full-scale, pilot-scale or laboratory scale). It is also a measure of heat retention, which allows the piles to undergo bio-oxidation (self-heating) A_{40}, or to sanitize compost piles from pathogens (A_{55}). For a full scale windrow composting systems, areas bounded by the curve and a 40^0C baseline (A_{40}) exceeded 624 ^{0}C·days, areas bounded by the curve and a 55^0C baseline (A_{55}) exceeded 60^0C·days, and times at 40 and 55^0C were >46 days and >24 days, respectively. For forced aeration systems at full scale, values of A_{40} exceeded 224 ^{0}C·days, values of A_{55} exceeded 26^0C·days, and times at 40 and 55^0C were >14 days and >10 days, respectively. Values of these four parameters for laboratory-scale reactors were typically considerably lower than for the full-scale systems, although temperature shape characteristics were often similar to those in full-scale profiles. Laboratory-scale reactor temperatures typically returned to under 40^0 C within relatively short time periods, with lower temperature–time profile parameters than those measured for full-scale systems. Where temperatures returned to under 40^0C within the data period, A_{40} values ranged between 68 and 313 ^{0}C·days, A_{55} values between 0 and 44

$^{0}C\cdot$days, and times at 40 and 55 ^{0}C were approximately 6–16 days, and 0–7 days, respectively.

Also, Yu *et al*. (2008) proposed nonlinear mathematical model for characterising the temperature time series (Equation. 1):

$$T_i = T_0 + T_M\left(e^{-e^{-k_M\cdot(t-t_M)}}\right) + T_T\left(e^{-e^{-k_T\cdot(t-t_T)}}\right) - T_c\left(e^{-e^{-k_C\cdot(t-t_C)}}\right) \qquad \mathbf{1}$$

The first term "T_o" corresponds to the start and usually the end temperature, which is the ambient temperature; the second term "$T_M\cdot exp\{-exp(-k_M\cdot(t-t_M))\}$"describes the temperature increase by mesophilic microbial activity, where, "T_M" represents the heating potential of the mesophilic stage, "k_M" maximum mesophilic heating coefficient and "t_M" time when maximum mesophilic heating rate occurs; the third term "$T_T\cdot exp\{-exp(-k_T\cdot(t-t_T))\}$" describes the temperature increase by thermophilic microbial activity, where, "T_T" is the heating potential of the thermophilic stage, "k_T" maximum thermophilic heating coefficient and "t_T" time when maximum thermophilic heating rate occurs and the forth term "$T_C\cdot exp\{-exp(-k_C\cdot(t-t_T))\}$" represents the temperature decline during microbial decay, where, "T_C" is the cooling potential, "k_C" maximum cooling coefficient and "t_C" time when maximum cooling rate occurs. "Tc", also, represents the difference between the combined maximum temperature and the ambient temperature, indicating the magnitude of the temperature drop from the time of maximum activity to compost maturity. Temperatures are in degree Celsius, time in hours (but was worked out in days in this study) and the coefficients without units. Yu *et al*. (2008) indicated that the above statistical model could not accommodate discontinuous data such as those from compost trials that involve turning and/or re-mixing.

2.2.2 *Moisture Content (MC)*

Moisture management requires a balance between two functions: encouraging microbial activity and permitting adequate oxygen supply. The optimum range generally recommended as conducive for composting is 50–65% (NRAES, 1992; Tiquia *et al.*, 1998; Richard *et al.*, 2002; Ahn *et al.*, 2008a; Ahn *et al.*, 2008b). However, Optimum Moisture Content for biodegradation can vary widely for different compost mixtures and time in the composting process, ranging from near 50% to over 80% on wet basis (Richard *et al.*, 2002; Ahn *et al.*, 2008a). Indeed, Moisture Content of the composting pile is an important environmental variable as it provides a medium for transport of dissolved nutrients required for the metabolic and physiological activities of microorganisms (McCartney and Tingley, 1998; VanderGheynst, 2007).

Optimum MC in the composting pile increase microbial access to nutrient. If the moisture level drops below about 40 to 45 percent, the nutrients would be no longer in an aqueous medium and easily available to the microorganisms (EPA-US, 1994). Hence, expected microbial activities decrease and the composting process decelerates. Liang *et al.* (2003) reported that maximum microbial activities were provided by MC in the range of 60–70%. He further indicated that when moisture levels fell below 50% the composting process slowed; hence recommending 60% MC as optimal moisture level for biosolids composting.

Observations have been made that composting at high moisture contents can increase compaction and thus limiting oxygen diffusion into the composting matrix (Miller, 1993; Das and Keener, 1997). Hence, it is imperative to avoid high moisture content that may introduce anaerobic conditions from water logging in the pore spaces (Tiquia *et al.*, 1996). Nonetheless, successful composting has been reported for initial moisture levels well above the 40-65% wet basis range (Sartaj *et al*., 1997; Liang *et al*., 2003; Mason *et al*., 2004).

Moisture Content has a critical place in designing composting systems, especially passive aerated compost piles (Lynch and Cherry, 1995; Sylla *et al*., 2006; Ahn *et al*., 2008a; Yu *et al*., 2009). According to Ahn *et al*. (2008a) the optimum moisture content of each material occurred near its measured water holding capacity, which ranged from near 60% to over 80% (wet basis). Nakasaki *et al*. (1994) reported that composting of grass clippings with high moisture content (70% wet basis) failed, because the structure collapsed and air could not get through the compost matrix; but, however, found moisture content of 50% suitable for this type of feedstock.

Moisture and aeration conditions present operational concerns in the management of composting processes. Failure to manage these can lead to the production of odour, and the release of unstable leachate (Epstein, 1997; Granville and Trampel, 1997).

2.2.3 *pH and Electrical Conductivity*

Hydrogen ion (H^+), as pH, evolution reflects the changes in chemical composition of feedstock material during composting. The general phenomena of pH, is the observation of an initial decrease and then a rise during composting (especially with food waste). This may be explained as (Eklind and Kirchmann, 2000; Beck-Friis *et al*., 2003; Sundberg, 2005) follows:

(1) the initial microbial degradation leads to the production of intermediate organic acids (dominantly acetic and lactic acid dominate) influenced by CO_2 production, which cause the pH to decrease;

(2) the active oxic (dominantly acetic and lactic acid dominate) microorganisms consumes a large quantity of oxygen initially causing insufficient oxygen in the compost and anoxic fermentation, hence a drop in pH;

(3) the subsequent rise of the compost pH is caused by the decomposition of nitrogen-containing organic matter leading to the accumulation of NH_3 that dissolves in moisture to form alkaline NH_4^+ (Wong *et al*., 2001; Sanchez-Monedero *et al*., 2001; Sundberg *et al*., 2004); and additionally,

(4) during the composting process, the intermediate organic acids are decomposed biologically to form gaseous carbon dioxide and water. The fatty acids formed from the decomposition of fat may also further be decomposed into smaller molecular acids to evaporate.

These above phenomena can cause the compost pH to increase or decrease; but it is expected that the pH reaches a steady value near neutral (7.0) to warrant compost use for crop production. The preferred range of pH is 6.5 to 8.0 for optimum growth of microorganisms during composting process (Pace *et al*., 1995; NRAES, 1994; Sundberg, 2005; Moldes *et al*., 2007).

Electrical Conductivity (EC) measures the total soluble salts in the compost; higher EC may indicate more nutrients. However, EC higher than 4 dS/m (Lin, 2008) will adversely influence plant growth, e.g. low germination rate, withering, etc. Otherwise, compost with low EC can be used directly; while compost with high EC value must be mixed well with soil or other materials with low EC's before it can be used for growing crops (Lin, 2008). Tiquia and Tam (2002) observed EC values of between 2.40 and 3.97 dS/m in their forced aerated composting of poultry manure. Also, Zmora-Nahuma *et al*. (2007) indicated that EC values are lower (<3.5 dS/m) in woody and crop residual feedstock and higher (>4.0 dS/m) in animal and oil-plant or vegetable feedstcok in most cases; but may vary with the country of origin. Indeed, a high electrical conductivity level may reflect a high nutrient value in compost (Jones *et al*., 2009).

2.2.4 ***Carbon – Nitrogen (C/N) Ratio***

The C/N ratio represents one of the best indices to evaluate the maturity of compost (Abouelwafa *et al*., 2008). Microbial growth utilizes approximately 25-30 units of carbon for every unit of nitrogen, and so the desirable C/N ratio needed for effective composting is proposed between 20 and 40, depending on the particular organic substance (Golueke, 1991; Haug, 1993). The most important elements required for microbial decomposition are carbon and nitrogen. Carbon provides an energy source and the building material representing 50% of the microbial cell biomass. Nitrogen is a critical component of the proteins, nucleic acids, enzymes, and coenzymes necessary for cell growth and function.

The ideal C/N ratio for composting is generally considered to be around 25:1-30:1(NRAES, 1992; Haug, 1993). To obtain this optimum, ratio it is necessary to know the C/N ratio of the organic materials that will be used as compost (Table 2.2). The composting of materials with low C/N ratio result in more N losses than in high C/N ratio wastes (Sanchez-Monedero *et al*., 2001). High C/N ratios make the process very slow as there is an excess of degradable substrate for the microorganisms (Bernal *et al*., 2009); however, optimum C/N ratio will enhance the control of nitorgen losses.

Table 2.2: Carbon-to-Nitrogen ratio of some organic materials

Organic Material	C/N
Leaves and Yard waste	34–85
Straw	40-50
Sawdust	150-700
Paper	100-300
Vegetable and Food waste	20-35
Sewerage sludge	6-11
Organic fraction of solid municipal wastes	12-50
Manure	5–25
Riverweed	19-25

(NRAES, 1992; Haug, 1993)

2.2.5 *Organic Matter (OM) Loss*

The timely supply of plant nutrient is a major limiting factor for crop growth (Braimoh and Vlek, 2004), consequent of which, soil fertility depletion is the major biophysical cause of per capita food production. Loss of soil organic matter (SOM) destroys soil structure and accelerates desertification. (Braimoh and Vlek, 2004). Hence , in order to improve the food production capacity of soils in any country, especially in small-holder farms, there is the need to evolve soil management systems that are not only acceptable but also affordable (Buri *et al.*, 2005). Such management systems must also enhance the organic matter content of the soils. Composting can contribute to the achievement of this goal.

During composting organic matter is degraded with the release of principally CO_2 and H_2O into the atmosphere. A stable organic matter, at the end of the composting process may contain essential nutrient capable of improving soil structure and fertility (potential). Mineralisation of OM during composting, determined by the OM loss, generally follows a first order kinetic equation (Paredes *et al.*, 2000):

$$OML_t = OML_0(1 - e^{-kt}) \quad \textbf{2}$$

where OML_t indicates the mineralized OM (g kg^{-1} or %, DM) at time *t* (days), OML_0 the maximum mineralisable potential OM (g kg^{-1} or %, DM) and *k* the rate of mineralization or degradation (day^{-1}). Values reported by various researchers on the rate of mineralization or degradation vary from about 0.018 day^{-1} through 0.044 day^{-1} to 0.051 day^{-1} (Paredes *et al*., 2002; Benito *et al*., 2009; Larney *et al*., 2000) The maximum degradation or mineralization potential is reported to be about 39.3 - 67.1% (Larney *et al*., 2000; Benito *et al*., 2009; Paredes *et al*., 2002). However, some feedstock and their treatments may conform to a zero order kinetic equation (Paredes *et al*., 2002), where values of 0.49 day^{-1} have been reported for the slope in degradation, *op cit*. Notably, some authors have fitted the degradation of OM or organic carbon during composting using combinations of the first order or zero order kinetics (Bernal *et al*., 1998).

2.2.6 ***Other Indicators and Nutrients***

The control of Ammonium (NH_4^+) and Nitrate (NO_3^-) ion concentration during composting has been used by various authors as indicators of compost maturity over the processing time (Huang *et al*., 2004; Cegarra *et al*., 2006). During composting, NH_4^+ content in feedstock pile is either fixed in transformed lignocellulosic molecules as organic Nitrogen N (Thorn and Mikita, 1992) or oxidized to NO_3^- through nitrification (Paredes *et al*., 1996; Paredes *et al*., 2002; López *et al*., 2010). Nitrification in a mature compost sample is measured as NH_4^+/NO_3^- ratio, with a general value reported as <1.00 (Garcia *et al*., 1992; Paredes *et al*., 1996; Bernal *et al*., 1998; Ko *et al*., 2008). However, the US Composting Council and the United States Department of Agriculture (2001) proposed values between 0.5 and 3.0.

During composting gases such CO_2, CH_4, NH_3, or N_xO may evolve (Szanto, *et al*., 2007; Lin, 2008). Aerobic decomposition from well managed composting results in the emission of CO_2 and H_2O. However, emission of CH_4 may emerge in well managed or aerated piles (Szanto *et al*., 2007; Amlinger *et al*., 2008; Lin, 2008); and are oxidized eventually in the pile. Lopez-Real and Baptista (1996) report a higher significant decrease in NH_3 emissions in passively aerated static piles compared to a turned and forced aerated system. Furthermore, Pel *et al*. (1997) showed that methanotrophs are capable of NH_4 oxidation under thermophilic conditions, where CH_4 is present at the O_2-limited interfaces in the manure–straw aggregates. Non-autotrophic nitrification by methanotrophs has also been observed by others (Roy and Knowles, 1994; Szanto, *et al*., 2007).

High levels of heavy metals (e.g., Cd, Cr, Cu, Pb, Ni and Zn) in composts represent an obvious concern if they are to be applied to food crops (Déportes *et al*., 1995; Papadimitrou *et al*., 2008), and applying compost within regulated limits is critical to sustain the integrity of the soil or water ecological system. Heavy metals do not degrade throughout the composting process, even in specialized separation systems (Richard and Woodbury, 1992). These become more frequently concentrated due to the microbial degradation and loss of carbon and water from the compost (Richard, 1992). Substrates contributing the most to heavy metal concentration could be said to have high ash, fine particle size or may have undergone multiple handling process prior to their application for composting, which may cause some level of contamination in the final compost (Zhang et al, 2008). Hence, a production of clean compost commences from the feedstock raw material used (Richard and Woodbury, 1992; Haug, 1993, Veenken and Hameler, 2002).

Table 2.3: Heavy metal limits in EU and British compost regulations, $mgkg^{-1}dm$

Heavy Metals	Regulation Values	MSW Compost	Source Separation MSW Compost	Biological Waste Compost	BSI (2005) limit
Cd	1.2–4.0	4.4	1.22	0.84	1.5
Cr	50–750	90.8	34.9	35.8	100
Cu	60–1200	298.1	72.4	46.8	200
Pb	120–1200	455.0	147.4	83.1	200
Hg	0.3–25	—	—	0.38	1.0
Ni	20–400	76.3	17.5	20.5	50
Zn	200–4000	919.8	326.6	249.6	400

Sources: Day and Shaw (2001); BSI (2005)

EU limits for heavy metal in compost product have been summarized by Day and Shaw (2001) in Table 2.3. Apart from these heavy metals being present in the compost, the availability of macronutrients such as phosphorus (P), Potassium (K), Magnesium (Mg), and Calcium (Ca) is also very important to justify the final compost quality or grade.

2.2.7 *Prediction of Nutrient Content of Compost Piles using Regression Models*

Analyses of chemical parameters during composting using standard laboratory methods although accurate are expensive and takes time. Therefore, a frequent requirement of the analysis of parameters may not be practical for most on-farm composting or composting on any level. Studies have demonstrated that knowledge of a range of properties could provide useful practical estimates of nutrient concentration of compost matrix. Possible correlation between easily determined parameters like pH, electrical conductivity, density, redox potential, dry matter or chemical composition in composts could be used to estimate the nutrient content of matured compost. This method has been reported by various researchers to estimate nutrient values of manure from livestock farms.

Moral *et al.* (2005) found that EC seemed to be the most appropriate easily determined parameter for estimation of TN and TK in pig slurries. Various physicochemical properties and nutrients in livestock manure have been estimated using single or multiple linear regression equations (Yang *et al*., 2006; *Zhu et al*., 2004; Chen *et al*., 2009). Yang *et al*. (2006) reported that EC is a good indicator of the electron flow and could be used to estimate the contents of Ammonium-N and TK. Chen *et al*. (2009) and Marino *et al*. (2008), estimated macro-nutrients with EC or DM giving varied levels of goodness of fit for the linear regressions used. Other researchers were able to adapt time, temperature or chemical composition in a linear and quadratic regression to estimate nutrient or maturity in the composting pile (Tiquia and Tam, 1998; Tiquia and Tam, 2002; Larney *et al*., 2008).

Linear regression models developed in literature have also captured inconsistencies, primarily because of the variability of animal diet/feedstock, housing or management system (population of livestock, storage of manure or compost, turning/coverage; age or treatment method). Thus, results of regression analyses to predict parameters may be specific for feedstock or management system, which require more reporting from research.

2.3 **Composting Systems and Pile Structure**

Composting systems are defined by the aeration technology used or the pile containing structure (Fig. 2.5). Various studies have been conducted to explain aeration (natural, passive or active) system in composting (Haug, 1993; Sartaj *et al*., 1996; Tiquia *et al*., 1997; Tiquia and Tam, 2002; Mason *et al*., 2004; Szanto *et al*., 2007; Ruggieria *et al*., 2008). These systems could generally be categorized as opened or enclosed composting system (Table 2.4). Enclosed systems are generally marked by a short retention time; this may be followed by the aerated and turned; aerated static; turned windrow; passive aeration static pile; and the naturally aerated static piles.

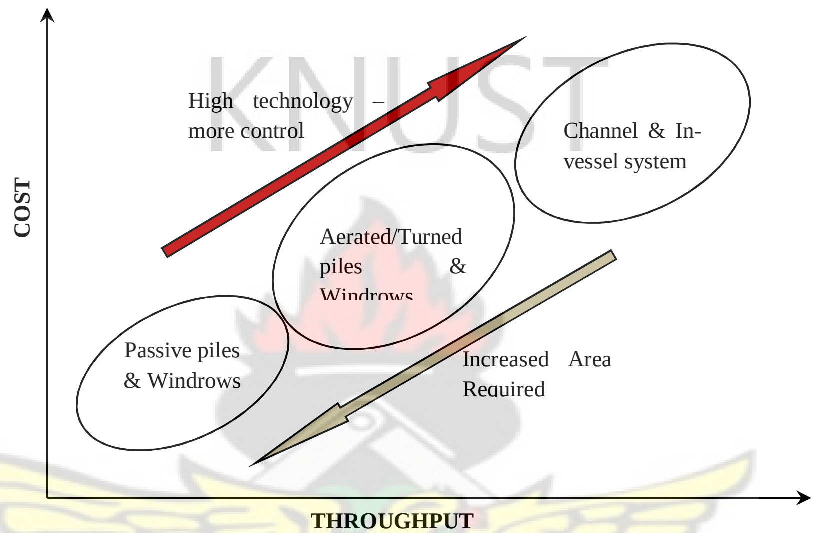


Figure 2.5: Composting technologies (Leonard, 2001)

Among all the available composting methods, open-air pile systems are the most simple and require the lowest investment (Haug, 1993). Indeed, the two most common methods of aeration are pile turning for windrows and forced air supply for static piles (Avnimelech *et al*., 2004). Aeration or turning is a key factor for composting. Achieving proper aeration facilitates the temperature control, removal of excess moisture and CO_2 and provides O_2 for the biological processes. Turning of compost feedstock is reported to significantly decrease temperature build-up during composting (Zhu *et al*., 2004; Tognetti *et al*., 2007). However, studies have shown that, passive aerated composting system have comparable efficiency compared to some turned and force-aerated systems (Fernandez and Sartaj, 1997; Solano *et al*., 2001; Zhu *et al*., 2004; Sylla *et al*., 2006). Several methods have been used to provide oxygen to composting material (Table 2.4). In the passive aeration method, oxygen supply is achieved by means of the natural convective movement of the air through the pile (Mason *et al*., 2004).

Table 2.4: Classification of composting methods and systems

Method and Description
Open Methods
Naturally aerated static piles: Freestanding piles that are turned infrequently or not at all and aerate passively without aeration aids.
Passively aerated static piles: Static windrows and piles with passive aeration aids such as perforated pipe and aeration plenums;
Turned windrows: Long narrow piles that are regularly turned and aerated passively;
Aerated static piles and bins: Free-standing piles or simple bins with forced-aeration and no turning;
Aerated and turned piles, windrows, and bins: Freestanding piles or windrows, or simple bins with forced-aeration system. Materials are turned regularly or occasionally;
In-Vessel or Contained Methods
Horizontal agitated beds: Materials are composted in long narrow beds with regular turning, usually forced-aeration, and continuous movement;
Aerated containers: Materials are contained in variety of containers with forced-aeration;
Aerated-agitated containers: Commercial containers that provide forced-aeration, agitation, and continuous movement of materials;
Silo or tower reactors: Vertically oriented forced-aerated systems with top to bottom continuous movement of materials;
Rotating drums: Slowly rotating horizontal drums that constantly or intermittently tumble materials and move them through the system;

Source: Rynk and Richard (2001)

Another system of aeration or composting that is not common in Ghana, yet applicable on a small or decentralized scale is vermicomposting. Vermicomposting technology using earthworms as versatile natural bioreactors for effective recycling of organic wastes in the soil is an acceptable means of converting waste into high nutrient value compost for crop production. Studies have also shown that vermicomposting of organic waste accelerates organic matter stabilization (Frederickson *et al*., 1997; Mainoo *et al*., 2009) and gives chelating and phyto-hormonal elements (Tomati *et al*., 1995) which have a high content of microbial matter and stabilized humic substances.

2.4 Sources and Utilization of Biodegradable Waste in Ghana

Biodegradable Waste (BW) resources available in Ghana can be classified into two main sources: (1) agro-industrial (recovered from the soil and water bodies) and (2) from municipal solid waste. Table 2.5 below provides some sources relating to Ghana. These waste resources contribute different nutrients, and physico-chemical characteristics to a well-mixed feedstock for composting.

Table 2.5: Potential organic waste resources in Ghana

Source	Classification
1. Household	Organic fraction of household waste, yard trimmings
2. Agro-industrial	Animal waste (abattoir waste & animal droppings), crop residues, fruit and vegetable waste, aquatic weeds (water hyacinth), fish and marine waste, sawmill waste, Rhizobium and blue algae.
3. Civil Establishments	Organic fraction of waste from schools & institutions, commercial centre wastes; sewage sludge and night soils and city refuse (from public park).

Various local research works have been conducted to study the use of crop residues or leguminous plants/weeds to improve soil fertility and productivity in agricultural soils, with the rationale of reducing the reliance on mineral inorganic fertilizer (Quansah *et al*., 1998; Quansah *et al*., 2001b; Tetteh, 2004; Fening *et al*., 2005). Also reported are studies on the perception of farmers using biodegradable municipal solid waste (BMSW) compost or manure (Quansah *et al*., 2001a; Danso *et al*., 2006), quantifying BMSW or potential compost availability (Leitzinger, 2001); and the supply or market of BMSW as potential compost (Kindness, 1999; Asomani-Boateng *et al*., 1996; Danso *et al*., 2006) for local application.

River reed or hippo grass (*Vossia cuspidate),* water hyacinth (*Eichhornia crassipes*), *Polygonum senegalens,* water lettuce (*Pistia stratiotes)* and the *Cyperus sp*. are but a few aquatic weeds that have potential usefulness for composting in Ghana. These noxious weeds have attracted worldwide attention due to their fast spread and congested growth, which lead to serious problems in water transport navigation, irrigation, power generation, and spreading of bilharzia (Pierce and Anthonty, 1969; Epstein, 1998; Goyal *et al*., 2005), adverse effect on the growth of tourism and the improvement for livelihoods of most lakeside dwellers. These aquatic weeds can be composted for soil amelioration.

The use of water hyacinth on land either as surface mulch or as compost or vermicast has been reported by several researchers (Woomer *et al*., 2000; Gajalakshmi *et al*., 2002; Malik, 2007). Gunnarsson and Petersen (2007) and Malik (2007) have reported potential uses of aquatic weeds for compost, biogas, briquettes, animal fodder/feed and bio-alcohols. Currently dredges, barges or manned-canoes are the prime harvesters for aquatic weed in Ghana. Fresh aquatic weeds have high moisture content (~80-90% wb); hence little additional water is needed during the composting (Malik, 2007). Composting can play a major role in the management of the waste resources of Ghana; composting play an integral role in the countries' integrated waste management option, a reflection of the sustainable option of recycling.

2.5 The Consumption of Mineral Fertilizers in Soil Fertility Management

Ghana's economy is driven mainly by its agricultural sector (Aryeetey and Fosu 2003; Benin *et al*., 2008; GSS, 2008). The process of economic development in Ghana is, to a large extent determined by the mining and timber industries and a rapidly industrializing and export-oriented agricultural sector, mainly based upon cocoa and oil palm, but diversifying into a wide array of tropical fruits and vegetables (Hens and Boon 1999). Ghana's dependency on agriculture will require that it prudently manages its soil fertility, along with other sound agricultural practices. Successful management of tropical soils requires the combined use of mineral and organic fertilizer for maintenance of soil fertility (Vlek, 2005).

Mineral fertilizer, is widely used in agricultural production in Ghana. All chemical fertilizers consumed in Ghana are imported (Seini, 2002). A summary of Ghana's fertilizer consumption from 1986 to 2007 is shown in Figure 2.6. Chemical Fertilizer was not imported in 1991 because stocks exceeded demand, and government controlled fertilizer imports. The significant drop in the fertilizer imports and hence consumption in the country is due largely to the removal of subsidies on fertilizer prices in 1990-94; which before have been in the range of 40 to 80 percent (Dreschel and Gyiele, 1999; Seini, 2002). The withdrawal of subsidy discouraged consumption and the substantial price increases between 1990 and 1998. However, the increase in fertilizer consumption from 2000 reflects Ghana government's policy support to invest more into agriculture through various support assistance directed at subsidising agricultural inputs (Fertilizer and pesticides especially).

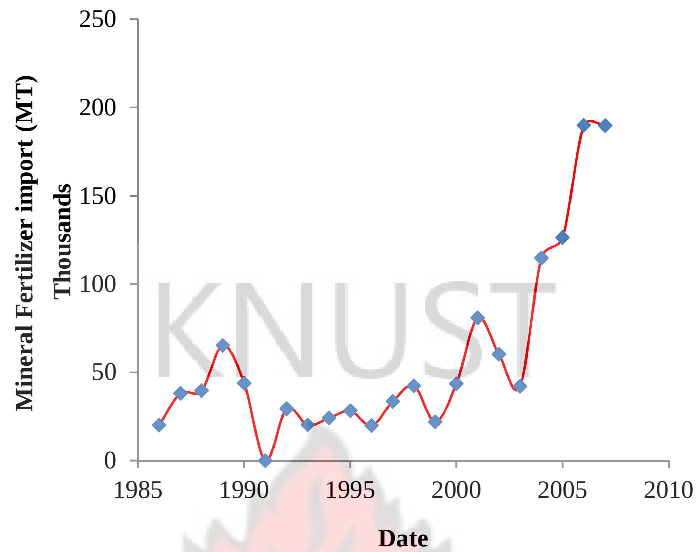


Figure 2.6: Mineral fertilizer import into Ghana from 1986-2007

(Compiled from available data from Ministry of Food and Agriculture-Crop Services Department, 2004; Ministry of Trade and Industry-Research Information and Statistics Division, 2009)

Although nutrient deficiencies could be remedied through mineral fertilizers, desirable soil physical properties such as water holding capacity, congenial conditions for microbial activity and efficient use of applied fertilizers could be maintained by addition of compost or organic manures. Consequently, there is an increasing interest in using crop residues and animal manure for improving soil productivity which can reduce the use of external inputs of mineral fertilizers for agricultural production in the tropics (Quansah *et al*., 1998; Quansah *et al*., 2001b; Tetteh, 2004; Fening *et al*., 2005). Smaling *et al.* (1996) asserted that farm holders, developers and policy makers in sub-Saharan Africa recognise soil nutrient depletion as one of the major constraints to sustainable agricultural development.

2.6 The Role of Composting in of Municipal Solid Waste Management

The organic biodegradable fraction of MSW is an important component, not only because it constitutes a sizable fraction (>50%) of the solid waste stream of most developing country but also because of its potentially adverse impact upon public health and environmental quality (Ashworth, 1996). It also provides an opportunity to divert nutrient from dumpsites to agricultural land and contributes one of the most practical solutions for managing solid waste in developing countries (Ali, 1997; Leitzinger, 2001; Danso *et al.*, 2006; Hofny-Collins, 2006).

Salifu (2001) reported that adopting appropriate technologies for composting MSW, especially near the point of generation, could accrue a net savings on transport to the local authorities. It was consequently extrapolated that a 20% reduction in biodegradable fraction of MSW could have a significant reduction in maintenance cost of the Kumasi landfill; while increasing its life span by nearly 5years. The municipal authorities spend about 60% or more of their budget to collect waste, therefore composting near the point of generation may be worth considering to reduce transport costs (Ali, 1997; Zürbrugg and Schertenleib, 1998; Danso *et al.*, 2004; Imam *et al.*, 2008).

Very few composting facilities exist in Ghana, and barely operate to their designed Capacity. The biodegradable fraction of agricultural and municipal solid waste forms about 55-65% of waste characterized. A household solid waste characterization study carried out in different income classes in Accra in 1999 showed that the proportion of organic waste from high income households was higher (approx. 70%) than that of waste from medium (60%) and low income (49%) groups (Fobil, 2000).

Opportunities to divert organic fractions of MSW to agriculture or horticultural use in urban, peri-urban and rural area exist. It is worthy to note that anaerobic digestion of some agricultural waste and faecal sludge materials has been successfully undertaken to produce biogas (Aklaku *et al*., 2006; Ofuso and Aklaku, 2009). Peri-urban refers to areas located within and on the periphery of cities and towns. Leitzinger (2001) reports that, up to 66% of household food demand are supplied by peri-urban agriculture. The same Author reiterates that composting could recycle a significant amount of plant nutrients for agricultural use, which would have otherwise been lost to the environment. Consequently, Leitzinger (2001) suggested the need for special focus on feasibility studies to discover the cost of waste examining composting and the availability of sustainable market.

Danso *et al*. (2006) analyzed the perceptions and willingness-to-pay (WTP) for composted municipal solid and faecal waste among urban and peri-urban farmers and other potential compost users in Ghana. Their analysis revealed that the effective demand for compost for agricultural purposes is marginal and limited by farmers' transport costs. This was revealed by a positive relationship between income and WTP, indicating that farmers with a higher ability to pay and able to understand the benefits and risks of compost show a higher WTP. Hence, the demand gap left could be filled by the construction sector, an initiative that must be driven by a public private partnership (PPP). The government (local authorities) through, its national beautification policy, could adopt the use of compost, instead of the use of dug topsoil ("black soil") for landscaping purposes.

2.7 Lessons from Ghana's Local Composting Experience

A survey to assess the state of local composting experiences in Ghana and their possible replication in other districts was conducted from January, 2007 - December, 2009. Visits to the composting facilities were undertaken and interviews conducted using a structured questionnaire (Appendix A) which sought to determine issues about the capacities of the facilities, ownership, source of raw-material, method of production, estimated project cost, and challenges hampering the smooth operation of the facility. Supervisors or managers or their equivalent at composting or material recovery facilities were interviewed with the help of a structured questionnaire.

The facilities identified included the Teshie-Nungua Accra Metropolitan Assembly Composting Plant - AMACP; the Ashiedu Keteke Community Participation Project – AKCPP at James Town; the VREL -Akuse; the Blue Skies Composting facility - Doboro; and the BOPP composting facilities – Twifo-Praso. It is important for other emerging facilities, either privately funded or donor funded, to learn some lessons from the above facilities to ensure that they are more capable of operating such facilities in a sustainable manner.

2.7.1 *The Accra Metropolitan Assembly Composting Plant (AMACP)*

This facility was designed and built in 1979 and became operational in 1980 (Djabatey, 1998; Awuye, 2008). The system could be described as a centralized sheltered Mechanical Biological Treatment (MBT) facility with an open-air windrow (operated under a shed) and faecal treatment (3-series) pond. The design capacity was 200 MT/d of mixed MSW (Etuah-Jackson et al., 2001) and was established at a cost of about USD 2.5 million (Djabatey, 1998; Awuye, 2008). After the breakdown of its Topturn machine, a front-loader was used in turning the compost pile as a means of controlling temperature and ensuring uniform moisture content, which was controlled by wastewater from the faecal treatment stabilisation ponds in the later days of its operation. This plant was serving AMA and its surrounding communities. The matured pile was passed through a mechanical sieving drum, separating out any components larger than 10 mm as residual; however the final product had a high contamination of glass and metals (Asomani-Boateng and Haight, 1999; Awuye, 2008; Hofny-Collins, 2006).

(a) Composting area

Figure 2.7 Non-operational AMACP composting facility

(b) Pile of refuse dumped

The failure of the AMACP is mainly attributed to: poor maintenance culture, the weak market and quality control of the compost produced; which was then competing with easily accessible substitutes (such as: cow manure, poultry manure and top/black soil), lack of a funding mechanism to re-invest into the facility as per its estimated life-span of about 20 years (1978-1998), high operating and maintenance cost that was increasing and was considered unsustainable for the local government to support, the absence of an appropriate service fee for the management of the municipal waste and its treatment and the lack of motivation and training for personnel involved. The above findings and inferences have been corroborated by Lardinois and van de Klundert (1994), Ali (1997), Asomani-Boateng and Haight (1999), Etuah-Jackson et al. (2001) among others, who have all reported on constraints and failures of such a centralized facility to operate efficiently and reliably in developing countries. Unfortunately, the AMACP was turned into a make-shift dumpsite (Figure 2.7 above), before it was contracted for decommissioning in August, 2009.

2.7.2 *The AKCPP (James Town)*

Established in 1997 as a non-governmental organization supported by the AMA and other development partner supports, the Ashiedu Keteke Community Participation Project (AKCPP) facility was treating MSW collected from surrounding markets and those collected from households through door-to-door services. The collected waste was sorted and the organic fraction put into piles mixed with dewatered faecal sludge from the local Sewage Plant near Korle Gono all within the jurisdiction of the Accra metropolitan assembly (AMA). The feedstock was formulated in a ratio of 1:4 of faecal sludge to biodegradable fraction of MSW. The piles were then turned regularly. Although the optimum capacity of the facility was reported to be about

1,300 tonnes MSW per annum (Hofny-Collins, 2006), it was also operating irregularly below capacity at approximately 2-5 tonnes MSW per day, at an average production rate of 150 tonnes MSW per annum. With the unattended to accumulating residuals at the site, uncertain ownership, increasing cost of transporting feedstock materials and the inability to produce compost at a competitive price, this facility is no longer operational (Fig. 2.8).

Figure 2.8 AKCPP project with a rotary screen

(source of photo: WASTE Consultants, 1993 in Lardinois and van de Klundert, 1993)

2.7.3 *Volta River Estate Limited (VREL) and Blue Skies Products (Ghana) Limited (BSGL) facilities*

The VREL composting system, located near Akuse and Kpong, in the Eastern region of Ghana has been the most organized and functioning facility at the time of the study. The method of operation used involves a mechanically-turned windrow system (Figure 2.9) that is always covered with a "Toptex" (fleece) sheet to prevent excessive moisture loss or gain due to excessive evaporation or precipitation respectively. The fleece also controls dust triggered by the wind on the compost piles. The main feedstock material used at this facility is river reed (vossia cuspidate or the Hippo grass) harvested from the Volta Lake, which forms about 75% of the total pile constructed. Amendment materials such as cocoa seed shell/husk, poultry manure, cow manure, banana waste, rice husk and clay are used. ‘SoilTechTM solutions’ starter inoculants are used to accelerate decomposition. An estimated pile dimension of 50 m (L) ×2 m (B) ×1.5 m (H) is normally used and turned frequently to ensure that temperature or the carbon dioxide gas (CO_2) levels did not exceed 65^0C or 20% respectively. The main equipment used for mixing the pile is a “Sandberger ST 300” pulled by a 90 HP tractor. Additionally, a 165 HP front-loader is used to form or reshape piles. Although designed to operate at a capacity of 25,000 m3 or 15,000 tonnes of compost per year, the facility was estimated to be operating at capacity of 5,000 m3 per year in 2008.

Figure 2.9: Mechanically-turned windrow composting piles in Ghana

(a) Composting at VREL (b) Composting of fruit waste BSGL

BSGL’s composting facility near Nsawam in the Eastern region of Ghana operates with the same principles as that described for the VREL composting facility. The main difference between the two facilities is with feedstock formulation, which, in the case of BSGL, is made up of mainly fruit waste (pineapple, mango and passion fruit) and is amended with poultry manure, clay/soil and bulking agents such as wood shavings or cardboard or coconut husk. Like the VREL facility, its reason for composting is to develop an organic fertilizer or compost, with the added advantage of waste management. The compost produced is used to grow fruits processed by the company to maintain its certification requirement for organic products (pineapple, banana, passion fruit, mango etc.). The fruits grown with the compost have a premium value higher than crops maintained with chemical fertilizer. BSGL at the production period of 2008/2009 was producing about 400 MT of compost per year, about 50% percentage of its estimated potential capacity. However, the company has the intention to double the facility's operational capacity in the future.

2.7.4 *Benso Oil Palm Plantation (BOPP) Composting Facilities*

The composting facility at BOPP located in the Western region was established to process oil palm Empty Fruit Bunches (EFB) and palm oil mill effluent (POME) into compost for smallholder and out-grower farmers. This is expected to enhance fruit yield and drive their sustainable environmental management**.** The facilities have been operating since 2005/2006 (Fig. 2.10). This is an improvement on the past practice, where the EFB was sent into the field to decompose as a mulch to enrich the soil. This approach reduces the cost of transporting and chemical fertilizer use. Plans to implement a similar facility the Twifo Oil Palm Plantation (TOPP) in Central region of Ghana is still pending.

Figure 2.10: Empty fruit bunches being composted with POME

2.7.5 *Compost Product Quality of Operational and Non-operational Facilities*

The compost produced from these facilities were (or are) mainly utilised by farms (small, medium or large scale), Estate Developers, Hotels, and Horticulturist, or for various research projects with varied qualities (Table 2.6). It can be seen from the summary presented in Table 2.7 and Table 2.8 that most of the recent composting initiatives are emerging from the Private Sector and are utilizing mechanical equipment in their operation which adds to the cost of composting. The major constraint to these facilities is the cost of operating and maintaining their equipment, hence there is the need to consider technologies that will limit the use of mechanical equipment or its frequency in the composting operations. The mechanical equipment are used primarily for turning the windrows, hence forced or passive aeration mechanism could be investigated and recommended to ensure the sustainability of the composting process where applicable.

Table 2.6: Capacity, feedstock and method of operation and end-use of product

Facility	Ownership	Cap. (t/y)	Status	Method	Maturity	End-users
VREL	Private	~7,800	Operational	MTW	~2mth	F
BSGL	Private	~3,300	Operational	MTW	~2mth	F, RED, H/L
AMACP	Government	~14,400	Decommissioned	MBT	~2mth	F, H/L, RED, LC
AKCPP	CBO	<1000	Decommissioned	mTW	~5mth	H/L,RED,F
BOPP	Private	~2,000	Operations	MTW	~5mth	F

CBO - Community Based Organizations; MTW-Mechanically Turned Windrow; MBT-Mechanical biological Treatment; mTW- manually (labour) Turned Windrow; F-Farms; RED-Real Estate Developers; H/L-Horticultural/Landscaping; LC-Landfill cover

Table 2.7: **Operation characteristics and constraints of facilities**

Facility*	VREL	BSGL	AMACP	AKCPP	BOPP
Feedstock	Agro-waste , soil	Agro-waste, soil, sawdust	MSW, FS	MSW, FS	Agro-waste
System	Turned Windrows with fleece covers	Turned Windrows with fleece covers	Sheltered Mechanical Biological Treatment (MBT) facility	Windrow, Labour intensive.	Labour , shredder front-loader
Parameter used in Monitoring	Temperature, Moisture Content and CO_2	Temperature, Moisture Content and CO_2	Temperature, moisture Content	Temperature, moisture Content	Temperature, moisture Content
Major Equipment	PTO Mounted Turner, front-loader, Truck, trailer	PTO Mounted Turner, front-loader, Trommel screen, truck	Grab crane, Hammer mills, Rotary sieve, magnetic separate, front- loader, vibrating screen, Compost Turner	Small scale rotary screen	Front-loader, trucks
Addition of Inoculums	Yes	Yes	No	No	No (POME)
Major Constraints	Accessibility to the site, cost of operating and maintaining equipment	Accessibility to the site, cost of operating and maintaining equipment	Poor pricing or product, frequent equipment breakdown, non-availability of funds to sustain operation; contamination of final product.	Poor pricing or product, and ownership crisis.	Cost of operating and maintaining equipment

* Reference year, 2009; MSW- Municipal Solid Waste; FS-Faecal Sludge; POME - Palm Oil Mill Effluent, PTO – Power Take Off

Table 2.8: Reported quality of compost product

Facilities	Parameter*											
Parameters	**OM**	**pH**	**C**	**N**	**P**	**K**	**Zn**	**Cu**	**Cd**	**Cr**	**Ni**	**reference**
Units	(%)	-	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
VREL	30.6	8	5	0.24	0.18	0.39	19	36	0.30	14	12.5	1
BSGL	10.8	7.3-8.2	4.57-24.3	0.3-0.41	0.31-0.56	0.35-0.75		-	-	-	-	1
AMACP	8-23	6.8-8.6	2.02-12.3	0.17-1.68	0.25-2.21	0.17-0.71	92-837	19-272	0.2-1.15	22-54	11.2-18.1	1, 2, 3,4
AKCPP	20.2-31.8	6.1-7.0	6.42-8.39	0.75-1.15	4.1-4.8	0.22-0.46	233-241	29.4-40.7	0.33-0.76	12.9-14.4	10.4-11.6	1,3
BOPP	~80	6.0	43.96	1.50	0.12	2.74	-	-	-	-	-	1

*** -** Parameters are reported on (w/w) basis, except for pH; Reference: 1 – facility internal records; 2 - Hogarh *et al*. (2008); 3 - Hofny-Collins (2006); 4 - Etuah- Jackson *et al.* (2001)

The study established that, the final compost quality from the various facilities that, BOPP's compost presented the highest organic matter content (OM), Nitrogen and Potassium concentrations (Table 4.3). While the AKCPP facility presented the highest elemental phosphorous concentration among the composts listed; which may be attributed to the high proportion of dewatered sewage sludge used in composting. The highest heavy metal concentration was observed in AMACP compost. This could be traced either to the source of municipal organic fraction or the quality of faecal sludge used or the method used in separating potential contaminants and size reduction processes. The presence of batteries and rusting tins/cans in municipal solid waste stream are a major source of metal concentration in the final compost produced. Clearly, the lack of effective pre-sorting prior to composting could have contributed to the level of contamination reported for compost product from AMACP. Thus, pre-sorting in AKCPP gave a better quality of compost compared to AMACP. Richard and Woodbury (1992) indicated that mixed municipal solid waste composting were susceptible to high metal concentration, which in most cases are above recommended limits.

In the case of the agricultural waste composted by VREL, BSGL and BOPP farms, the products were mostly used internally on their farms or distributed to out-growers to meet their planned production methods of improving soil organic matter content or growing 'organic' fruits. For most of the operational facilities surveyed it was clear that monitoring of the piles were conducted by using temperature readings, gas analysis (CO_2 titrimetric device) or visual inspection. It was also revealed the rapid monitoring of macro-nutrient, without necessarily undertaking chemical analysis was desired.

However, compost produced from MSW or faecal sludge (dewatered) will require substantial educational campaign to subside any common negative perceptions of the compost (Cofie *et al.*, 2010); although this situation has been noted to be improving (Cofie and Kone, 2009). In many cases, and not limited to donor operated composting facilities in Ghana, but in other West African countries (Asomani-Boateng & Haight, 1999; Hofyn-Collins, 2006); the project sustainability has being greatly tied to the continuous funding by the grant agency.

2.7.6 *Opportunities and Factors to Consider in the Application of Composting as Suitable Biodegradable Waste Treatment Option in Ghana*

Smaling *et al*. (1996) asserted that farm holders, Developers and Policy Makers in Sub-Saharan Africa recognise soil nutrient depletion as one of the major constraints to sustainable agricultural development. Opportunities exist to divert organic fractions of MSW and agro-waste to agriculture or horticultural use in urban, peri-urban and rural areas (Peri-urban refers to areas located on the periphery of cities and towns). Leitzinger (2001) recommended composting as a means of recycling a significant amount of plant nutrients for agricultural use, which would have otherwise been lost to the environment. Consequently, he suggested that a special focus be put on feasibility studies to discover the cost of waste management examining the composting technology and the availability of a sustainable market. All the facilities surveyed could not reconcile their cost of operation or investment made on the projects, because of poor record keeping, poor allocation of cost to assignment of equipment or other assets. However, it was clear that the sustainability of the composting project were influenced by the availability of markets for these organic products; or because of the quest of an organization to improve the organic matter content in their farm soils or reduce their consumption of mineral fertilizer.

Danso *et al*. (2006) analyzed the perceptions and willingness-to-pay (WTP) for composted municipal solid and faecal waste among urban and peri-urban farmers and other potential compost users in Ghana. Their analysis revealed that effective demand for compost for agricultural purposes is marginal and limited by farmers' capacity to transport products. Thus, farmers with a higher ability to pay and understand the benefits or risks of compost show a higher WTP (Danso *et al*., 2006). Hence, the identified demand gap or market niche could be filled by the construction sector, through an initiative that must be driven by a public-private partnership (PPP). Government (local authorities), through its national afforestation or beautification programmes (Greening Ghana), could adopt the use of compost instead of the use of dug topsoil ("black soil") for nursery planting media and landscaping purposes.

Based these experiences, the following have been proposed as prerequisites to establishing a sustainable composting or material recovery (with composting) system within an integrated waste management framework for urban cities in Ghana:

1. Assessing a feedstock of good quality for composting, which may require source-separation;
2. Stimulating potential markets for compost use. National or Local authorities could support such facilities with tax incentives or some guaranteed markets if quality specifications are met. Already, the government of Ghana is subsidising significantly chemical fertilizer imported for farmers;
3. Formulation of feedstock recipes that will ensure optimal process efficiency or control and reduce cost of operation;
4. Appropriate siting of facility, to ensure continuous supply of raw material or reduce public objection;
5. Choosing appropriate technology and scale, to ensure the prudent management of operational and maintenance cost.

6. Local authorities may wish to charge or allocate appropriate rates (tipping fee for MSW) or subsidise costs to cover or ensure the sustainability of a facility within a well-structured maintenance culture.
7. Availability of qualified personnel to effectively manage the proposed facility. Thus, continuous training becomes a relevant management strategy in operating such plants.
8. A continuous effective public awareness and sensitization about separation at source of MSW and the beneficial use of compost and related recyclables is recommended.

The future of a sustainable composting may be influenced heavily by the availability of a market to absorb the final compost products; either as an organic or organo-mineral product. It is important to package the compost product in a way that meets the needs of each identifiable market sector. For this reason, accreditation from the Ministry of Food and Agriculture (Plant Protection and Regulatory Services Directorate, PPRSD) or an appropriate certification authority to stimulate consumer confidence in the quality the compost product is necessary. Again, pre-sorting before composting and the factoring of the cost of disposal of residual material is critical for reduction of the occurrence of heavy metals in the final product. Much so, there would be the need to formulate an equivalent subsidy programme for compost in line with other chemical fertilizers.

2.7.7 *Opportunities that Exist for Composting in Ghana*

Windrow composting with turning was found to be the most applied means of composting in Ghana. Commercial facilities used at least a mechanical turner (Self-propelled or power-take off or front-end loader) to turn or aerate compost piles. Key challenges identified from the surveyed composting facilities highlighted the unavailability of markets to absorb compost produced and high operational and maintenance cost (electricity/fuel); although facilities were not able to back this later concern with enough data. Development of appropriate markets for compost is key to the sustainability of any composting program and thus needs government support through enforcement of appropriate regulations and incentives. In this regard the study observed that government support through the provision of incentives, subsidies or grants to develop composting as a waste management option to reduce the amounts of MSW or agro-waste that require landfilling. This is justified by the fact that the government of Ghana is already subsidising significantly waste collection services, landfill management and chemical fertilizer imports. Thus, the course of subsidies should be towards cleaner treatment methods. The opportunity also exists to explore composting technologies that require less energy (turning) input like passive mechanisms in the light of the need to reduce processing cost by reducing energy requirements; while decentralizing the treatment operations. Due to the concern for high operational cost for most of these facilities investigated, there is the need to investigate new feedstock and aeration mechanisms that may improve compost process efficiency in existing or conceived projects.

The finding from the survey further suggests that the private sector composting facilities were better managed as compared to the government or public/community based facilities. This could be attributed to the clearly defined ownership and less bureaucracy involved in the approval systems of the privately operated facilities to ensure the smooth operations of such facilities. Thus, it is recommended that management of composting facilities should be skewed towards the private sector or a well worked out public-partnership agreement in Ghana. The survey revealed that compost quality was dependent on the feedstock used in the composting process. More so the levels of heavy metal in compost from facilities utilizing MSW and sewage/faecal sludge reported high amount of Zn and Cu concentration which were also inherent in the initial feedstock. It is recommended that future composting programme considering utilizing MSW as part of their feedstock should include strategies that will encourage source separation from the various generating sources and an effective pre-sorting system.

CHAPTER 3 :   MATERIALS AND METHODS

3.1 Experimental Sites

The research involved both field and laboratory studies. The field experiments were conducted at the Agriculture Mechanization farm at KNUST (6º40′44.79″N, 1º33′22.05″W) and the VREL Composting Site (6° 7'2.18"N, 0° 5'29.16"E). The laboratory studies were conducted at the Soil Science Laboratory, Faculty of Agriculture, KNUST - Kumasi; The Environmental Sanitation Lab, Civil Engineering Department, KNUST - Kumasi; The Analytical Lab of Soil Research Institute, Kwadaso - Kumasi, which is about 8km away from Kumasi; and the Ecological Laboratory (ECOLAB) of the University of Ghana, Legon - Accra. The analyses of heavy metal contents in compost and most of referenced literature cited was undertaken at the Department of Civil Engineering- University of Western Ontario, London, Canada. The electrical control circuit for the forced-aeration experiment, using the river reed substrate, was built with the assistance of the Electrical and Control Unit of the Tema Oil Refinery (Appendix B).

3.2 Field Experiments for Abattoir Composting Piles and their Formulation

3.2.1 *Feedstock used in Abattoir Waste Composting*

The effect of feedstock composition or turning frequency on composting process was investigated in this experiment. The main substrate for the study Abattoir Waste (AW), also known as slaughterhouse waste, material from the Kumasi Abattoir Company Ltd (KACL) was utilized. This consisted mainly of dung and rumen content. The KACL has an operational capacity to process over 230 Cattle, 120 Goats/Sheep, and 10 Pigs daily (Rockson and Aklaku, 2006). An estimated average of 9 tonnes of abattoir waste is generated daily, which are then disposed-~~off~~ of at the KMA landfill site at Kaase-Dompoase, Kumasi (Rockson and Aklaku, 2006). Other material such as source separated market/commercial waste (MW), cocoa pod husk (CPH), corn stoves, yard trimmings and sawmill wood shavings (SW) were added to the abattoir waste, to serve as an amendment material or bulking agents, to form the different feedstock formulations studied. The MW was collected from KNUST campus' commercial area and Ayigya markets over a period of three days. This was mainly, vegetable (such as cabbage, lettuce, and carrots), peels of cassava tubers, plantain, and left over food. The CPH was collected from a nearby farm at Koforidua in the Ejisu-Juaben district; the pods were said to have been harvested for about a month. Corn stoves were also collected from the dehusking facility at the Agriculture Mechanization farm in KNUST, courtesy a project being undertaken by the Crop Science Department of the Faculty of Agriculture, KNUST. Yard trimmings and sawmill wood shavings (SW) were also obtained from facilities on KNUST campus. The above materials were added to the AW for composting mainly in order to balance C/N ratio Moisture Content of the formulations. These materials were also considered to be readily available for any future composting of AW to be undertaken in Kumasi.

3.2.2 *Experimental Design for Abattoir Waste Composting*

The composition and physicochemical characteristics of each feedstock prepared for this composting experiment are presented in Table 3.1. The experimental set up was a 3×3 factorial design with three feedstock AMYC (consisting of abattoir waste, market waste, yard trimmings and corn straw/stoves), ACC (consisting of abattoir waste, corn straw/stoves and cocoa pod husks) and ACS (consisting of abattoir waste, cocoa pod husks and sawmill waste) of similar C:N ratio of about 25:1, and with turning frequencies/ mixing regimes at intervals of 3-days (3-DT), 7-days (7-DT) and 14-days (14-DT). These nine (9) piles were set-up in boxes of average dimensions 1m×1m×1m (Figure 3.1) and maintained at moisture content of about 55-75% wet basis over the period of composting. This Moisture Content was selected to influence high organic matter degradation and a possible increment or minimize loss on Total Nitrogen (TN) (Bueno *et al*., 2008).

Table 3.1: Formulation of feedstock

Samples	Unit	AMYC	ACC	ACS
AW	kg (%)	140.0(42.2)	150.4(46.9)	132.4(41.3)
M W	kg (%)	140.2(42.2)*	-	-
CSW	kg (%)	27.6(8.3)▼	20.2(6.3)▼	-
YTW	kg (%)	24.1(7.3)*	-	-
CPH	kg (%)	-	150.0(46.8)*	165.0(51.5)*
SW	kg (%)	-	-	23.0(7.3)▼

AW-Abattoir Waste; MW-source separated Market Waste; CSW-Corn Straw/Cob Waste; YTW-Yard Trimming Waste; CPH-Cocoa Pod Husk; SW-Sawmill Waste. Values in parenthesis (), are the percentage weight composition of feedstock material used in the composting process. * - feedstock used as amendment; **▼**- feedstock used as bulking agent.

About 320kg of feedstock was formulated for each setup of abattoir waste composting, which was ideal to fit into the 1m^3 frames used for the study. Feedstock formulations of available materials were designed to achieve an initial characteristic MC and C/N ratio of about 65% (wet basis) and 25:1 respectively. These were evaluated using a modelled Microsoft sheet designed by the Cornell University (Richard, 2006), that helps composters to establish a desired MC and C/N ratio simultanously. The Characteristics of initial feedstock piles in the three formulations are described in Table 4.2 (page 75 of Section 4.1). There was very little observation of leachate formation from the piles as a result of precipitation. The piles were formed under a shed to prevent any effects from direct rainfall.

(a) A mixture of AMYC and ACC feedstock

(b) A mixture of ACS and ACC feedstock

Figure 3.1: Feedstock for composting of abattoir waste

The essence of turning is to ensure that microbes and moisture are more uniformly distributed in the composting piles. Thus, the turning frequencies were selected to align with the growth and decay cycles for microbes or pathogens. Most microbes survive or deactivate during composting within 3, 7, 14 days at thermophilic temperatures (Haug, 1993; Epstein, 1997; Cekmecelioglu *et al*., 2005); and to assess the different effect that turning may cause to thermophilic or mesophilic microbial community during composting. Furthermore, the turning regimes enhance the ability to control temperature and moisture developments during composting (Robinzon *et al*., 2000; Ogunwade *et al.*, 2008). Thus, in community or commercial composting practice, the cost of labour or operation could be optimized around these turning frequencies if their impact on process efficiency is properly understood.

3.3 Field Experiments for River Reed Composting Piles and their Formulation

3.3.1 *Feedstock used in River Reed Composting*

Under an already existing formulated feedstock composition using river reed harvested using boats from the Volta Lake, a pilot scale experiment was conducted to assess the effect of aeration mechanism on the composting process. The river reed from the Volta Lake, near Akosombo, is typically made up of Hippo grass (*Vossia cuspidate*), Water Hyacinth (*Eichhornia crassipes*) and Water lettuce (*Pistia stratiotes*). However, the hippo grass was the dominant biomass used for the composting experiment at Volta River Estate Limited (VREL). Cocoa seed husk was collected from the Cocoa Processing Company (CPC) Ltd, Tema; while poultry manure came from mostly poultry farms from the Eastern and Ashanti Regions of Ghana. Banana waste, from VREL's various farms were brought to the composting facility, while materials like rice husk, cow dung or manure were bought from local farms in Akuse and its environs. Top soil, clayey in nature, from the banks of the lake and plots being prepared for cultivation near the composting facility were used in the formation of piles. The river reed was used as the main substrate in the feedstock. The feedstock composition on weight basis is captured in Table 4.33 (page 145 Section 4.6) with river reed forming about 75% on weight basis. The composition used by VREL was adapted for this study.

(a) River reed

(b) banana waste (stock and fruit)

(c) Clay soil

(d) Cow dung

Figure 3.2: Feedstock for co-composting of river reed

3.3.2 *Experimental Design for River Reed Composting*

Two passive aeration mechanisms, the Dome Aerated Technology (DAT) and Horizontal-vertical (HV) channel mechanisms were applied. Additionally, an ON-OFF static pile forced-aeration mechanism and a mechanically turned static pile were also studied. The dimensions of these piles were influenced by previous research experiments influenced by the surface area to volume ratio. The aeration systems differ one from the other, thus the scale down of DAT (Trois *et al.*, 2007) and FA (Tiquia *et al.*, 1997; Gao *et al.*, 2010) and scale-up of HV (Sylla *et al.*, 2006; Solano *et al.*, 2001). The sizes of the piles were built to ensure that the surface area to volume ratio is close enough to 3:1 - 3.5:1 m^2/m^3 for a full scale set-up (Mason, 2007). Since it is virtually impossible to maintain the pile height of the TW above 1m throughout the thermophilic phase, setting equal dimensions for the piles will not be practical.

3.3.3 *Dome Aerated Technology (DAT) System*

The DAT is a passive aeration system that utilizes thermal convection to drive the aeration process within a windrow of waste. The principle of the DAT method is the creation of large voids in a windrow of waste, using in this case, bamboo structures, called domes and channels. This is a scale-down from a research conducted by Trois and Polster (2007) and Trios et al. (2007); having composed MSW and pine bark to a scale of over 300m^3. Domes were positioned centrally in the windrow to allow for venting of the hot gasses generated by the degradation reactions through the chimneys and channels. The layout of the DAT system is presented in Figure 3.3.

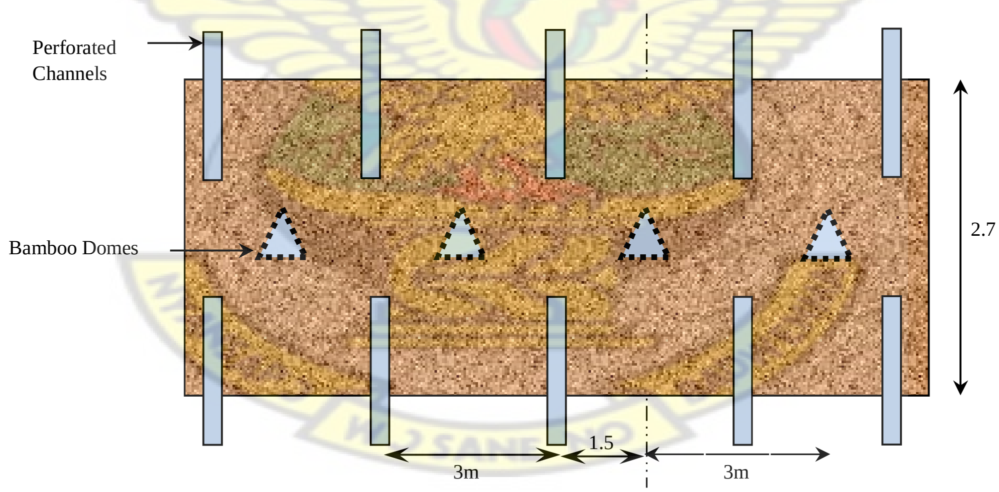
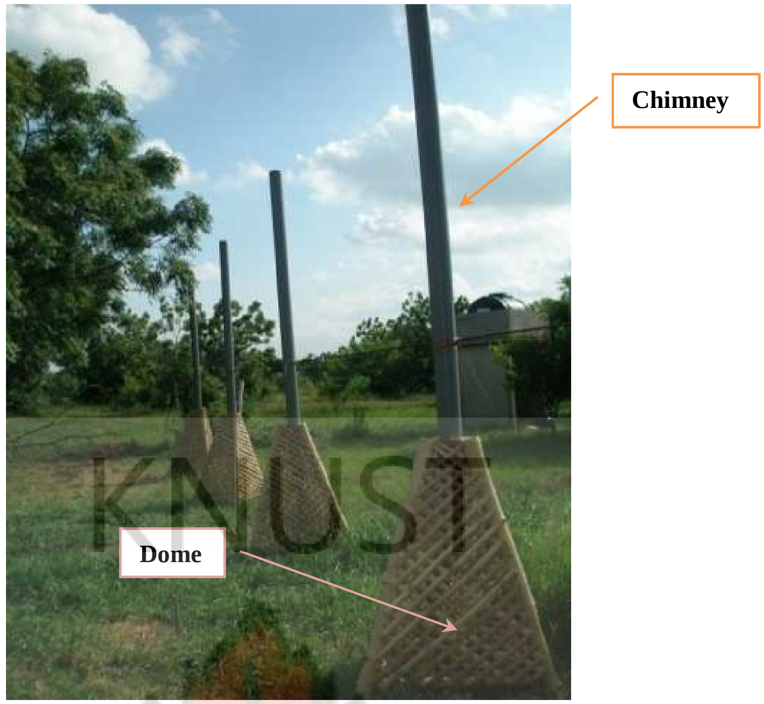


Figure 3.3: A schematic diagram of the Dome Aerated Technology (DAT) system



(a) Bamboo DAT aeration structure

(b) Set-up for bamboo DAT composting

Figure 3.4: Composting of river reed using a bamboo DAT

This pile is structured around four (4) bamboo domes with matching chimneys (uPVC pipe 101.6 mm in diameter, and 2.50 m high, figure 3.4). The triangular base bamboo dome was 1.40 m high; 0.75 m equilateral base. The rhombus-like grits in the domes were arranged to providing an average spacing of about 50.8 mm. Additionally, 10 pieces of perforated uPVC (101.6 mm in diameter and with holes of 25.0 mm and spaced at 300 mm) were placed beneath the pile to promote the 'chimney effect' by driving fresh ambient air into the compost pile (seen in Figure. 3.4a and b). The chimney pipes were supported by a cable to hold the pipes in position. The dimensions for the DAT composting system were 13.7 m × 2.7 m ×1.8 m (L×B×H). From this pile, sampling was conducted at three locations for laboratory analysis namely top, middle and bottom just as implemented in the other methods of aeration.

3.3.4 *Horizontal-Vertical (HV) Aeration Technology*

(a) Perforated uPVC pipes for HV system (b) HV set-up pile covered

Figure 3.5: Construction of the Horizontal-Vertical (HV) pile

The horizontal-vertical (HV) aeration technology was adapted from (Sylla *et al*., 2006), and works on the same principle as the DAT. The difference with this set-up was with the use of larger uPVC pipes, 152.4 mm diameter, perforated with holes to effect the passive aeration. The sign is adopted as a scale-up of a passive aeration study reported by (Sylla et al., 2006). The pipes were inverted, T-shaped and were perforated on the horizontal section to allow ambient air to move into the pile. The vertical section was also perforated to also allow warm and waste gases to exit the compost mass. The dimension of the pile was 6.8 m (L) ×2.6 m (B) ×1.7 m (H) and was covered with a "Toptex" (fleece) sheet. The vertical pipe was perforated to about 1.2 m high from the bottom (Figure 3.5).

3.3.5 *Mechanically Turned Windrows*

For the mechanically turned windrow system, the feedstock was initially turned four times. A fraction of this feedstock was used in the forced-aeration pile experiment. The dimensions for this pile were 35 m ×2 m ×0.9 m (L ×B×H) (Figure 3.6). Turning was conducted on the piles when temperature or CO_2 concentration levels exceeded 65 ^{0}C or 20% respectively. This process was undertaken by using the "Sandberger ST 300" (turning equipment) pulled by a 90 HP tractor. The front-loader (165 HP) was used to reshape the pile after which a "Toptex" (fleece) sheet was used to cover the windrow.

Figure 3.6: Preparation of the Turned Windrow pile

3.3.6 ***Forced-Aeration (FA) Technology***

This method used an electrical "DIETZ-Mortens" Radial-Ventilators (controlled intermittently by timers; Timer ON – 2 min. and Timer OFF -15/30 min.) with a specified maximum flow rate of 18m^3/min and power rating of 0.4 kW. Air was blown through 101.6 cm diameter perforated pipes with holes of about 2.50 cm and spaced at 300 mm on a pipe length of 3.00 m. The pile was mounted with the following dimensions; 4 m × 2 m ×1.5 m (L×B×H). The pile was mounted a day after turning the mixture. Wood shavings from a local wood processing facility was used as bulking material to facilitate even air distribution at the bottom of the pile and also prevent feedstock materials from blocking the perforated holes. The blower was covered with a metal can to protect it from rain, while the fleece was used to cover piles to prevent excess drying or precipitation.

Each feedstock pile was inoculated with a commercial inoculant "SoilTech™ solutions starter" which was found to contain dominant *Bacillus spp.* and *Corynebacterium spp* microorganisms. This was used with the aim of hastening degradation of organic matter and preserving nutrients; which is consistent with its use at the VREL site. The powdery "SoilTech™ solutions starter" was dissolved in the proportion of 500 g in 40 L water, and mixed with each primary feedstock pile (dimension of 2.0 m by 50 m by 1.5 m), which was turned twice to facilitate uniform mixing of inoculum. This inoculated pile was then used in setting up the experimental piles for monitoring and analysis.

(a) Forced-Aeration channel

(b) **Forced-Aeration pile covered with a Topex fleece**

Figure 3.7: Construction of the Forced-Aeration (FA) pile

3.3.7 *Replication of Piles*

As reiterated by some Authors investigating in this area (Sundberg, 2005; Bari *et al*., 2000; Benito *et al*., 2009), no replicate piles were formed because of the relatively larger scale of the experiment (at pilot scale, i.e. 100-2000L); and limited funding to undertake a wider range analysis of parameters. Thus, in implementing stratified sampling and properly mixing the samples to form a representative sample before transporting to the selected laboratories for analyses, we reckon, as with supporting literature will satisfy the integrity of the data obtained. A number of researchers have reported that running experiment at pilot to full scale can be expensive, sometimes difficult to control and may limit replication (Bari *et al.*, 2000; Sundberg, 2005; Zhu, 2006; Mason, 2007; Szanto *et al*., 2007; Benito *et al*., 2009). Indeed, work by Fernandez *et al*. (1994), showed that identical composting piles replicated under passive aeration demonstrated that parameters monitored can have high reproducibility. However, the experimental design and set have been elaborated with specifications (composition, dimensions and pictures) and relevant references to allow for replication by other researcher.

3.4 **Field Sampling and Measurements**

The turnover on Organic Matter and Nitrogen may vary with feedstock, aeration mechanism and size of the composting set-up. The 12-14 weeks of monitoring was adapted to able the study clearly differentiate between the active composting periods (temperatures $\geq$ 45^0C) and the maturation-curing period (temperatures < 45^0C). Sampling intervals for abattoir composting was conducting at 14days intervals, because of the size of the piles and the initial moistures control adopted for this study. Increasing the sampling time would have interfered with temperature development because of cooling effect from the ambient air due the rate of mass reduction accounted for by the frequent sampling and moisture level between 55-75%. However, in the case of river reed composting, the size of pile (field-scale) was relatively large, and could allow for a weekly sampling.

3.4.1 ***Field Sampling for Abattoir Waste***

The most frequent on-site measurement undertaken during this experiment was temperature. This was performed with the aid of a “Reotemp” (24”) thermocouple at three stratified locations in each pile; top, middle and bottom. Samples for laboratory analysis were collected before moisture adjustments and mixing of the piles. For the purposes of laboratory analysis, sampling from the stratified location were mixed to form a representative sample for each pile, accounting for about 2 kg of material. These representative samples were transferred into a labelled plastic bag and placed in an ice-chest for transportation to the principal laboratory.

3.4.2 *Field Sampling for River Reed*

For this experiment, the following parameters were measured; temperature (measured daily except on Sundays) and gaseous products (CO_2 and CH_4) on a weekly basis. Temperature was measured with the aid of a long-stem "Reotemp" (60.96 cm and 81.28 cm) thermocouple at stratified locations. Usually, for stratified sampling, the top (30 cm from surface of the pile), middle and bottom (30 cm from the base) were applied to the opposite ends of the length of the piles. The samples were collected each week with a spade to the depth of about 40 cm across stratified locations. The samples were mixed, coned and quartered to obtain a representative sample of about 2 kg, standard sample handling protocol as in the case of abattoir waste composting was adopted.

This was followed by analysis of gas concentrations in the composting piles. The gas analyses were conducted using portable 'Sewerin SR2-DO" which has high sensitivity for detecting even low concentrations of carbon dioxide (CO_2), methane (CH_4) and Hydrogen sulphide (H_2S). The instrument had an accuracy of ±3%, measured CO_2 and CH_4 over a range 0-100%, and H_2S over a range of 0-2000 ppm. Granules of Potassium Chloride (KCl) and filters were placed in gas collection tubes to filter and prevent moisture and dust from entering the analyser to avert possible damage or potential errors in analyser readings.

3.4.3 *Sample Handling, Processing and Storage*

Chemical analyses were performed at different laboratories due to logistic constraints. These included: the Department of Soil Science (KNUST), the Department of Civil Engineering (KNUST), the Soil Research Institute - Council for Scientific and Industrial Research (SRI-CSIR) in Kumasi; Ecological Laboratory (Ecolab) University of Ghana, Legon- Accra; and the Department of Civil Engineering- University of Western Ontario.

Mixed samples were divided into two fractions for wet-basis and air-dried processing. Wet samples were homogenised in a “Waring” laboratory blender or a kitchen blender prior to storage at 4^0C or frozen (-4^0C) prior to analysis or directly used in the determination of pH, electrical conductivity, moisture content, organic matter, and ammonium-nitrate ions. For air-dried sample processing, samples were air dried for about 5-8 days, pulverized in a hammer mill and sieved to about 1-2mm particle sizes. Parcelled air-dried and pulverized samples were kept in plastic bags and correctly labelled for use in the laboratory analyses.

3.4.4 *Physicochemical Analyses of Samples*

The compost monitoring parameters were selected to enable the study measure process efficiency based on: potential pathogen sanitization (using temperature and its models), turnover on Organic Matter (OM); turnover on Total Nitrogen; product quality based on EC and other macro nutrients; and heavy metals concentrations. Other parameters measured enable were used to as indicators to explain why a particular phenomenon occurred at a period or over a length of period of monitoring.

Parameters monitored included: pH, Electrical Conductivity (EC), Moisture Content, Organic Matter, Total Carbon and Total Nitrogen (TN). However, because of the putrescible nature of the abattoir waste feedstock, Total Nitrogen, using the same Kjeldhal method, was determined on wet basis and corrected with the respective moisture contents. Concentrations of Potassium, Calcium, Magnesium and phosphorous using ignited (ash) samples were determined at week 0 and 12 for abattoir waste composting. However, concentrations of Potassium and Phosphorous were determined in the river reed compost piles weekly. Further analysis was conducted to determine metal content (such as Ni, Cu, Zn, Cd, Pb) with the air dried compost materials using the inductively coupled plasma optical emission spectrometry (ICP-OES). The analytical methods employed in the analyses of compost are summarized in Table 3.2.

3.4.5 *Determination of Concentrations of K, Ca, Mg and Available P*

Concentrations of K, Ca, Mg and available P for abattoir waste feedstock and compost were determined calorimetrically using 0.1M ammonium acetate as extraction solution at a pH 7.0 on about 10g of ashed compost samples which was followed with ammonium paramolybdate and ascorbic acid solution to determine P (Soil Conservation Service, USDA 1972; Negassa *et al.*, 2001). Standard solutions of 0, 0.8, 1.6, 2.4, 3.2 and 4.0 mgP/l was prepared by diluting appropriate volumes of the 10 mgP/l standard sub − stock solution. These standards were subjected to colour development and their respective transmittances read as specified above. A calibration curve that plots concentrations of known standards against the instrument's response (absorbance or transmittance) was used to calculate the concentration of elements, in this case P and K.

Ten millilitres (10 ml) of the filtrate was pipetted into a 25 ml volumetric flask and 1 ml each of molybdate reagent and reducing agent were added for colour development. The percent transmission was measured at 520 nm wavelength on a "spectronic 21D" spectrophotometer. The concentration of P in the extract was obtained by comparison of the results with a standard curve.

Table 3.2: Summary of analytical methods for compost characterization

Parameter	Matrix	Measurement	Method	Reference
pH and EC	Compost/soil	Electrode meter	Water extract at (1:5; w/v)	Díaz, *et al*., 2002; Faithful, 2002; Meunchang *et al*., 2005
Total carbon	Compost	Thermo-gravimetric	(100-ash%)/1.83 or Eltra CS 500	Wu *et al*., 2000; Barrington *et al*., 2002; Haug, 1993
Organic Matter	Compost	Thermo-gravimetric	Furnace at 550 ^{0}C	Faithful, 2002
Dry matter	Compost	Thermo-gravimetric	Oven drying at 105 ^{0}C	Faithful, 2002
Total Nitrogen	Compost/soil	Reduction, distillation/ Titration	Mineralization with conc. H_2SO_4 and distillation using the Kjeldhal method	Faithful, 2002; Okalebo *et al*., 2002)
Total P and K	Compost/soil	Titrimetric/Colorimetric	Ammonium Acetate extraction	Negassa *et al.*, 2001
Total Ma and Ca	Compost/soil	Titration Colorimetric	Ammonium Acetate extraction	Negassa *et al*., 2001
Ammonium-nitrogen	Compost	Reduction and distillation/ Titration	2M KCl extraction and distillation with alkaline MgO	Faithful, 2002
Nitrate-nitrogen	Compost	Reduction and distillation/ Titration	2M KCl extraction and reduction with Devarda's alloy	Faithful, 2002
Total phosphorus (P)	Compost	Spectrophotometer or Induced Couple Plasma (ICP) spectrometer	extraction with acid followed by colorimetry or ICP-OES	Faithful, 2002; Okalebo *et al*., 2002; USCC and USDA*, 2001
Total Potassium (K)	Compost	Flame photometry or Induced Couple Plasma (ICP) spectrometer	extraction with acid followed by flame photometry or ICP- OES	Faithful, 2002
Heavy metal	Compost/soil	Induced Couple Plasma (ICP) Optical Emission spectrometer	Air-dry sample digested with HNO_3 $+H_2O_2$ and determined by ICP.	Faithful, 2002; USCC and USDA*, 2001
Bulk density	Compost/soil	Wet-basis, gravimetric	Calibrated bucket of 17 L	

*The US Composting Council and the United States Department of Agriculture

Observed transmittance (T %) of P was converted to absorbance using the expression 2-logT, which was matched with its corresponding concentration on a calibration curve.

$$\text{Available P (mg/kg)} = \frac{Graph\ reading \times 20 \times 25\ \times\ Ash\ content}{weight\ of\ sample(g) \times Aliquot}$$

Potassium in the sample extracts were determined by flame photometry. Standard solutions of 0, 2, 4, 6, 8 and 10 mg/l were prepared by diluting appropriate volumes of 100 mg/l K solution to 100 ml in volumetric flask using distilled water. Photometer readings for the standard solutions were determined and a standard curve constructed. Potassium concentrations in the soil extract were read from the standard curve.

$$\text{Exchangeable K (cmol/kg)} = \frac{Graph\ reading \times 100 \times\ Dilution\% \times Ash\ content}{weight\ of\ sample(g)}$$

Where:

w = sample of weight in grams (in this case 10.00 g)

Aliquot = initial sample solution volume (in this case 10 ml)

20 = ml extracting solution

25 = ml final sample solution

Ash content: is a fraction is of ash in dry matter of sample with time

Titre values of calcium (Ca) and magnesium (Mg) were determined with 0.02N EDTA. Calcium and magnesium were evaluated as;

$$\text{Exchangeable Ca (cmol/kg)} = Titre\ of\ Ca \times 2 \times Ash\ content$$

$$\text{Exchangeable Mg (cmol/kg)} = [Titre\ of\ (Ca + Mg)\ -\ Titre\ of\ Ca]\ \times 2 \times Ash\ content$$

Titre: volume of equivalence to reach indicative phase (ml)

3.4.6 *Determination of compost pH*

The pH values of various set-ups of composting piles were determined. The pH was measured using a digital pH-meter in a 1:5 (w/v) extract of compost material to water ratio. About 10.0 g of each of the material was weighed into a 100 ml beaker and 50 ml of distilled water was added, stirred for 30 minutes and was allowed to stand for 30 minutes. The electrode of a standardized pH-meter was inserted into the settled suspension after which, the pH values of aliquot were read from the pH scale and recorded (Faithful, 2002).

3.4.7 *Electrical Conductivity (EC)*

Electrical Conductivity of the sampled compost material was measured using the same aliquot made for pH determination. The electrical conductivity meter was calibrated with a KCl reference solution. The conductivity electrode was inserted into the supernatant and electrical conductivity reading was taken for each sample (Faithful, 2002).

3.4.8 *Moisture Content and Volatile Solid*

Moisture Content or total solids in the pile matrix were determined for all samples at 105^0C using digital ovens (Gallenkamp SANYO OMT Oven) for about 10 or 20 g of representative sample. Consequently, volatile solid (also known as the Organic Matter – OM) fraction was determined from the oven-dry samples, using a “Nebertherm” digital furnace which was set to 550^0C for 4 hours in porcelain crucibles. Losses of Organic Matter (OM) were calculated according to the following equations (Paredes *et al.*, 2000):

$$OM\ Loss\ (\%) = 100\% - 100\left\{\frac{(100 - OM_o) \times OM_t}{(100 - OM_t) \times OM_o}\right\}$$

Where, OM_o and OM_t are the initial and dynamic percentage Organic Matter contents for a sampling time, respectively. Thus, fitting to a general first order kinetic decay model:

$$OML = OML_0(1 - e^{-kt})$$

where OML is the remaining mass (%), OML_0 the potential residual mass (%), k the decomposition rate ($week^{-1}$) and t is time (weeks). Generally, nutrient loss on ashless basis during composting was evaluated according to (Paredes *et al*., 2000).

$$Y\ loss = 100\% - 100\left\{\frac{X_0 \times Y_t}{X_t \times Y_o}\right\};$$

where X_0 and X_t are the ash concentrations at time = 0 and time = t, and Y_0 and Y_t are the nutrient (parameters) concentrations at time = 0 and time = t respectively.

3.4.9 *Determination of Total Carbon in Soil and Compost Materials*

Carbon content of samples for experiments conducted at KNUST, Kumasi was determined by dividing the volatile fraction by 1.83 (Barrington *et al*., 2002). Carbon was therefore expressed as:

$$\text{Percentage Carbon, C \%} = \frac{(100 - \%ash)}{1.83}$$

The experiments conducted on the VREL project to determine Total Carbon were measured using an "Eltra CS 500" carbon/sulphur analyzer, calibrated to an equal mass of calcium carbonate ($CaCO_3$). Results are reported as means of at least three replicates, unless otherwise stated.

3.4.10 *Determination of Total Nitrogen, Phosphorus and Potassium*

In the determination of Total Nitrogen 1g of each soil sample was weighed into a digestion tube (APHA, WPCF, AWWA, 1995; Okalebo *et al.*, 2002). A volume of

2.5 ml of conc. H_2SO_4, selenium and salicylic acid mixture was added to the tubes and then digested for 1 hour. The digestates were allowed to cool and followed by the addition of 2.0 ml hydrogen peroxide. The mixtures were then digested further for 30 minutes. After this, the digestates were filtered into 100 ml volumetric flasks and made to the mark with distilled water.

A 5.0 ml aliquot of each digestate was pipetted into fresh digestion tubes followed by the addition of 5.0 ml of 40 % NaOH. A 5.0 ml aliquot of a mixture of 2% boric acid and methyl blue indicator was measured into 100 ml conical flasks. The digestates were then distilled and the distillates were collected into the boric acid and methyl blue mixture in the conical flask. The distillate was then titrated against 0.01M HCl. The Total Nitrogen concentration of the compost was calculated using the formula below:

$$\% \text{ TKN in compost} = \frac{\text{(a-b)} \times Molarity\ of\ acid \times Mw - N \times v \times 100}{w \times vol.of\ aliquot \times 1000}$$

Final volume of the digestate (v): 100 ml

Weight of the sample taken in grams (w): 0.1 g

Aliquot of the solution taken for analysis: 5 ml

Molarity of acid: 0.01N

Molar weight of Nitrogen: 14.0 g/mol

For available Phosphorus, in the river reed piles, 5.0 ml of the supernatant (aliquot) was pipetted into a 50 ml volumetric flask. The pH of the solution was then adjusted by adding two drops of para-nitrophenol indicator and a few drops of 4N NH_4OH until the solution turned yellow. Eight (8) ml of ammonium molybdate-ascobic acid solution - $(NH_4)_6Mo_7O_{24}$..4H2O) was added and made to the mark with distilled water. The solution was mixed thoroughly by shaking and allowed to stand for 15 minutes for blue colour to stabilize. The intensity of the blue colour was measured with Spectrophotometer at a wavelength of 712 nm (Okalebo *et al*., 2002). The following formula was used for the calculation of available P in the compost.

$$\text{P in sample (\%)} = \frac{\text{Meter reading} \times v \times 100}{\text{w} \times aliquot \times 1000 \times 1000}$$

Total Potassium (K) was also determined, for the river reed piles, after pipetting an aliquot, from the total Kjeldhal nitrogen solution into a 50 ml volumetric flask. The volume was made up to the mark and flashed into a "JENWAY PFP7" flame photometer to measure the concentration. Potassium concentrations present in the solution were read from the calibration curve prepared by plotting absorbance readings against potassium concentrations in the standard series.

$$\text{K in sample (\%)} = \frac{\text{corrected concentration} \times v \times f \times 100}{\text{w} \times 1000 \times 1000}$$

Where:

Corrected concentration of P in sample (mg/l) = sample reading – blank reading

v: volume of the digest = 50.00 ml

Aliquot = 10 ml

f : dilution factor and

w: weight of the sample taken = 0.10 g

3.5 **Data Analysis**

Analysis of Variance using GenStat3 was employed to determine significant differences among treatment means. Data on parameters sampled or analysed in the laboratory were conducted in triplicates and presented and analysed as means of the triplicate samples. Treatment mean differences were generally determined by the LSD (least significant difference) at 5% level of significance. Correlations and regression models were used to examine the relationships between measured parameters and goodness of fit expressed in terms of its residual (R^2). Generally, descriptive graphs and related data analysis and curve fittings were conducted with the SigmaPlot 10.0 functional tools. Initial parameter values, in the case of temperature analysis, were set to according to the guideline provided by Yu *et al*. (2008). Estimation of area under a graph was performed using Matlab 7.0.1 as a platform (Appendix D1). Plots of graph were made in MS-Excel and SigmaPlot 10.

CHAPTER 4 : RESULTS AND DISCUSSION

This chapter contains results and discussion on data collected for the thesis categorized into two main sections: Abattoir waste composting (feedstock formulation or turning frequency); and river reed composting (effect of aeration technology). This Chapter also compares results with other relevant literature.

4.1 Feedstock Characterization for Abattoir Waste Composting Experiment

The physicochemical characteristics of the component feedstock material used in the compost pile formulations are presented in Table 4.1.

Table 4.1: Physicochemical characteristics of component feedstock material

Parameter	AW	MW	CSW	YTW	CPH	SW
M C (%)	82.31(1.22)	63.11(10.33)	17.20(1.05)	37.0(0.4)	67.77(8.32)	13.54(0.46)
OM (%)	69.47 (0.65)	70.91(1.92)	82.19(1.05)	67.56(0.78)	71.04(0.21)	84.04(0.19)
TC (%)	37.96(1.03)	39.3(0.88)	47.51(1.37)	36.90(1.02)	39.91(0.01)	47.21(0.88)
TN (%)	2.10(0.07)	1.77(0.04)	0.51(0.09)	1.40(0.05)	1.71(0.06)	0.06(0.01)
C/N ratio	18.16 (1.18)	22.0(1.26)	92.94 (2.06)	26.4(0.71)	23.33(0.24)	366.67(0.67)
pH	7.41(0.33)	5.60(0.41)	5.67(0.05)	6.61(0.18)	7.85(0.23)	6.56(0.15)
EC (mS/cm)	3.45(0.06)	3.64(0.05)	1.22(0.08)	2.81(0.03)	3.16(0.04)	0.51(0.03)

AW-Abattoir Waste; MW-source separated Market Waste; CSW-Corn Straw/Cob Waste; YTW- Yard Trimming Waste; CPH-Cocoa Pod Husk; SW-Sawmill Waste.
Note: Numbers in parenthesis represent standard deviation of three replicates

Abattoir waste used as the main substrate for this section of study had the highest mean Moisture Content (M.C) of 82.31%. Mean Moisture Contents of the bulking agents (CSW and SW) were less than 20%. However, mean Organic Matter content (OM) for the analysed materials ranged between 67.56-84.04% of dry matter. The highest Total Nitrogen content was realized in abattoir waste (mean value of 2.10%), whiles the lowest mean nitrogen content noted in SW (mean value of 0.06%). Whereas Abattoir waste, Market waste, corn stoves and sawmill waste were acidic; Yard trimming and Cocoa pod husk recorded alkaline with pH. The highest electrical conduction was observed in the MW, which depicts a high ionic concentration; this concentration level does not form a basis for phytotoxicity.

Table 4.2: Physicochemical characteristics of formulated compost feedstock

Sample/Properties	AMYC	ACC	ACS
MC(%, wb)	65.73(4.31) *	76.37(1.65)	75.81(3.80)
OM(%,db)	71.50(2.78)	68.44(2.61)	65.76(4.22)
TC (%, db)	39.07(1.52)	37.40(1.43)	35.94(2.30)
TN (%,db)	1.54(0.17)	1.62(0.09)	1.58(0.12)
C/N (db)	25.63(3.42)	23.10(1.70)	22.92(3.05)
pH (wb)	7.28(0.15)	7.38(0.01)	7.32(0.08)
EC (mS/cm; wb))	2.13(0.14)	1.89(0.27)	1.64(0.30)

AW-Abattoir Waste; MW-source separated Market Waste; CSW-Corn Straw/Cob Waste; YTW- Yard Trimming Waste; CPH-Cocoa Pod Husk; SW-Sawmill Waste; wb- Wet basis; *means of three values calculated on the wet basis (wb) or dry basis (wb) unless otherwise specified

Initial Organic Matter (OM) content of between 65.76 to 71.50 % of dry matter (DM); Carbon-Nitrogen (C/N) ratio between 22.92 to 25.63, is within the suitable range recommended for composting (Haug, 1993; Mason, 2007); and Moisture

Content (MC) ranging from 65.73 to 76.37 % on wet basis (wb) was recorded after analysis. Moistening of the piles was conducted to keep MC during the active phase of composting above 65%, but less than 80% (to prevent an anaerobic system in the piles).Initial Total Nitrogen (TN) and Total Carbon (TC) content varied from 1.54-1.68% and 35.94-39.07 % (DM) respectively; while pH and Electrical Conductivity (EC) values varied between 7.28-7.38 and 1.64-2.13 respectively on the average (Table 4.2). These are within the recommended ranged suitable for optimal composting.

4.2 Temperature Profile: Abattoir Waste Composting Experiment

The temperature characteristics of the feedstock piles (AMYC, ACC, and ACS) and turning frequencies (3DT, 7DT and 14DT)[1] are shown in Figure 4.1 - 4.3. The achievement of a thermophilic phase was observed in some piles, while other piles showed a dominant mesophilic phase over the monitoring period; a period of 93 days for feedstock ACC and ACS, 83 days for feedstock AMYC.

In measuring performance, the areas bounded by the temperature-time profile and reference temperatures of 40 and 55 ^{0}C baselines, A_{40} and A_{55} (Appendix D1), the times for which these temperatures were exceeded (t_{40} and t_{55}), and times to which temperatures peaked were determined (Mason and Milke, 2005). The generic characteristics shape for temperatures formed in feedstock AMYC and ACC and their respective turning frequency regimes showed similarities to generic profiles, while that of ACS and its respective turning frequencies showed differences to generic profiles.

[1] 3DT: 3 days turning frequency; 7DT: 7 days turning frequency; 14DT: 14 days turning frequency

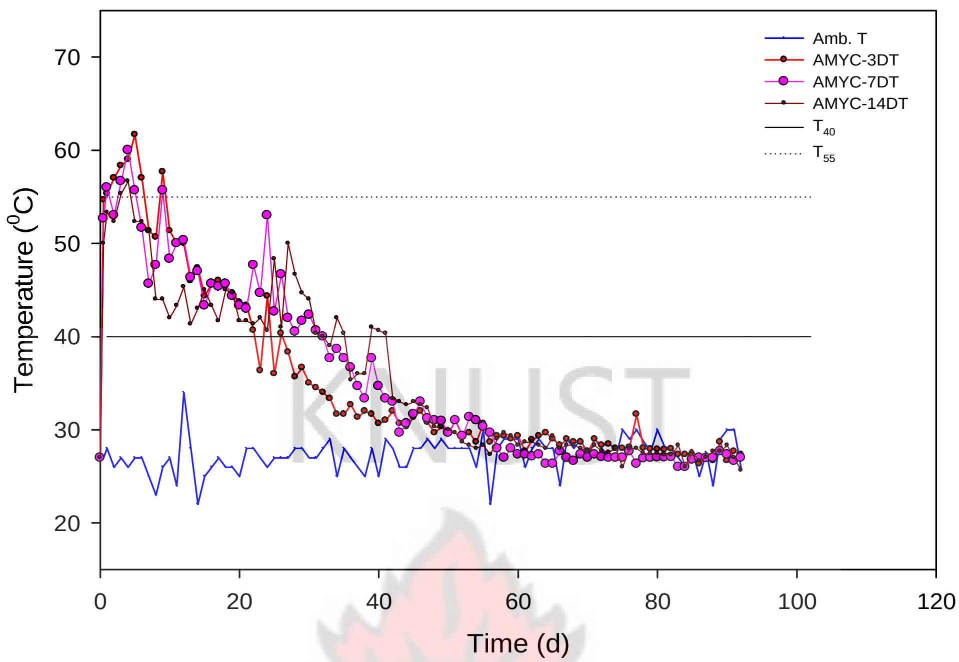


Figure 4.1: Temperature profile observed in AMYC treatments

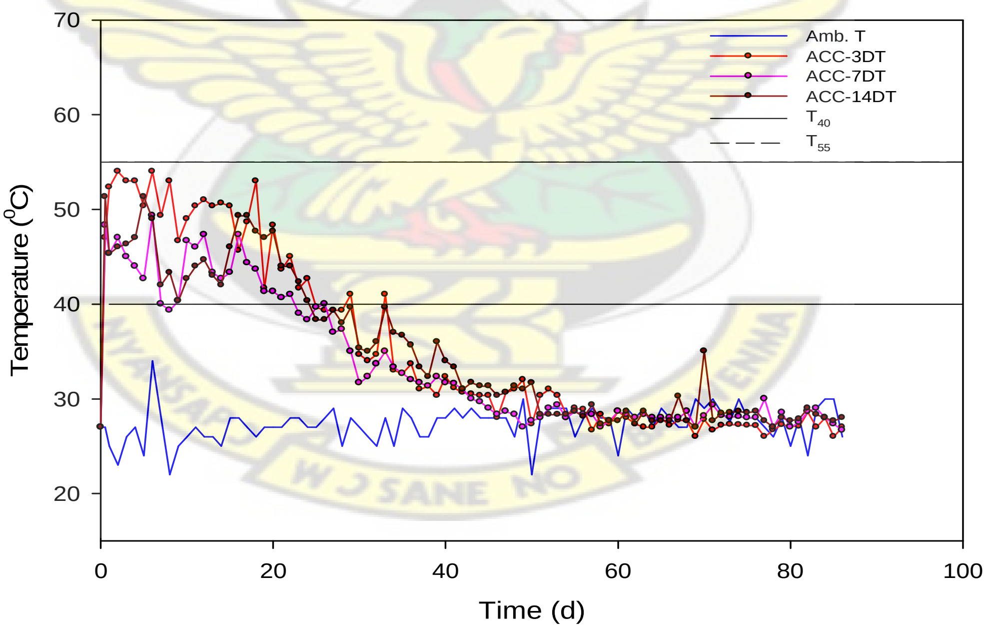


Figure 4.2: Temperature profile observed in ACC treatments

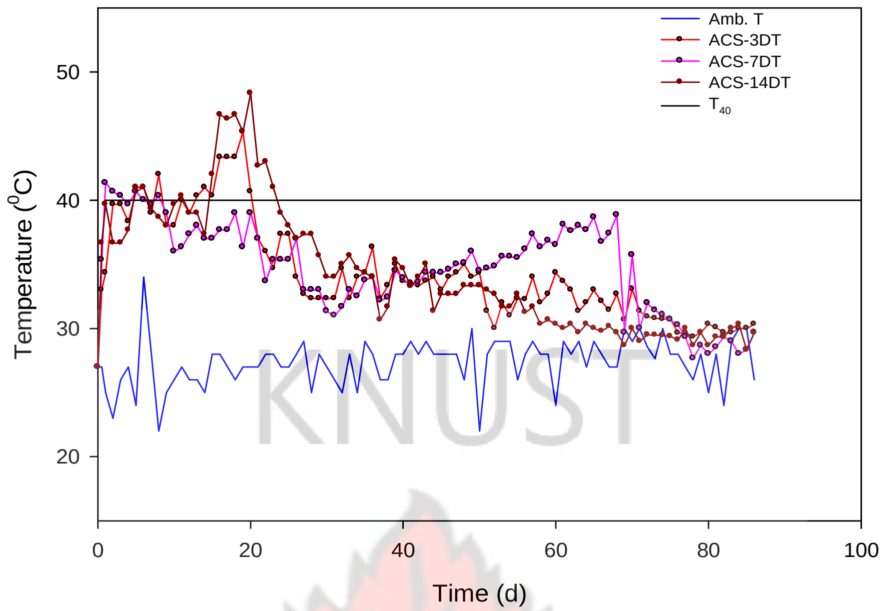


Figure 4.3: Temperature profile observed in ACS treatments

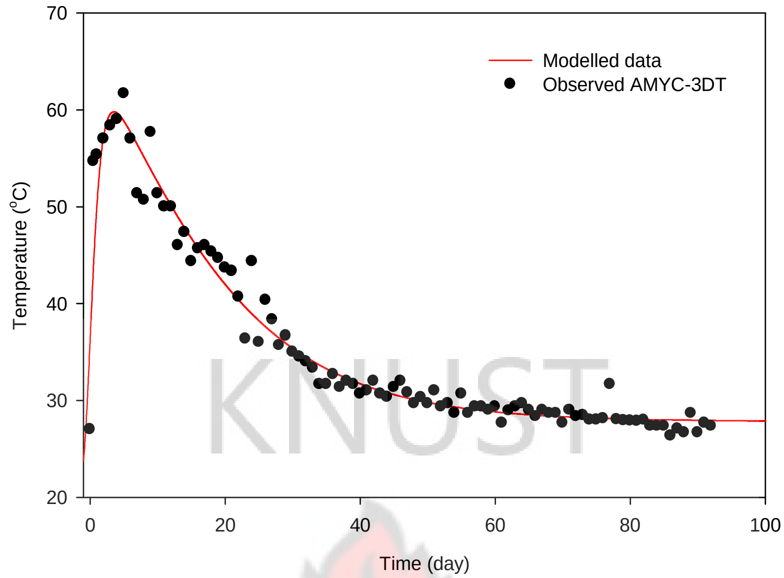
The temperature-time profiles for the composting of abattoir waste under the aforementioned treatments (feedstock and turning frequency) are presented in Table 4.3. Peak average temperature values recorded were highest (61.7 ^{0}C) in AMYC at 3DT, in week 4. On the other hand, low peak values ranging from 41.3 to 54.0 ^{0}C was recorded in feedstock ACC and ACS. The longest period taken to reach the peak value was observed in treatment ACS at14DT. The AMYC treatments were the only mixtures that were able to reach or exceed 55^{0}C temperature reference. Tiquia *et al.* (1996) reported low temperatures and microbial activity in composting piles maintained at 70% MC as compared to those maintained at 50 & 60% MC during composting of pig manure-sawdust litter. Generally, it can be said that small compost piles are often characterized by lower temperatures in comparison with large compost piles because of higher heat losses in small piles. The low peak temperature values observed could be attributed to the size of the piles.

Table 4.3: Temperature profile parameters in abattoir composting study

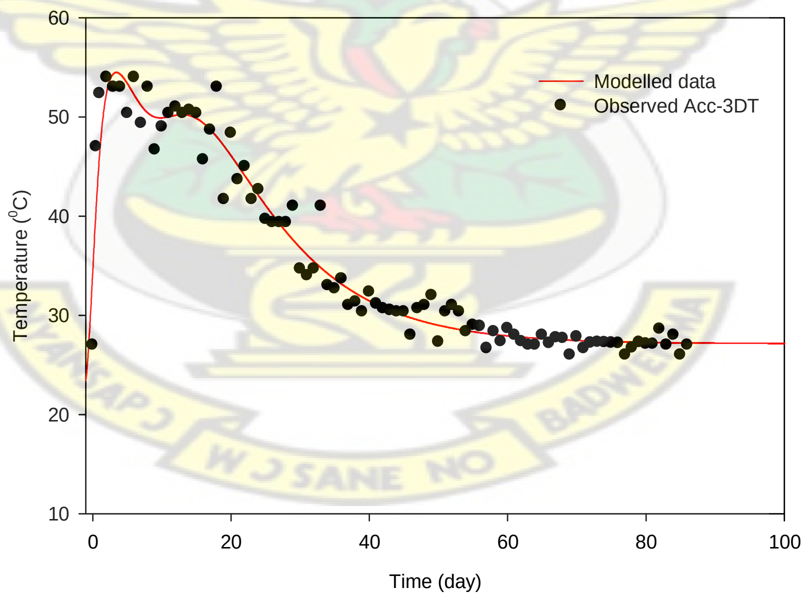
Indicator	Unit	AMYC			ACC			ACS		
		3DT	7DT	14DT	3DT	7DT	14DT	3DT	7DT	14DT
Initial	^{o}C	55.3	52.7	50.0	47.0	48.3	51.3	33.0	35.3	36.6
Peak Temperature	^{o}C	61.7	56.0	56.7	54.0	49.3	51.3	45.3	41.3	48.3
Time to reach peak	d	4	1	4	2	6	5	19	1	20
Period above 55 ^{o}C, t_{55}	d	5	5	2	0	0	0	0	0	0
Period above 40 ^{o}C, t_{40}	d	23	32	37	25	23	24	20	6	12
Area above the 55^{o}C, A_{55}	$^{0}C \cdot d$	18.3	6.3	1.6	0	0	0	0	0	0
Area above the 40^{o}C, A_{40}	$^{0}C \cdot d$	227	236.5	180	217.7	82	124.7	7.3	2.7	26.0

To improve compost sanitization potential in these studies, moisture content may have to be set within 55-65% to facilitate better passive aeration in piles. Also, an increase in pile size to improve heat retention may prove beneficial in improving the temperature-time characteristics to ensure better pathogen sanitization, which is a very important factor for composting process efficiency. The temperature-time profile for the selected feedstock formulation and turning frequency recorded A_{40} values of between 2.7 to 236.6 ^{0}C·days (AMYC-7DT>AMY-3DT>ACC-3DT>AMYC-14DT>ACC-14DT>ACC-7DT>ACS-14DT>ACS-3DT>ACS-7DT, see Table 4.3 above). Also, evaluation of A_{55} values revealed that piles AMYC-3DT AMYC-7DT and AMYC-14DT were the only treatments recording values above 0 (i.e., 18.3, 6.3 and 1.6 ^{0}C·days respectively). Indeed, the temperature-time characterizations of the self-heating piles indicate that feedstock AMYC had a better thermophilic activity and potential pathogen elimination compared to the other feedstock formulations.

These values were much lower compared with the characteristics of full-scale pile set-up. The pilot composting of abattoir waste showed temperature-time characteristic in the resemblance of laboratory scale experiment, A_{40} and $A_{55,}$ published by Mason and Milke (2005). Values evaluated are within the range reported for laboratory-scale reactor or small pilot experiments: A_{40} values ranging between 68 - 313 ^{0}C·days, A_{55} values between 0 - 44 ^{0}C·days *op cit*. The time period of t_{40} of 6 - 37 days was recorded for the nine treatments; while that of t_{55} measured 5 days in AMYC (3DT and 7DT) and 2 days in AMYC-14DT. Time above the 40 ^{0}C reference temperature in treatments (AMYC, ACC and ACS-3DT) exceeded values, 6 - 16 days, published by Mason and Milke (2005), and t_{55} values of the understudied treatments were within range approximately, 0 - 7 days.



(a) AMYC-3DT treatment



(b) ACC-3DT treatment

Figure 4.4: Non-linear regression to predict temperature in selected compost piles

Table 4.4: Non-linear regression for temperature-time series in composting piles

Parameters*	Units	Initial	AMYC			ACC			ACS		
			3DT	7DT	14DT	3DT	7DT	14DT	3DT	7DT	14DT
T_0	^0C	20	35.000	27.843	29.308	23.875	28.758	29.151	21.701	26.713	25.415
T_M	^0C	10	30.221	29.958	24.868	39.513	24.475	24.932	18.340	14.793	14.732
k_M	d^{-1}	0.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
t_M	d	1	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
T_T	^0C	10	16.376	23.677	27.399	18.726	29.672	17.741	9.378	23.128	12.920
k_T	d^{-1}	0.01	1.000	0.211	0.196	0.279	0.241	0.413	1.000	0.105	1.000
t_T	d	1	0.010	17.839	18.896	11.237	10.887	12.961	15.677	43.888	14.704
T_C	^0C	10	53.769	55.000	55.000	54.987	55.000	43.914	17.243	55.000	22.784
k_C	d^{-1}	0.05	0.070	0.084	0.078	0.087	0.104	0.082	0.301	0.027	0.115
t_C	d	30	3.051	17.839	18.896	11.237	10.887	12.961	18.803	52.240	19.788
R			0.975	0.965	0.952	0.976	0.958	0.954	0.913	0.876	0.951
r^2			0.950	0.932	0.906	0.953	0.919	0.910	0.834	0.768	0.905
No. of Iteration			**27**	**20**	**15**	**27**	**30**	**15**	**21**	**20**	**22**

*: $T=T_0+T_M*\exp(-\exp(-k_M*(t-t_M)))+T_T*\exp(-\exp(-k_T*(t-t_T)))-T_C*\exp(-\exp(-k_C*(t-t_c)))$

Yu *et al*. (2008) indicated that their statistical model could not accommodate discontinuous data such as those from compost trials that involved turning and/or re-mixing. However, this work, in testing the model gave good fits to describe the temperature-time series during a composting process that involved turning (Figure. 4.4, Table 4.4, and Appendix D2). The summarized parameters of the non-linear regression evaluated to describe the temperature time profile in the piles resulted in a regression co-efficient r^2 between 0.768 and 0.953 (Table 4.4). This model describes the biological activity of the piles. The parameter 'T_0' describes the temperature at the start or end of the temperature profiles (Yu et al., 2008). The study revealed that treatment AMYC-3DT recorded that highest modelled initial temperature of the pile (35.0^{0}C), whiles ACS-3DT recorded the lowest temperature of the pile (21.70^{0}C). Treatments AMYC, 14DT and AMYC-3DT achieved the highest initial temperature of 30.717^{0}C, 27.958^{0}C and 35.00^{0}C respectively in the model (Table 4.4).

The maximum mesophilic heating coefficient (k_M) and time when maximum mesophilic heating rate occurs (t_M) were all similar with examined treatments (1 d^{-1} and 0.01 d respectively). Thus, mesophilic temperature contribution to the overall pile temperature profile started at the beginning of the pile set-up. The highest heating potential of the mesophilic stage (T_M) modelled were achieved in treatments ACC, 3DT and AMYC-3DT (29.64^{0}C, 29.358^{0}C and 30.221^{0}C) respectively above the start or ambient temperature). These were the highest mesophilic microbial contribution to temperature increase above ambient temperature with respect to treatments. The highest maximum temperature increases above a mesophilic temperature plateau stage (TT) were observed in treatments AMYC, 7DT and ACC-7DT (22.484^{0}C, 24.492^{0}C and 29.672^{0}C respectively). The highest maximum thermophilic heating coefficients (k_T) were observed in treatment ACS, 3DT, AMYC-3DT, ACS-3DT and ACS-14DT respectively).

Treatments ACC, 3DT and AMYC-3DT recorded the fastest time at which maximum thermophilic heating rate (t_T) occurred at 11.695 days, 8.875days and 0.010days respectively. These values also indicate that these treatments had relatively shorter lag time to reach their respective maximum thermophilic potential, as a result of thermophilic microorganism growth or aeration of the piles. The modelled cooling potential (T_c) which is the difference between the combined maximum temperature and the ambient or starting temperature [($T_0 + T_{hm} + T_{ht}$) - (T_0); or $T_{hm} + T_{ht}$]–indicates the magnitude of temperature drop from the time of maximum activity to compost maturity. These cooling phenomena also demonstrated the extent of microbial decay, which would have otherwise promoted bio-oxidation and generate heat (Yu, 2007). The highest cooling coefficients were realized in treatments ACS, 3DT, ACS-3DT. This could be attributed to the high moisture contents with respect to the feedstock composition of the treatments.

The results points to the fact that frequent turning (3DT) of the piles after they have reached their peak values may facilitate cooling than bio-oxidation. In this study the time when maximum cooling occurred (t_c) either coincided with the time when maximum mesophilic heating rate occurs (t_{hm}), ($t_c \geq t_{hm}$). This observation may vary with other treatments.

4.3 Effect of Feedstock Mixture on the Temperature Profile, Degradability and Nutrient of Abattoir Waste Composting

4.3.1 *Effect of Feedstock Composition on Temperature*

The ANOVA demonstrates that there exists a high significant difference ($p < 0.001$) in temperature between treatments during most parts of the composting process. The ANOVA results presented in Table 4.5 shows that mean temperature readings at week 0, ranged between 35.0 - 52.4^{0}C, with AMYC > ACC > ACS. A significant difference ($p < 0.007$) in temperature between ACC and the other treatments was observed in the transition period of week 6 of the composting process. None of the treatment achieved a thermophilic temperature reading (>40^{0}C) at or after the transitional stage; the thermophilic temperature time-phase of feedstock used in the study were relatively shorter compared to other experiment with relatively large pile sizes (Brito *et al.*, 2008). Temperatures recorded at the final stage of composting were slightly above the ambient temperatures recorded during the process.

Table 4.5: Effect of feedstock composition on temperature changes

Feedstock	Week						
	0	2	4	6	8	10	12
AMYC	52.4	45.8	41.4	32.8	28.6	27.4	26.4
ACC	48.9	45.1	37.9	30.9	28.8	26.7	28.0
ACS	35.0	38.4	34.2	32.9	31.3	29.7	29.4
LSD	5.920	2.319	2.578	1.293	0.762	0.426	0.972
p-value	<0.001	<0.001	<0.001	<0.007	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.739

Temperature evolution is considered an indicator of microbial activity during the composting process, and can be used to estimate the end of the bio-oxidative phase (Haug, 1993, Yu *et al*., 2008). Bio-oxidation with respect to feedstock composition was more pronounced in treatment with easily biodegradable material. This was observed as prolonged thermophilic temperatures recorded. Thus, AMYC and ACC could be said to have more easily biodegradable material or as per its constituents (sugars, Cellulose, hemicelluloses, lignin etc.) there is a potential residual amount of TC constituents (in the form of hemicellulose, cellulose and lignin) which varies bio-oxidation rate and it constants between different mixtures (Haug, 1993; Eklind and Kirchmann, 2000). This may be coupled by a high microbial activity due to good balance of initial C/N and MC. Thermophilic temperature developed poorly in feedstock maintained above 70% (wb) during the active phase and after, and this was comparable with the initially low organic matter levels.

Due to the relatively smaller size of the pile and the cooling effect of the environment, temperatures did not exceed 60^0C; however the optimum of 55^0C (Larney *et al*., 2000; Sundberg, 2005; Mason and Milke, 2005; Yu *et al*., 2008) was achieved in treatment AMYC and ACC only. As explained by Goyal *et al*., (2005) and Shaw *et al.* (1999), feedstock composition influences the maximum temperature reached or temperature pathways during composting.

4.3.2 *Effect of Feedstock Composition on Electrical Conductivity*

Apart from the type of feedstock composition showing significant effect on the EC values monitored; it is quite vivid that the source-separated market waste (MW) contributed to this effect. Market waste analysed before composting had the highest EC of 3.64 mS/cm among the materials used for the compost feedstock formulation.

A highly significant difference in EC values was observed among the feedstock formulation in most stages of the composting process. Notably, this was also observed with respect to turning frequency. However, the EC values analysed based on the effect of feedstock composition generally increased with time (Table 4.9). Since electrical conductivity gives indication of the nutrients level of the compost matrixes (Jones *et al*., 2009), mainly derived from the constituents of the feedstock, the significant differences recorded among treatments is attributable to the differences in feedstock compositions (AMYC>ACS>ACC, see Fig. 4.5). This ranking is also reflected in the moisture content of the treatment; the lower the Moisture Content (MC) the higher the EC values (Zameer *et al.*, 2010). The EC observed in the final compost pile did not exceed the 4mS/cm limit on phytotoxicity recommended by Lin (2008). The highly significant difference and relatively higher values recorded with feedstock AMYC could be as a result of the higher presence of vegetable and animal tissues in the pile (Zmora-Nahuma *et al.*, 2007; Appendix Table E3).

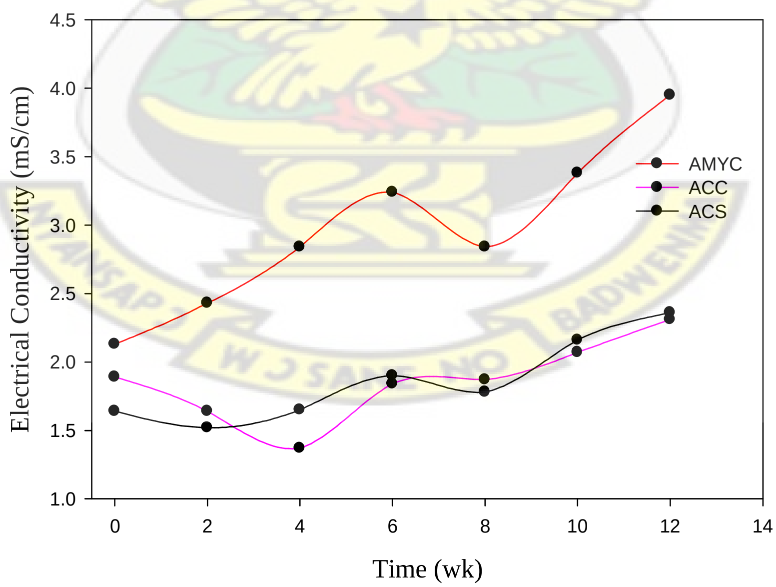


Figure 4.5: Effect of feedstock on Electrical Conductivity (EC, mS/cm)

4.3.3 ***Effect of Feedstock Composition on pH***

Hydrogen ion concentration (pH values) examined in the treatments for feedstock composition indicated that feedstock had highly significant effect ($p < 0.001$) on pH at every stage of the composting process. Contrary to pH values observed in most biowaste composting, where pH at the beginning of the composting process are relatively acidic (Sundberg, 2005), the feedstock formulations in this study recorded slightly neutral to alkaline initial pH values. More alkaline pH conditions were observed in the various formulations during the transitional phase (Fig. 4.6; Appendix E5); an indication of the breakdown of organic acid in the substrate and the decomposition of nitrogen-containing organic matter leading to the accumulation of NH_3 that dissolves in moisture to form alkaline NH_4^+ (Paredes *et al.*, 2000; Sanchez-Monedero *et al.*, 2001; Wong *et al.*, 2001; Sundberg, 2005).

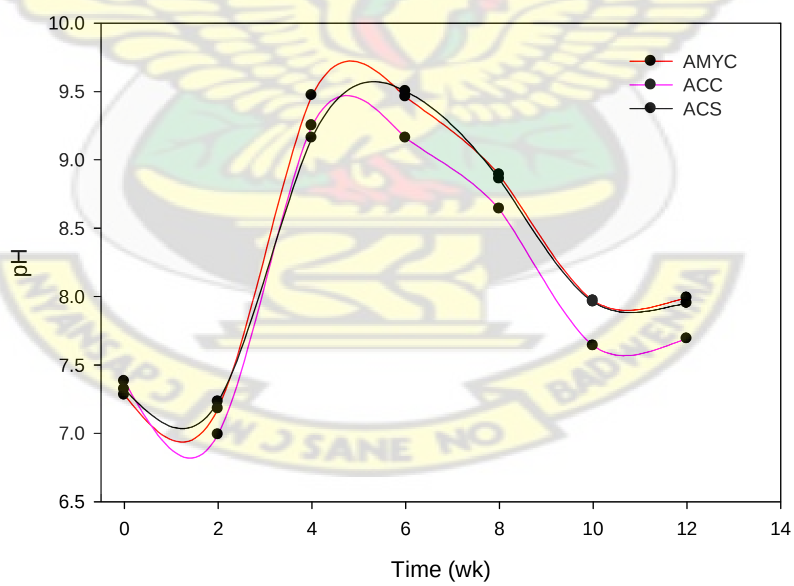


Figure 4.6: Effect of feedstock composition on pH during composting

4.3.4 *Effect of Feedstock on Moisture Content*

The highest mean Moisture Content (MC) recorded during the composting process was 76.37%, occurring in feedstock composition ACC at week 0 (Fig. 4.7; Appendix 7). A significant difference ($p < 0.001$) in MC was observed in different treatments at week 0. Feedstock compositions ACC and ACS in most cases recorded higher Moisture Content as compared to AMYC. At the final stage of composting there was a marked difference between all the treatments ($p < 0.05$). Liang *et al.* (2003) and NRAES (1992) reported that maximum microbial activities were provided by MC in the range of 60–70%. Brito *et al.* (2008) observed a decline in temperature with MC of about 75%; a high MC is critical, and could impede effective composting to enable oxygen diffusion into the pile to maintain aerobic microbial activity.

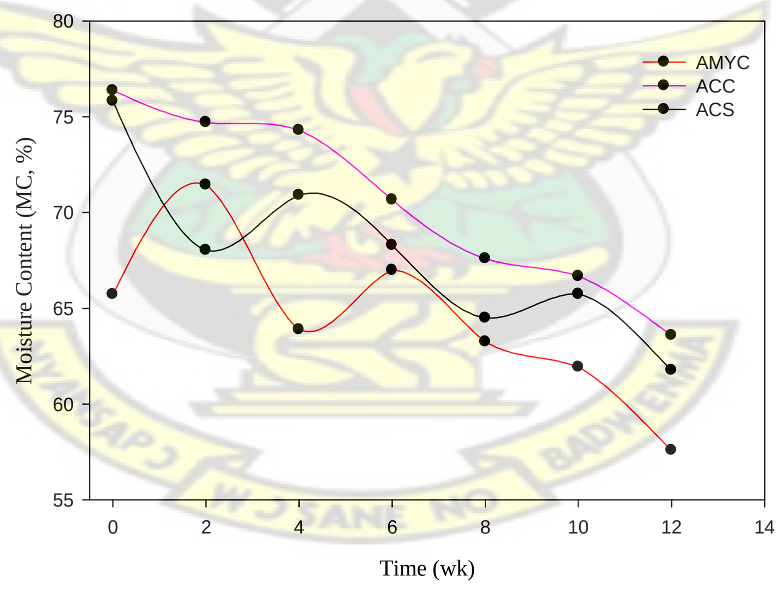


Figure 4.7: Effect of feedstock on Moisture Content (MC, %)

Moisture in some cases, due to low water holding capacity of feedstock material used (either as a substrate, amendment or bulking agent), may reduce air space in treatments and impede oxygen diffusion. This is able to reduce bio-oxidation, and Slow down OM and carbon degradation in compost pile (Ahn *et al.*, 2008a; Richard *et al*., 2002). This is indicative of the low thermophilic temperatures observed within the first few weeks of composting for treatment ACC and ACS. The presumed higher potential water-holding capacity (WHC) of feedstock AMYC and ACC may be contributing to the piles' ability to maintain high moisture content. Ahn *et al.* (2008a) reported a higher WHC for wood shaving, straw or stalks whereas that of soil, compost, litter leaves were found to be low.

4.3.5 *Effect of Feedstock on Organic Matter Content*

Highly significant ($p = 0.009$) differences in Organic Matter (OM) level were observed in the various feedstock formulations at the start of the experiment; and this was found between AMYC and ACS. Generally OM level decreased with composting time (Table 4.6). No significant difference in OM levels were observed between the different piles of different feedstock composition at the transitional period of week 6. However, at the end of the processing period, a highly significant difference ($p < 0.001$) was observed between AMYC and ACC. Organic Matter loss resulting from the study ranked AMYC > ACC > ACS, with losses ranging between 51.47-71.90%. Thus Organic Matter turnover or degradation was higher AMYC than the other feedstock. Zhu *et al.* (2004) reported organic matter degradation varying from 64.53 - 67.16% for composting of swine manure under different aeration regimes. Ogunwande *et al.* (2008) reported degradation level of between 51.71-62.24% for poultry manure. The results of this experiment are also consistent with reports by Tiquia *et al.* (2001), indicating observed degradation or losses of 50.2-64%.

The decomposition of OM to stabilize the compost followed 1st-order decay kinetics in the case AMYC and ACC; feedstock ACS followed a Zero-order kinetic model. Similar analysis was conducted by Paredes *et al*. (2000) and Benito *et al.* (2003), which distinguished the stability of organic matter by comparing the maximum degradation potential (OML_{max}), rate constant (k) and their product. With respect to this study AMYC (OML_{max}= 92.433%; k = 0.1243wk^{-1}, R^2 = 0.9743) was slower in stabilizing Organic Matter compared to ACC (OML_{max}= 52.891%; k = 0.2962wk^{-1}, R^2 = 0.9782), which is demonstrated by comparing the product of OML_{max} and k of these feedstock.

Table 4.6: Effect of feedstock on OM content (%, DM)

Feedstock	Week						
	0	2	4	6	8	10	12
AMYC	71.50	66.40	63.96	55.57	46.70	46.37	41.35
ACC	68.44	61.10	58.00	56.98	52.96	51.33	49.69
ACS	65.76	63.56	62.64	57.19	55.15	48.72	48.24
LSD	3.39	2.03	1.80	2.36	2.54	2.69	3.25
p-value	0.009	<0.001	<0.001	0.313	<0.001	0.005	<0.001

LSD for comparing means at the same level of treatment (significance, p<0.05): 2.52

The results of this study showed a higher maximum degradation potential and rate constant compared to studies conducted with pruning waste and spent horse litter, and olive wastewater (Paredes *et al*., 2000; Benito *et al.*, 2009). The different temperature regimes point to the fact that different feedstocks may exhibit different levels of bio-oxidation, resulting in the evolution of CO_2 and heat (Barrington *et al.*, 2002). Paredes *et al*. (2000) found that composition of initial mixtures influences OM degradation and N losses during sludge composting. Thus, the slow degradation rate experienced in treatment ACS could be associated to the expected recalcitrant lignin level in the wood sawmill waste incorporated in the formulation of this feedstock (Solano *et al.*, 2001; Wong *et al.*, 2001).

4.3.6 *Effect of Feedstock Composition on C/N Ratio*

During the composting of abattoir waste feedstock with varied composition (Table 4.7), the mean C/N ratio observed decreased by about 16.32 - 24.74% (AMYC > ACC > ACS) from an initial mean value ranging 22.92 - 25.62 to 18.73 - 19.29. The statistics on the effect of feedstock composition on C/N ratio did not prove any significant effect at beginning (week 0) of the composting process (p = 0.092). However, a significant effect (p < 0.001) was observed on feedstock composition ACC, AMYC and ACS at week 6. At the final week of sampling, treatments did not indicate any significant difference (p = 0.533) caused by feedstock composition on C/N ratio. The notable recalcitrant lignin in feedstock ACS could account for its relatively low change in C/N ratio. The C/N ratios of final compost provide another indication of compost stability. The treatment (AMYC, ACC and ACS) with acceptable initial C/N ratio (NRAES, 1992; Haug, 1993; Larney and Hao, 2007) are considered to be stabilized and matured when their C/N ratio has decreased below 20 (Larney and Hao, 2007; Sánchez-Monedero *et al*., 2001).

Table 4.7: Effect of feedstock composition on C/N ratio

Feedstock	**Week**						
	0	2	4	6	8	10	12
AMYC	25.63	22.17	24.87	18.67	20.36	18.77	19.29
ACC	23.10	19.71	20.14	21.37	18.77	18.71	18.73
ACS	22.92	22.45	21.13	24.60	24.37	20.66	19.18
LSD	2.73	1.06	0.77	1.39	1.22	1.22	1.10
p-value	0.092	<0.001	<0.001	<0.001	<0.001	0.005	0.533

LSD for comparing means at the same level of treatment (5% level of significance):1.38

4.3.7 *Effect of Feedstock Composition on Carbon (C, %)*

Feedstock formulation plays a critical role in achieving ideal starting conditions for composting. The contribution of substrates, amendments and bulking material may either increase or decrease the start-up C/N ratio. At the start-up of the composting experiment, feedstock AMYC and ACS exhibited a highly significant difference in carbon concentration ($p = 0.009$). Generally, the carbon content in the treatments decreased across the operation time (Table 4.8).

No significant difference in carbon content was observed between treatments in the transitional stage (week 6) of the composting process. However, at the end of the composting process (week 12), a significant difference was identified between formulations AMYC and ACC. The carbon loss, on an ash free basis evaluated, ranked the loss as ACC > AMYC >ACS (following from the trend established with OM), shows that abattoir waste amended with biodegradable fraction of corn stove, yard trimmings and cocoa pod husk was more favourable toward carbon mineralization. This observation indicates that the different feedstock may exhibit different levels of bio-oxidation, resulting in the evolution of CO_2 and heat (Barrington *et al.*, 2002; Beck-Friis *et al.*, 2003).

Table 4.8: Effect of feedstock composition on carbon (C, %)

Feedstock	**Week**						
	0	2	4	6	8	10	12
AMYC	39.07	36.29	34.95	30.37	25.52	25.34	25.35
ACC	37.40	33.39	31.69	31.14	28.94	28.05	28.12
ACS	35.94	34.73	34.23	31.25	30.14	26.62	26.68
LSD	1.85	1.11	0.98	1.29	1.39	1.47	1.49
p-value	0.0091	<0.001	<0.001	0.313	<0.001	0.005	0.004

LSD for comparing means at the same level of treatment (5% level of significance): 1.31

4.3.8 ***Effect of Feedstock Composition on Total Nitrogen (TN, %)***

The effect of feedstock composition on TN at the start of the composting process was not significant ($p < 0.326$), generally TN decreased with composting time (Figure

4.8). Among treatment, there existed a highly significant difference ($p < 0.001$) in TN from week 2 through to week 12. In the transitional stage (week 6) of composting, TN could be ranked as AMYC>ACC>ACS between treatments. However, at week 12, final sampling week, the observed TN in the treatments ranked as ACC>ACS>AMYC comparing the level of TN nutrient concentration. A significant difference ($p < 0.05$) in TN loss was observed between the treatments especially with respect to AMYC compared with ACC and ACS at week 12. Feedstock AMYC recorded the highest loss in TN (58.35% ash free basis), compared to ACC and ACS (41.92% and 41.80% respectively, Figure 4.8; Appendix E9) by the close of the experiment.

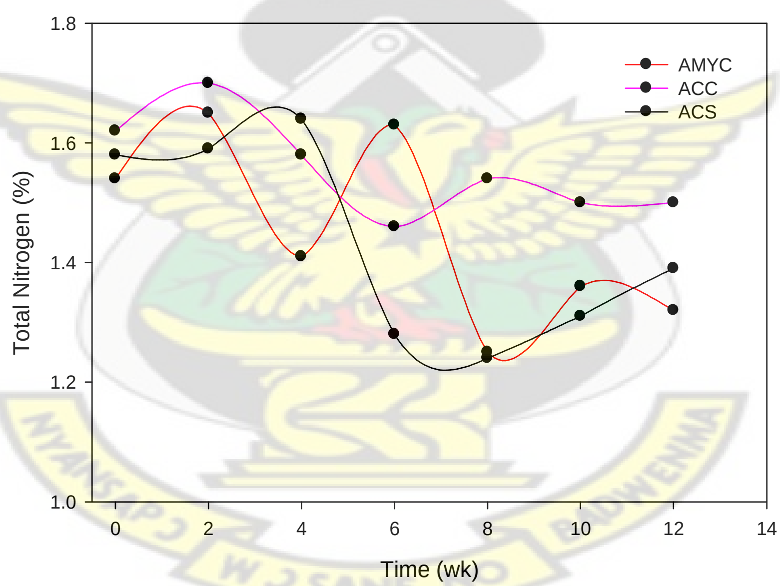


Figure 4.8: Effect of feedstock composition on Total Nitrogen (TN, %)

Tiquia and Tam (2002) reported TN losses of between 37-59% in composting hoops. Further analysis showed ACC to be following a 1st-order decay model compared to AMYC and ACS that were better fitted to a zero-order kinetic decay model (Appendix E20-22). Thus, in terms of conserving the nitrogen value of the compost, AMYC or ACS may serve as better feedstock. The correlation relation between TN and OM, Temperature or MC, also indicates a positive relationship (Table 4.10, page 99). Thus, losses in OM or TC related well with observed losses in TN. Indeed, the high OM or TC loss in AMYC explains the correspondingly high nitrogen loss in this treatment. Paredes *et al.* (2000) found that composition of initial mixtures influences OM degradation and N losses during sludge composting. Also, the high pH observed after the transitional phase (week 6) contributed to the high losses in TN in the treatment (Sanchez-Monedero *et al*., 2001; Wong *et al*., 2001; Sundberg, 2005).

A remarkable increase in percentage loss of TN (on ash-free basis) observed during composting could be indicative of atmospheric N fixation. Total Nitrogen losses during the composting of a range of different starting materials have been widely reported (Sánchez-Monedero *et al*., 2001) and were mainly attributed to NH_3 volatilisation during the thermophilic phase as well as to N_2O emissions through denitrification by bacteria at mesophilic temperature (Liang *et al*., 2006). Nitrogen fixation during composting is less frequent, but has been likewise reported (Paredes *et al*., 1996; Hatayama *et al*., 2005; Beauchamp *et al*., 2006). Nitrogen fixation tendencies noted for occurring during the thermophilic phase when the NH_4^+ content was suspected to be low (Paredes *et al*., 1996; Cayuela *et al.*, 2009) is likely in this experiment, especially for ACS. This suggests that TN could have become a limiting factor, and may have resulted in the growth of nitrogen fixing organisms. In this study, the feedstock composition affected the nitrogen conservation or loss of abattoir composting.

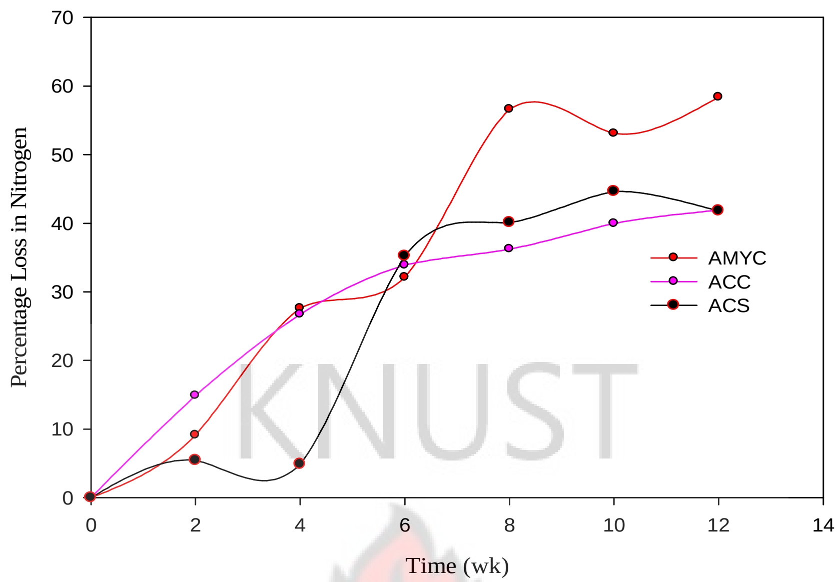


Figure 4.9: Nitrogen losses in formulations during composting

4.3.9 *Effect of Feedstock Composition on Ca, Mg, P and K*

The ANOVA on the concentration of Ca, Mg, TP and TK demonstrates that at week 0, only Mg, Ca and TK recorded a significant ($p < 0.05$) variation in means. However, at the final sampling period, only TP recorded a significant variation ($p = 0.022$) in mean. This could be noticed between treatment AMYC versus ACC and AMYC versus ACS. Phosphorous in AMYC recorded the highest value of 20.1 g/kg, although treatment AMYC recorded the least concentration in TP at week 0 (Table 4.9).Feedstock composition influenced the concentration of TP in the treatments and this could be attributed to the bio-oxidation of organic matter. Generally, Mg, TP, and TK concentrations significantly ($p < 0.05$) increased with composting time.

Table 4.9: Effect of feedstock composition on Ca, Mg, P and K

Feedstock	Week							
	Mg (%)		Ca (%)		TP (g/kg)		TK (g/kg)	
	0	12	0	12	0	12	0	12
AMYC	0.84	2.41	1.62	3.46	8.43	20.1	13.05	42.00
ACC	1.25	2.26	3.24	2.88	6.60	12.0	15.64	29.70
ACS	1.60	2.67	3.28	2.93	10.53	13.0	23.24	35.50
LSD	0.41	0.73	0.51	1.28	3.55	5.99	4.25	10.16
p-value	0.004	0.486	<0.001	0.576	0.094	0.022	<0.001	0.063

4.3.10 **Correlat*ion of Physicochemical Parameters with Respect to Feedstock Composition***

The correlation of monitored parameters with respect to the effect of feedstock composition on abattoir waste composting recorded a highly significant and strong negative relationship between Electrical Conductivity (EC) and the temperature transforms (especially $\Delta T/T$, $r = 0.9253$, $p < 0.001$). Conversely, pile moisture content (MC) and Organic Matter (OM) concentrations recorded a significant and strong positive correlation with the temperature and its transforms (e.g. T versus MC: $r = 0.9169$, $p<0.001$; T versus OM: $r = 0.9722$, $p < 0.001$). The results also indicated that there exist a strong and negative correlation between MC/OM and the temperature transforms produced (i.e. T, ΔT and $\Delta T/T$), as this generated a coefficient of correlation of 0.9696 ($p < 0.001$).

A strong positive correlation was observed between Total Nitrogen (TN) and the temperature transforms monitored during the experiment ($r = 0.9169$, $p < 0.001$ with respect to T). Moisture Content (MC) and Organic Matter (OM) content demonstrated a significant strong and positive correlation with TN. Benito *et al.* (2003) and Bernal *et al.* (2009) have stressed that the availability of rich carbon amendment is capable of supporting TN conservation. Thus, feedstock as in this study is associated with the conservation of TN. Although a strong and negative correlation was observed between EC and TN, this relationship was not significant ($p < 0.05$).

Table 4.10: Correlation of physicochemical parameters and transforms based

	ΔT	ΔT/T	T	EC	pH	MC	MC/OM	OM	TN
ΔT	1								
ΔT/T	0.9882^{***}	1							
T	0.9875^{***}	0.9594^{***}	1						
EC	-0.8896^{**}	-0.9253^{**}	-0.8466^{*}	1					
pH	-0.3779	-0.2493	-0.4094	0.072	1				
MC	0.9072^{**}	0.9115^{**}	0.9169^{**}	-0.9132^{**}	-0.1449	1			
MC/OM	-0.9602^{***}	-0.9604^{***}	-0.9696^{***}	0.8825^{**}	0.1845	-0.9372^{**}	1		
OM	0.9566^{***}	0.9501^{***}	0.9722^{***}	-0.8964^{**}	-0.214	0.9722^{***}	-0.9905^{***}	1	
TN	0.9266^{**}	0.9033^{**}	0.9313^{**}	-0.7247	-0.4053	0.8431^{*}	-0.8755^{**}	0.8789^{**}	1

*, ** and *** indicates the Significant level of $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ respectively.

4.3.11 ***Prediction of N Based on Feedstock Composition***

Total Nitrogen (TN) content in most agricultural materials is higher than TP or TK, and it is also the most difficult of these three principal nutrients to estimate by indirect correlation methods due to its varying composition in feedstock (Moral *et al*., 2005) and the effect of the biodegradation process during composting. Total Nitrogen is considered a critical agronomic limiting factor for the use of compost as an organic fertilizer or soil amendment. The ability to predict the amount of TN in a linear regression model with other parameters or their transforms (such as presented in Table 4.11) could largely facilitate the rapid assessment of process quality or efficiency during composting.

Findings in this study reveal that the multiple linear regression adopted by analysing parameters separately significantly predict the concentrations of TN in feedstock AMYC and ACC yielding R^2 values of 0.942 ($p = 0.038$) and 0.999 ($p = 0.016$) respectively. There was no significance established for feedstock ACS, although a strong co-efficient of multiple-linear determination was obtained ($R^2 > 0.879$). The common parameter featuring in all the models is EC, which has been reported to have good correlation with TN in most livestock manure analysis (Moral *et al*., 2005; Martinez-Suller *et al*., 2008). Thus, this physicochemical analysis could be adapted for onsite application. The varied relation between the parameters is an indication that feedstock variation is influencing the composition of the predictive model.

Table 4.11: Regression model for TN with respect to feedstock composition

Treatment	Best Model Equation Total Nitrogen	R^2	Probability
AMYC	$-7.29 + 0.2344EC + 3.171MC/OM + 0.0789OM - 0.507\,\Delta T\,/\,T$	0.942	0.038
ACC	$7.077 - 0.565EC - 1.2089\,MC\,/\,OM - 0.03576MC + 0.005559T - 0.07886pH$	0.999	0.016
ACS	$4.63 + 0.729EC + 0.0241OM + 0.138\Delta T - 0.1762T - 0.1045pH$	0.879	0.238

However, a general assessment of TN in feedstock produced a negative correlation for ΔT/T and T, while showing a positive correlation with pH and OM. The results of this study compares very favourably with regression correlations established by Marino *et al*. (2008), Martinez-Suller *et al*. (2008) and Chen *et al*. (2009) who predicted TN in livestock manure or compost with R^2 values ranging between 0.59 and 0.92.

4.3.12 *Effect of Feedstock Formulation on Heavy metal concentration abattoir compost*

The heavy metal found with the highest concentration in the compost product was zinc (157.7 - 202.7 mg/kg), while Cd, As, Ni, Co and Mo recorded values below 1.5mg/kg DM of compost. Cadmium was significantly high ($p < 0.001$) with respect to feedstock composition, with feedstock ACC demonstrating a higher concentration in Cd compared to ACS and AMYC. Also feedstock ACS showed a high concentration in Cd compared to AMYC. Mean arsenic concentrations in final compost with respect to feedstock could be ranked as ACC > ACS > AMYC. Highly significant differences ($p < 0.001$) in arsenic concentration were observed between different feedstock formulations. This could be observed in ACC, which was significantly higher than ACS and AMYC. Chromium concentrations in the final compost were not significantly different with respect to feedstock composition. However, mean cobalt concentrations in the feedstock showed a significant difference ($p < 0.001$), which could be ranked as ACS > AMYC > ACC. Thus, the difference in mean was observed between ACS and AMYC & ACC, and between AMYC and ACC.Cocoa pod husk (CPH) represents a major contributor of Cd, As, Cr, Cu, Ni, Pb, Mo and Mn concentrations in the feedstock formulations (Table 4.19). However the concentrations are within the limits recommended by BSI (2005). Sawmill waste recorded the highest mean concentration of zinc, 150.160mg/kg DM, compared to 17.070mg/kg DM analysed for the garden waste (GW) used in the feedstock formulation. Corn stove and husks (CSH) represented a cleaner form of amendment material or bulking agent because the values of all heavy metals observed in it were within recommended or acceptable limits (BSI, 2005; Day and Shaw, 2001).

Copper concentration was significantly different ($p < 0.005$) with differences observed between AMYC & ACC and AMYC & ACS respectively. Significant difference was also observed in Lead (Pb) concentration which was due to differences observed between AMYC and ACC. Both Mn and Mo recorded a highly significant difference in mean concentrations for different feedstock ($p < 0.001$). Manganese concentration was higher in ACS compared to AMYC and ACC whereas mean concentration of Mo in ACC was more than fourfold and threefold greater than AMYC and ACS respectively. A highly significant difference ($p = 0.002$) in mean nickel concentration with respect to AMYC and the other formulations was observed. A significant difference in Zn concentrations (p = 0.023) with respect to feedstock formulation was observed between formulations ACC and ACS only.

Table 4.12: Heavy metal concentrations in compost based on feedstock composition and some raw materials

	AMYC	ACC	ACS	LSD	GW	CSH	CPH	SW
				mg/kg DM				
Cadmium (Cd)	0.070	0.452	0.206	0.1207	0.004	n.d	0.470	0.001
Chromium (Cr)	3.48	3.62	3.82	1.727	1.582	0.024	3.380	0.185
Copper (Cu)	2.608	3.236	3.484	0.4931	1.349	0.623	7.894	0.089
Mercury (Hg)	-	-	-	-	-	-	-	-
Nickel (Ni)	0.565	1.316	0.994	0.3586	0.237	n.d	1.559	n.d
Lead (Pb)	1.776	1.990	2.349	0.3816	1.131	0.061	1.361	0.695
Zinc (Zn)	183.5	157.7	202.7	30.82	17.070	44.246	143.553	150.160
Arsenic (As)	0.054	0.516	0.191	0.1586	0.053	0.001	0.364	0.063
Cobalt(Co)	0.805	0.269	1.187	0.2337	0.253	0.333	0.451	n.d
Molybdenum (Mo)	0.198	0.960	0.312	0.2715	n.d	n.d	0.580	0.084
Manganese (Mn)	29.76	30.26	50.29	2.331	19.543	4.549	61.111	3.113

n.d – not detectable

The heavy metal concentrations observed in compost produced from the various feedstock formulations were way below the limits reported by Day and Shaw (2001) and proposed by BSI (2005). The fact that the feedstock materials where not mobilized from mixed MSW could be contributing to the low heavy metal concentration in the produced compost. The heavy metal concentration observed in the abattoir waste composts had superior quality compared to the values observed with Richard and Woodbury (1992) for Municipal, whether it be compost produced from mixed or source separated organic waste. This could be attributed to the feedstock materials used, which were biowaste and contained natural background amounts of the heavy metals (Veenken and Hameler, 2002). Thus compost produced from this feedstock formulation could be applied severally without any immediate concern to bio-accumulation of heavy metals in the soil. Substrates contributing the most to heavy metal concentration could be said to have high ash content, fine particle size or may have undergone multiple handling processes prior to their application for composting (Zhang *et al*, 2008). Indeed, the feedstock selection, its intrinsic quality and its preparation (pre-processing) for composting could play a critical role in ensuring that the heavy metal concentrations in the final product is within the regulated limits (Richard and Woodbury, 1992; Haug, 1993; Veenken and Hameler, 2002).

4.4 Effect of Turning Frequency on the Temperature Profile, Degradability and Nutrient in Abattoir Waste Composting

4.4.1 *Effect of Turning Frequency on Temperature*

Significant difference in temperature was observed in week 2 and week 4 of the composting process. Turning frequency 3DT recorded a significantly higher ($p < 0.001$) temperature than treatment 7DT and 14DT at week 2 while in week 4 the opposite of this trend was observed resulting in temperature records of 14DT > 7DT > 3DT (Table 4.13). This explains the incidence of thermophilic conditions or atmospheric cooling influenced by the turning frequency. The significant differences were observed during the active phase of the composting period. No significant difference ($p > 0.05$) was indicated in week 10 and 12 when comparing means at the same level of treatment. Frequent turning of compost piles is reported to significantly decrease temperature build-up during composting (Zhu *et al*., 2004; Tognetti *et al*., 2007).

Table 4.13: Effect of turning frequency on temperature

Feedstock	Week						
	0	2	4	6	8	10	12
3DT	44.9	46.3	35.8	32.0	30.0	28.1	28.4
7DT	45.4	42.2	37.4	31.8	29.1	27.9	27.3
14DT	46.0	40.8	40.3	32.8	29.6	27.8	28.1
LSD	5.92	2.32	2.58	1.29	0.76	0.43	0.97
p-value	0.926	<0.001	0.005	0.259	0.755	0.272	0.073

LSD for comparing means at the same level of treatment (5% level of significance): 0.74

Average means for period for temperature above 55^0C (section 4.2, Table 4.3) indicated that turning frequencies 3DT and 7DT gave similar effect of temperature sanitization values of more than a day, whereas 14DT indicated a period of less than a day. Thus, turning frequencies 3DT and 7DT have a better potential sanitizing effect on the compost treatment compared to 14DT. In fact, the mean area also indicated that the sanitizing potential of turning frequency 3DT (6.10 ^{0}C·d) was more than 10 folds a better sanitizing treatment option compared to 14DT (0.53 ^{0}C·d) and about 2 folds better than 7DT (2.10 ^{0}C·d). Temperature can be used to assess the progress of decomposition, sanitization of pathogens and thus the performance of a composting system (NRAES, 1992; Haug, 1993; Mason, 2007; Yu *et al*., 2008).

The account of Tiquia *et al*. (1997) and Ogunwande *et al*. (2008) demonstrates that turning frequency has an effect on temperature and oxygen concentration of composting piles. Thus, a higher frequency of turning could create a situation that increases bio-oxidation and temperature of the compost; or this may increase the bulk density of the pile, which may cause temperature to drop significantly because of the pile size or the stage of the composting process (Tognetti *et al*., 2007; Tirado and Michel, 2010) A higher turning frequency mostly increases the distribution of the free air space and ensures a more uniform distribution of moisture, micro-organisms, particle size and temperature (Haug, 1993; Kader *et al*., 2007; Szanto *et al*., 2007).

4.4.2 *Effect of Turning Frequency on Electrical Conductivity*

Electrical Conductivity values generally increased with composting period (Fig. 4.9). The EC recorded for the final compost can be ranked as 3DT > 7DT > 14DT. The decreases in EC could be attributed to the low rate of organic matter degradation during the composting process. Thus increased turning influences a higher EC. This phenomenon is observed at the transitions of both thermophilic and mesophilic phases, and recurred towards the end of the composting process, accounting for significant effects ($P < 0.05$) recorded.

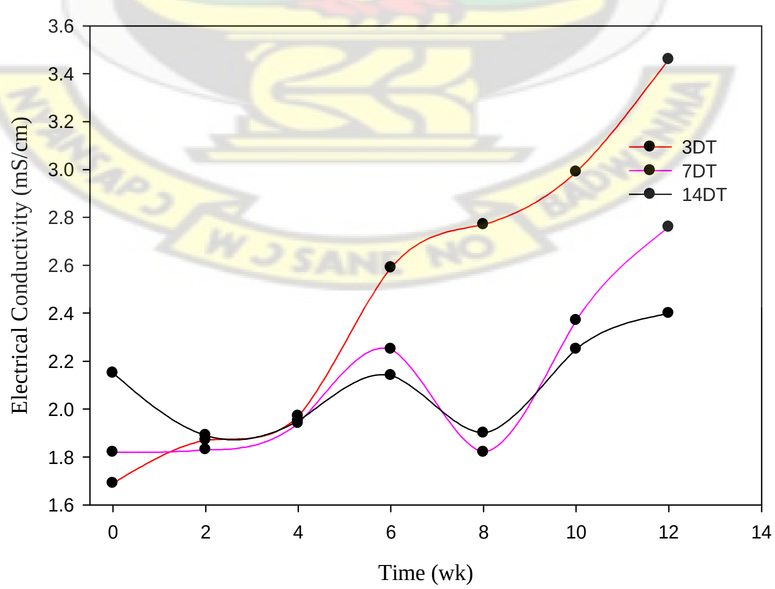


Figure 4.10: Effect of turning frequency on Electrical conductivity (EC, mS/cm)

The EC values observed for all the treatments monitored as a result of the turning frequency did not exceeded the threshold of 4.0 dS/cm recommended by Rao Bhamidiamarri & Pandey (1996) and Lin (2008). The salinity (EC) of the final compost for all treatment was less than the salinity limit value suitable for agricultural use.

4.4.3 *Effect of Different Turning Frequency on pH during Composting*

The pH dynamics observed during the composting process depicted a decrease from the initial value to mean values of between 7.07 - 7.17 in week two, but increased during the thermophilic to transitional phase of weeks 4 to 6; with mean values exceeding 8.50 (Fig. 4.10). The observed values of pH increased from a seemingly neutral range to an alkaline range during the transition phase.

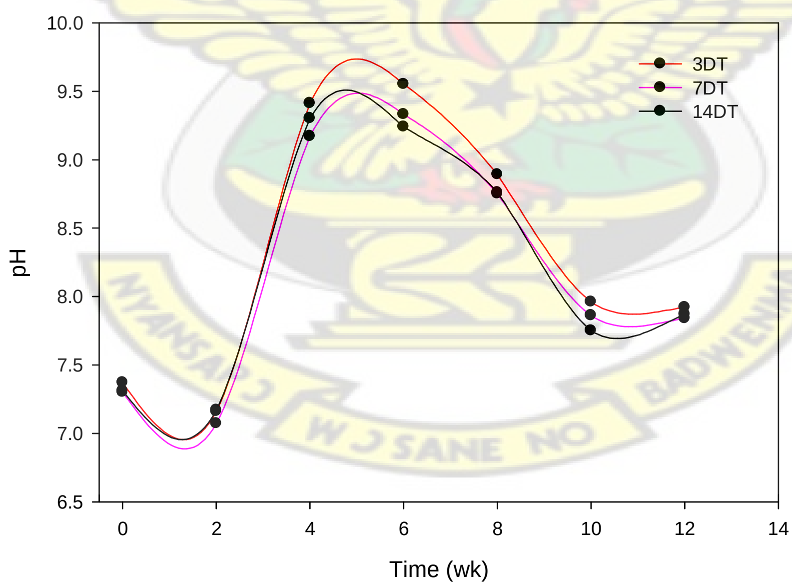


Figure 4.11: Effect of different turning frequency on pH during composting

Similar phenomena have been observed by Tumuhairwe *et al*. (2009). According to Pace *et al*. (1995) and Moldes *et al*. (2007), the preferred range of pH is 6.5 to 8.0 for optimum growth of microorganisms during composting process. The pH value being higher than 8.5 (Week 4 to 8), tends to influence nitrogen losses, which become unavailable to microorganisms and thus slows decomposition (NRAES, 1994). This agrees with the observation made for N content (Appendix E10). Also, Sanchez-Monedero *et al*. (2001) observed an increase in pH up to about 8.8 in the composting of biowaste; an observation that he attributed to well oxygenated and not already nitrified treatment of the pile. However, these values decreased to pH values of less than 8.00 at the end of the process. The final pH readings obtained in this study are within acceptable limits suitable for soil application (Moldes *et al*., 2007; Bernal *et al*., 2009).

Turning frequency of 3DT yielded a significantly ($p < 0.05$) higher pH value compared to 7DT or 14DT. Treatment 7DT and 14DT did not show significant changes at the monitoring periods in most cases. The recorded pH from treatments, decreased afterward in conformity with reported trends cited in literature. Eklind and Kirchmann (2000), Beck-Friis *et al*. (2003) and Sundberg (2005) have reported similar occurance of decreases and a subsequent rise during composting subjected to varied treatments. The initial low pH values recorded in treatments can be attributed to organic acidic formation; while the subsequent increase is linked to the breakdown of organic acids in the substrate and the decomposition of nitrogen-containing organic matter leading to the accumulation of NH_3 that dissolves in moisture to form alkaline NH_4^+ (Sanchez-Monedero *et al*., 2001; Wong *et al*., 2001; Sundberg, 2005). As experienced by Paredes *et al*. (2001) in the composting of olive mill waste, OM decomposition brought about significant increase ($p < 0.05$) in pH in all treatments

(Table 4.14, page 110). This could be as a consequence of the possible degradation of acid type compounds.

4.4.4 *Effect of Different Turning Frequency on Moisture Content*

The treated piles generally experienced a continuous loss in moisture with processing time (Fig. 4.11). However, statistical analysis demonstrates that turning had a significant influence on the moisture contents of the piles. As per the scope of the experiment, moisture contents were kept within the 50-75% limits. Highly Significant differences ($p < 0.001$) in MC were found at Week 6 and Week 12 for the treatments. Pile MC at the end of the composting process could be ranged as 14DT > 7DT > 3DT treatment, and with significant difference following the same order. The outcome of this study seems to suggest that a more frequent turning frequency would increase MC loss (Haug, 1993, Larney *et al*., 2000; Tirado and Michel, 2010).

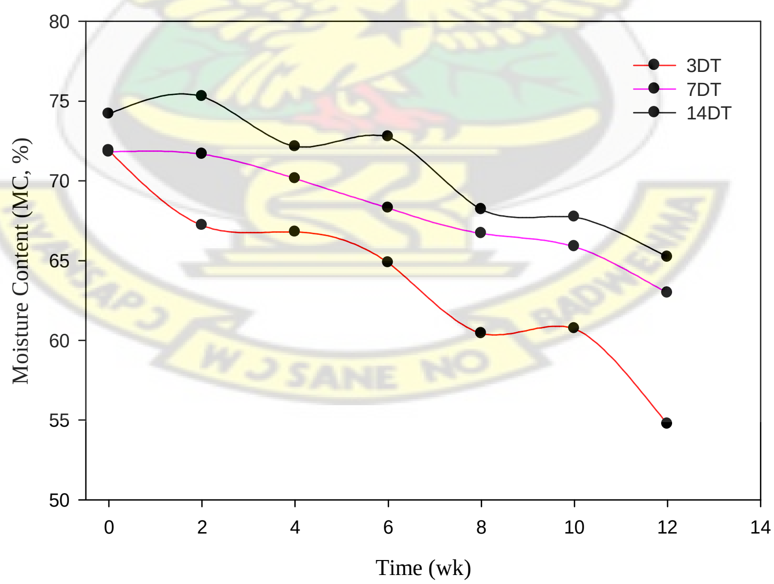


Figure 4.12: Effect of different turning frequency on Moisture Content

The moisture loss is influenced by the turning frequency (treatment 3DT > 7DT >14DT); such that, as turning frequency is increased in a pile faster rate of evaporation is induced to encourage the loss of moisture. Also, the hastening of degradation as a result of turning frequency tends to produce CO_2 and H_2O in a phase suitable to promote moisture loss. Conversely, because high moisture content lead to poor porosity, low turning frequency may serve as a disadvantage to the diffusion of oxygen in the treatment.

4.4.5 *Effect of Different Turning Frequency on Organic Matter Content*

Generally, the organic matter content during the composting period decreased with time (Table 4.24). The initial OM content of the treatments was not significantly different (p = 0.201). Also, during the transitional period of week 6, the treatments did not exhibit any significant differences (p = 0.158). The turning frequency did not show any significant impact on OM content in week 12 (p = 0.670). The percentage change in OM with respect to treatment ranged from 30.83 - 35.09%, with treatment 3DT >14DT > 7DT.

Table 4.14: Effect of different turning frequency on OM Content (% DM)

Turning	**Week**						
Frequency	0	2	4	6	8	10	12
3DT	70.30	63.32	62.65	55.49	50.37	49.77	45.63
7DT	67.85	62.54	60.36	56.49	50.80	46.62	46.93
14DT	67.56	65.21	61.58	57.76	53.64	50.02	46.71
LSD	3.39	2.03	1.80	2.36	2.54	2.69	3.25
p-value	0.201	0.036	0.051	0.158	0.031	0.029	0.670

LSD for comparing means at the same level of treatment (5% level of significance): 2.52

Mineralization of organic matter on an ash-free basis demonstrates that treatment 3DT (OML_{max} = 69.77%, k = 0.184wk^{-1}, and R^2 = 0.968) and 7DT (OML_{max} = 78.12%, k = 0.124wk^{-1}, and R^2 = 0.984) followed a first order decomposition kinetics, compared with treatment 14DT which was better fitted to a zero-order kinetic. The mineralization of OM was better in treatment 3DT compared to 7DT and 14DT, as accessed through the product of the potential maximum loss and the rate constant.

The study shows that an increased turning frequency facilitates a higher rate of organic matter decomposition. Most of such degradation is realized at the active thermophilic phase of the composting process, which has also been reported by Tiquia *et al.* (2002). This situation is noted to enhance aeration and proper mixing of substrates and microbes that are responsible for decomposition, as reported in Wong *et al.* (2001), Ogunwade *et al.* (2008) and Bernal *et al.* (2009). Thus, if the focus for undertaking a composting process is to reduce the size of the pile and stabilize OM or TC concentration, then turning the pile frequently may achieve this faster.

4.4.6 *Effect of Different Turning Frequency on C/N ratio*

The initial C/N of the piles was within the recommended ratio required to enhance effective composting (Golueke, 1991; Haug, 1993). There was no significant difference ($p = 0.753$) in C/N ratio observed in the piles at the start of the composting process. Generally, the C/N ratio decreased with time for treatments (Table 4.15).

Table 4.15: Effect of different turning frequency on C/N ratio

Turning	Week						
Frequency	0	2	4	6	8	10	12
3DT	24.45	21.66	23.11	20.81	21.05	18.99	18.71
7DT	23.56	22.14	20.77	21.91	20.03	18.36	18.04
14DT	23.65	20.52	22.26	21.93	22.42	20.80	20.45
LSD	2.73	1.06	0.77	1.39	1.22	1.22	1.10
p-value	0.753	0.015	<0.001	0.182	0.003	0.002	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 1.38

The obtained results also shows that there was significant effect of turning frequency on the final C/N ratio at week 12 ($p < 0.001$); with mean deceases in C/N ratio accounting for between 13.53 - 23.48% of the initial value (3DT > 7DT > 14DT). The decrease in C/N ratio with composting time can be attributed to either the mineralization of the substrates present in the initial composting materials or increase in total N concentration resulting from the bio-oxidation of TC concentration (Solano *et al*., 2001). Thus, this study demonstrates that, increasing turning frequency enhances aeration and exposes the feedstock to active microbial activity due to the seemingly increase in particle surface area.

4.4.7 *Effect of Turning Frequency on Carbon*

Table 4.16: Effect of turning frequency on carbon (%)

Turning	Week						
Frequency	0	2	4	6	8	10	12
3DT	38.41	34.60	34.23	30.32	27.52	27.20	27.25
7DT	37.07	34.18	32.99	30.87	27.76	25.48	25.50
14DT	36.92	35.63	33.65	31.56	29.31	27.33	27.41
LSD	1.85	1.11	0.98	1.29	1.39	1.47	1.49
p-value	0.201	0.036	0.051	0.158	0.031	0.029	0.028

LSD for comparing means at the same level of treatment (5% level of significance): 1.31

As demonstrated in Table 4.16, TC generally decreased with processing time; decreases of between 25.76 - 31.21% of the initial dry matter basis of TC mean values observed in the treatments (7DT > 3DT > 14DT). The initial mean values ranged from 36.92 - 38.41%. The ANOVA analysis revealed that, apart from TC values observed in week 0 and week 6, all other weeks demonstrated significant differences in mean of TC for the turning frequency treatments. The degradation of OM and TC in the treatment could be attributed to bio-oxidation of the pile resulting in the mineralization of OM or TC to release CO_2 (Beck-Friis *et al*., 2003).

4.4.8 *Effect of Different Turning Frequency on Total Nitrogen*

Significant differences ($p < 0.001$) in TN concentration were observed at both the transition stage and at the final stage of composting. A lower concentration in TN was observed with respect to treatment 7DT compared to treatment 3DT and 14DT. Although, it is illustrated in Fig. 4.11 that TN generally decreased with time, there exist at the final composting week a higher nominal concentration of TN compared to the preceding or a couple of preceding weeks during the composting process. The actual effect of turning frequency on TN could be examined through its rate of loss; which also explains to a large extent the level of TN conservation due to the treatment. Percentage loss in nitrogen was influenced by turning frequency such that increasing turning frequency tends to reduce the nitrogen concentration in the treatment pile.

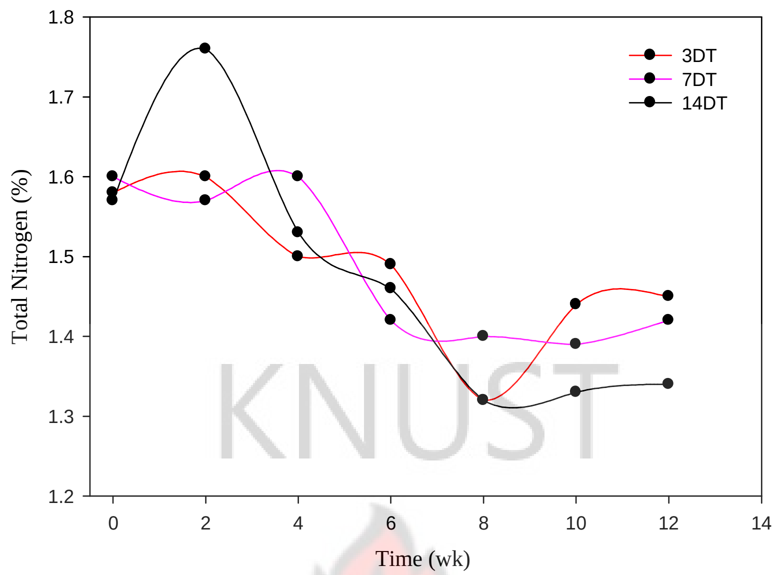


Figure 4.13: Effect of different turning frequency on TN (%)

It was observed that percentage loss in nitrogen amongst treatment could be ranked as 3DT > 7DT > 14DT. The gain in TN (on an ash-free) in the case of treatment 14DT could only be explained as persistence of nitrogen fixation, since relative OM loss was below 10% compared to other treatments (3DT and 7DT) which recorded magnitudes of more than two-fold in week 2. Treatment 14DT (NL_{max} = -3.43%, k = 4.762 wk^{-1}, R^2 = 0.9216) with zero-order kinetics, lost less TN compared to the first-order kinetics of treatment 3DT (NL_{max} = 59.58%; k = 0.1645 wk^{-1}, R^2 = 0.9690) and 7DT (NL_{max} = 64.85%, k = 0.1194 wk^{-1}, R^2 = 0.9840) respectively.

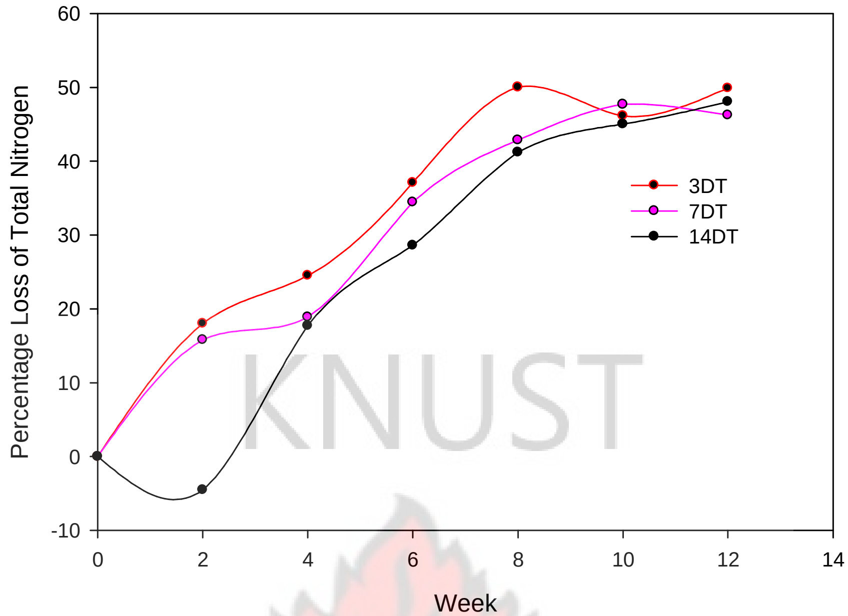


Figure 4.14: Nitrogen loss in treatments based on turning frequency

Findings from this study agree with the findings of Paredes *et al.* (2000). A higher turning regime is associated with higher volatilization of NH_3 accounting for most of the TN losses evaluated for the compost piles (Tiquia and Tam, 2000; Oguwande *et al.*, 2008). Thus, turning on a weekly or fortnightly basis would ensure a better TN conservation in the compost pile. The higher presence of concentrations P and Mg supports these phenomena; as Eklind and Kirchmann (2000) have recommended the addition of P and Mg salts to reduce TN loss during composting.

Ogunwande *et al.* (2008) reported that high frequency of turning during composting increases N losses and turning could have hastened volatilisation. Composting processes with higher turning frequency resulted in a material having lower amount of nitrogen and carbon as a result of volatilization of N as NH_3 and TC as CO_2. Beck-Friis *et al.* (2001) reported that decreasing temperature during the thermophilic phase is beneficial in preventing TN loss, since most thermophilic conditions are accompanied by pH rise. The TN loss on ash-free basis was less than 50% for the treatment. This is consistent with the range of TN loss reported in literature (Bernal *et al*., 2009; Liang *et al.*, 2006; Larney *et al*., 2006).

4.4.9 *Effect of Turning Frequency on Ca, Mg, P and K*

The ANOVA on the effect of turning frequency on Mg, Ca, P and K recorded no significant variation ($p > 0.05$) in the means of the nutrient with regard to the different turning frequencies. However, generally, nutrient concentration increased with time (Table 4.17).

Table 4.17: Effect of turning frequency on Ca, Mg, P and K

Turning Frequency	**Week**							
	Mg (%)		Ca (%)		P (g/kg)		K (g/kg)	
	0	12	0	12	0	12	0	12
3DT	1.27	2.79	2.52	3.23	7.92	14.4	18.31	38.30
7DT	1.08	2.17	2.68	2.98	7.85	16.6	16.44	34.10
14DT	1.34	2.37	2.94	3.06	9.78	14.1	17.18	34.90
LSD	0.41	0.73	0.51	1.28	3.55	5.99	4.25	10.16
p-value	0.082	0.481	0.244	0.915	0.960	0.736	0.650	0.659

But for the marginal increase of Ca in treatment 7DT, most nutrients increased by about two folds from the initial concentration to the final concentration Increasing or reducing turning frequency did not necessarily influence the concentration of P, K, Ca, and Mg in the treatment. This has been attributed to the OM loss which normally relatively increases the concentration of nutrient with processing time. Indeed, P, K, Ca and Mg did not exhibit a significant difference ($p > 0.050$) in mean concentration with time. This phenomenon is consistent with observations reported by Parkinson *et al.* (2004) and Larney *et al.* (2008). However, the ash-free losses of these parameters could be attributed to the marginal leaching that may have taken place (Sommer, 2001).

4.4.10 *Correlation of Physicochemical Parameters with Respect to Turning Frequency*

The correlation of physicochemical parameters with respect to the effect of turning frequency on abattoir waste composting recorded a highly significant and strong negative relationship between Electrical Conductivity (EC) and the temperature transforms ($0.8466 \leq r \leq 0.9253$, $p < 0.001$). Conversely, pile Moisture Content (MC) and Organic Matter (OM) concentrations recorded a significant and strong positive correlation with the temperature and its transforms (e.g. T versus MC: $r = 0.9168$, $p < 0.001$; T versus OM: $r = 0.9722$, $p < 0.001$). The results also indicated that there exist a strong and negative association between MC/OM and the temperature transforms produced (i.e. T, ΔT and $\Delta T/T$), as this generated a coefficient of correlation above 0.960 ($p < 0.001$). The study also observed a strong positive association between Total Nitrogen (TN) and the temperature transforms monitored during the experiment ($0.912 \leq r \leq 0.9384$, $p < 0.01$ with respect to T).

Table 4.18: Correlation of the effect of turning frequency in abattoir waste composting

	ΔT	ΔT/T	T	EC	pH	MC	MC/OM	OM	TN
ΔT	1								
ΔT/T	0.9914***	1							
T	0.9875***	0.9664***	1						
EC	-0.8891**	-0.9233**	-0.8466*	1					
pH	-0.3779	-0.2638	-0.4097	0.0718	1				
MC	0.9066**	0.9152**	0.9168**	-0.9132**	-0.1454	1			
MC/OM	-0.9603***	-0.9657***	-0.9695***	0.8826**	0.1847	-0.937**	1		
OM	0.9564***	0.9563***	0.9722***	-0.8964**	-0.2144	0.9722**	-0.9905***	1	
TN	0.9336**	0.912**	0.9384**	-0.7328	-0.4017	0.849*	-0.8858**	0.8878**	1

*, ** and *** indicates the Significant level of $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ respectively

Moisture Content (MC) and Organic Matter (OM) content correlated positively with TN ($r = 0.849$, $p < 0.05$; $r = 0.887$, $p < 0.01$ respectively). This relationship supports the fact that a higher loss of MC or OM, will contribute to the relatively higher TN loss (Wong *et al.*, 2001; Benito *et al.*, 2003; Ogunwande *et al.*, 2008); thus, a higher turning frequency may account for both situations. Laos *et al.* (2002) reported that significant changes in TN are related to mineralization of OM by micro-organisms. Notably, EC and TN produced a strong and negative correlation this relationship was not significant ($p < 0.05$, Table 4.18). The strong correlation of TN with temperature and its transform is indicative of the effect of temperature on airflow rate in passive or windrow composting systems (Szanto *et al.*, 2007). Thus, an intense turning frequency is expected to shorten the thermophilic and active phase of the composting, which normally results in a significant cooling of the compost pile (Zhu *et al.*, 2004; Tognetti *et al.*, 2007).

4.4.11 ***Prediction of N Based on Turning Frequency***

The relationship between TN and physicochemical parameters analysed with respect to turning frequency of the experiment is presented in Table 4.19. Significant and very strong regression co-efficient were evaluated as $R^2 \geq 0.990$ ($p < 0.05$). Just as was presented with the effect of feedstock composition, varied regression correlations between the parameters are observed for turning frequencies. The factor contributing most to the turning frequencies 3DT and 14DT is the passive diffusive parameter of $\Delta T/T$ which contributes about 5.151% and 1.282% factor respectively to the variation in TN, when other parameters are held constant. Also, 'Moisture-to-Organic matter' ratio was modelled to contribute 1.4437% and 1.4422% factor to the variation of TN in 3DT and 7DT respectively, when other parameters are held constant.

Table 4.19: Multi-regression model for TN with respect to turning frequency

Treatment	Model Equation of Total Nitrogen	R^2	Probability
3DT	$1.8256 + 0.14144pH + 0.0647\,EC - 1.4437MC/OM + 0.11905\Delta T - 5.151\,\Delta T/T$	0.999	0.022
7DT	$3.6096 + 0.12286pH + 0.082098T - 1.4422\,MC/OM - 0.22398\,\Delta T/T - 0.073932OM$	1.000	0.005
14DT	$-0.707 - 0.06138pH - 0.05563OM + 0.00641T + 1.2820\,\Delta T/T + 0.07630MC$	0.998	0.028

Superior correlation co-efficient (R^2 values) for predicting TN, during composting with varied turning frequencies was obtained in this study as compared to linear regression correlations established by Marino *et al.* (2008), Martinez- Suller *et al.* (2008) and Chen *et al.*, (2009) even though more than three parameters were used in the model (Table 4.19). The common parameter featuring in the treatment model is pH. Literature reports of good correlation with TN on the basis of EC, dry matter (DM), pH or specific gravity (Moral *et al.*, 2005; Martinez- Suller *et al.*, 2008). The current study presents evidence of the use of physicochemical analysis to predict the nutrient value of compost. The varied relation between the parameters is an indication that turning frequency variation may influence the composition of a predictive model.

4.4.12 *Effect of Turning Frequency on Heavy Metal Concentration Abattoir Compost*

Zinc was found to be the heavy metal with the highest concentration, 175.9-190.2 mg/kg DM, in the compost produced in terms of turning frequency while Cd, As, Ni, Co and Mo recorded values below 1.5mg/kg DM (Table 4.20). No significant statistical difference ($p > 0.05$) in the concentration level of As, Cd, Cr, Co, Cu, Mo, Ni and Zn was observed in the compost piles with respect to turning frequency. However, Pb and Mn recorded significant variations ($p = 0.012$; $p < 0.001$ respectively) in mean concentrations due to the turning frequencies the compost piles were subjected to. The significant difference in mean values of Pb concentrations relative to turning frequencies was observed between treatments 3DT and 14DT only. Also, it was observed that pile 14DT contained a higher concentration of Mn compared to the 3DT and 7DT piles. Heavy metal concentrations were within the limits for use for agricultural purposes could act as micro nutrients in the soil. Compost within these levels observed would not pose a phytotoxicity threat to plants.

Generally a frequent turning regime did not influence significantly the concentration levels of heavy metals in the composting of abattoir waste, but for Pb and Mn elements. Elemental Pb concentrations were far below the 20mg/kg values reported by Hofny-Collins (2006) for some composting experiences in Accra. It would have been expected that increased handling or turning frequency would warrant an increased in heavy metal concentration in compost especially with Pb and Mn in this study, as suggested by Richard and Woodbury (1992) and Zhang *et al.* (2008). The results showed that a hypothesis suggesting that an increased turning frequency would result is an increased heavy metal concentration may not hold.

Table 4.20: The effect of turning frequency on heavy metals concentrations of compost

Turning frequency	3DT	7DT	14DT	LSD	GW	CSH	CPH	SW
				mg/kg DM				
Cadmium (Cd)	0.201	0.284	0.243	0.1207	0.004	n.d	0.470	0.001
Chromium (Cr)	4.08	3.38	3.46	1.727	1.582	0.024	3.380	0.185
Copper (Cu)	3.014	2.905	3.407	0.4931	1.349	0.623	7.894	0.089
Mercury (Hg)	-	-	-	-	-	-	-	-
Nickel (Ni)	1.023	0.862	0.990	0.3586	0.237	n.d	1.559	n.d
Lead (Pb)	2.360	2.009	1.744	0.3816	1.131	0.061	1.361	0.695
Zinc (Zn)	175.9	177.8	190.2	30.82	17.070	44.246	143.553	150.160
Arsenic (As)	0.268	0.309	0.183	0.1586	0.053	0.001	0.364	0.063
Cobalt(Co)	0.801	0.657	0.804	0.2337	0.253	0.333	0.451	n.d
Molybdenum (Mo)	0.479	0.535	0.456	0.2715	n.d	n.d	0.580	0.084
Manganese (Mn)	34.53	35.84	39.94	2.331	19.543	4.549	61.111	3.113

n.d – not detectable

Intense turning frequency regime or handling are noted to reduce a large portion of the compost participle sizes or fineness to levels that may result in high concentration of heavy metal (Veenken and Hameler, 2002; Zhang *et al.*, 2008). Although the salinity and degradation rate of compost with respect to turning frequency were expected to yield higher mean values relative to Pb or Mn concentrations for rapid turning regimes (Parkinson *et al.*, 2004; Zhang *et al.*, 2008), this did not manifest in the abattoir compost, as the significant variations were observed with higher concentrations favouring 14DT. This could only be linked to leaching that this study could not eliminate completely.

4.5 Effect of Feedstock Composition and Turning frequency on the Temperature Profile, Degradability and Nutrient of Abattoir waste Composting

4.5.1 *Effect of Feedstock Composition and Turning Frequency on Temperature*

The interactive of turning frequency and feedstock composition did not record any significant change on temperature at the start of monitoring. The temperature values recorded ranged from 33.0 to 61.7 ^{0}C (Table 4.3 and 4.21). Significant effects on temperature by the interaction of turning frequency and feedstock composition were observed however in week 4 ($p = 0.006$), week 8 ($p < 0.001$) and week 10 ($p < 0.001$) of composting. In the case of week 4, interactive effects on temperature identified were with respect to AMYC-7DT, AMYC-14DT and ACC-3DT. Indeed, the temperature-time characterizations of the self-heating windrow piles indicate that the interaction effect of feedstock composition (AMYC) and turning frequency had a better thermophilic activity suitable for decomposition and pathogenic elimination potential compared to other feedstock.

This study also attests to the fact that there existed a significant surface loss of heat and cooling effects that could be due to the interactive effect and also the moisture content regimes used (Mason, 2007; Ahn *et al*, 2008b). Some authors, Larsen and McCartney (2000) and Leth *et al*. (2001) have accounted that the area between the compost temperature and ambient temperature profiles depicts the measure of heat retention in the pile. Given the scale or size and system (i.e. windrow composting) of this composting study, effect observed in AMYC-3DT, AMYC-7DT and ACC-3DT demonstrate a higher heat retention compared to the others. Thus, the interaction of feedstock compositing and turning frequency has an effect on the heat retention, microbial activity and the pathogen elimination potential.

Although, maintaining temperatures at an optimal level of 55^{0}C for at least 15 days inactivate pathogens, when the MC of the solids exceeds 70% (Table 4.24), thermophilic temperatures may not be attained or may be short-lived. The key factor influencing this situation is restricted movement of oxygen (Brito *et al*., 2008). This was the case for most of the interaction observed (Figure 4.1-4.3, pg. 77 & 78).

Table 4.21: Effect of feedstock and turning frequency on temperature

Feedstock	**Week**						
Turning	0	2	4	6	8	10	12
AMYC-3DT	54.7	47.3	35.7	32.0	28.7	27.7	27.3
AMYC-7DT	52.7	47.0	42.0	33.0	29.7	27.0	26.0
AMYC-14DT	50.0	43.0	46.7	33.3	27.3	27.7	26.0
ACC-3DT	47.0	50.7	39.3	30.7	29.0	26.0	28.0
ACC-7DT	48.3	42.7	37.3	31.0	28.7	27.0	28.0
ACC-14DT	51.3	42.0	37.0	31.0	28.7	27.0	28.0
ACS-3DT	33.0	41.0	32.3	33.3	32.3	30.7	30.0
ACS-7DT	35.3	37.0	33.0	31.3	29.0	29.7	28.0
ACS-14DT	36.7	37.3	37.3	34.0	32.7	28.7	30.3
LSD	10.260	4.016	4.466	2.239	1.321	0.738	1.683
p-value	0.707	0.080	0.006	0.266	<0.001	<0.001	0.157

LSD for comparing means at the same level of treatment (5% level of significance): 1.281

4.5.2 *Effect of Feedstock Composition and Turning Frequency on EC*

The interaction of feedstock composition and turning frequency showed a highly significant difference ($p < 0.01$ for week 10 and $p < 0.001$ for all other sampling dates) in EC throughout the composting process. The LSD values presented in Table 4.22 differentiate the significance amongst treatments. Generally, EC in the piles increased with the composting time as organic matter is bio-oxidized into more stable forms. EC in most treatments ranged between 1.33-2.29mS/cm at week 0. The final EC values in compost produced for all treatments were between 1.60-4.44 mS/cm.

Jones *et al*. (2009) and Gao *et al*. (2010) suggested EC gives indication of the nutrients and salinity level of the compost matrixes. Indeed, the examined interaction indicated a higher EC for AMYC and respective turning frequencies. Because leaching was controlled, high EC losses were not observed (Benito *et al*., 2009). However, mineralization of OM and nutrients contributed to the general increasing trend in EC. Salinity in source-separated market waste (MW; EC = 3.64 mS/cm) is notably contributing to this effect.

Table 4.22: Effect of feedstock composition and turning frequency on EC (mS/cm)

Feedstock	**Week**						
Turning	0	2	4	6	8	10	12
AMYC-3DT	1.97	2.29	2.96	3.33	3.31	3.67	4.23
AMYC-7DT	2.13	2.52	2.74	3.50	2.61	3.64	4.44
AMYC-14DT	2.29	2.47	2.81	2.88	2.60	2.85	3.18
ACC-3DT	1.54	1.65	1.51	2.33	2.92	2.83	3.38
ACC-7DT	1.98	1.33	1.03	1.57	1.22	1.47	1.60
ACC-14DT	2.15	1.95	1.57	1.63	1.48	1.90	1.97
ACS-3DT	1.56	1.68	1.45	2.12	2.07	2.47	2.76
ACS-7DT	1.33	1.64	2.05	1.68	1.62	2.01	2.25
ACS-14DT	2.01	1.23	1.45	1.89	1.63	2.00	2.06
LSD	0.01	0.06	0.00	0.00	0.00	0.00	0.01
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.02

Larney *et al*. (2008) related the level of EC to potassium concentration, or other dissolved cations. Thus, in this study, a high potassium or cation concentration would translate into a high EC value of compost. This ranking is also reflected in the moisture content of the treatment; the lower the Moisture Content (MC) the higher the EC values (Zameer *et al.*, 2010). EC observed in compost produced from treatments AMYC-3DT and AMYD-7DT did not meet the upper limit criteria of 4 mS/cm on phytotoxicity recommended by Lin (2008). Product from AMYC-3DT and AMYC-7DT may not be ideal for application to plants which may have tolerance of a medium sensitivity (Lasaridi *et al.*, 2006). Application of compost exceeding this limit may require that their use be appropriately timed to reduce plant stress.

4.5.3 *Effect of Feedstock Composition and Turning Frequency on pH*

The ANOVA test indicates that the interaction of turning frequency and feedstock composition had significant effect ($p < 0.001$) on the evolution of pH during the composting process. However, no significant effect ($p = 0.144$) of turning frequency and feedstock composition on pH was seen in the transitional period of week 6. The pattern in the changes of pH observed in the feedstock composition or turning frequency only is also observed in the interaction of feedstock composition and turning frequency (Table 4.23).

This phenomenon is not different from what was experienced by the composting of solid fraction of dairy cattle slurry by Brito *et al.* (2008). They also observed that composting process starts from marginally neutral pH of mean value range 7.11 - 7.46, which increases to an alkaline range 8.5 - 9.62 within the transitional period, then decreases and stabilizes at the later stages of the composting process. This high pH observed could be attributed to the buffering effects of bicarbonates (Cáceres *et al.*, 2006).

Table 4.23: Combined effect of feedstock and turning frequency on pH

Feedstock Turning	Week						
	0	2	4	6	8	10	12
AMYC-3DT	7.46	7.13	9.54	9.62	8.96	8.02	7.98
AMYC-7DT	7.11	7.26	9.50	9.42	8.86	7.96	8.02
AMYC-14DT	7.28	7.16	9.38	9.34	8.84	7.94	7.98
ACC-3DT	7.39	7.07	9.36	9.43	8.81	7.82	7.82
ACC-7DT	7.36	6.91	9.01	9.01	8.55	7.60	7.56
ACC-14DT	7.37	7.01	9.38	9.04	8.56	7.49	7.68
ACS-3DT	7.26	7.29	9.32	9.59	8.89	8.04	7.97
ACS-7DT	7.42	7.03	9.02	9.56	8.83	8.02	7.93
ACS-14DT	7.28	7.35	9.15	9.35	8.87	7.83	7.96
LSD	0.04	0.02	0.04	0.21	0.02	0.07	0.04
p-value	<0.001	<0.001	<0.001	0.144	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.05

4.5.4 *Effect of Feedstock Composition and Turning Frequency on MC*

Moisture Content in the composting piles generally decreased along composting period. The moisture content differences observed in the interaction of feedstock composition and turning frequency were highly significant ($p < 0.001$). The significant change in moisture is attributed largely to the turning frequency, and partially to the feedstock; with the later linked to the bulk density or porosity of the feedstock matrix (Ahn *et al*., 2008a; Day and Keener, 1997). Thus, it was demonstrated in week 12 that higher turning frequency favours a reduction in MC value observed. Quite also, feedstock composition with a higher bio-oxidation activity, such as AMYC degraded to influence the speedy evaporation of moisture in the piles. The mean minimum and maximum MC of final compost was 49.24 and 68.09 respectively (Table 4.24).

Table 4.24: Effect of feedstock composition and turning frequency on MC (%)

Feedstock	Week						
Turning	0	2	4	6	8	10	12
AMYC-3DT	66.58	66.96	58.29	60.50	58.20	55.59	49.24
AMYC-7DT	61.80	72.23	64.03	69.12	66.21	65.85	62.56
AMYC-14DT	68.79	75.12	69.35	71.31	65.33	64.36	60.98
ACC-3DT	77.66	71.87	71.89	68.46	62.15	62.92	57.44
ACC-7DT	76.82	75.62	73.70	67.17	68.02	65.15	65.24
ACC-14DT	74.64	76.63	77.27	76.34	72.60	71.94	68.09
ACS-3DT	71.47	62.80	70.20	65.65	60.93	63.70	57.56
ACS-7DT	76.82	67.17	72.70	68.61	65.86	66.63	61.10
ACS-14DT	79.15	74.13	69.81	70.62	66.67	66.88	66.60
LSD	3.83	1.47	0.22	1.85	1.07	0.48	0.44
p-value	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.09

Feedstock ACC's relatively high and significant ($p < 0.001$) moisture content could be attributed to the relatively high water holding capacity of corn stove present in the formulation (Ahn *et al*., 2008a). In this study however, apparent formation of leachate in the piles was assumed not to have a significant influence on the piles. The high moisture content might be a contributing factor to the slow rates of decomposition and the short thermophilic phase observed in most of the piles. As suggested by Das and Keener (1997), when the moisture content exceeds 60% air or O_2 movement is inhibited and the process tends to become anaerobic.

The link between MC and OM, viz-a-viz the interaction between feedstock composition and turning frequency is further explained in Section 4.5.6. The interactive effect portrays a higher degradation rate in treatments with 3DT turning frequency and feedstock ACC. This is observed in Table 4.26, with treatment 3DT or ACC depicting a first order decomposition to maximum phenomena, compared to a zero order phenomena.

4.5.5 *Effect of Feedstock Composition and Turning Frequency on Total Carbon*

The percentage loss in Total Carbon concentration during experiment were highest in AMYC (68.25%) and 3DT (59.98%), feedstock composition and turning frequency respectively. As of week 6, only pile AMYC-3DT had achieved a 50% reduction in carbon concentration or more inducing a significant change (p = 0.034) with most of the other treatments. At the end of the composting process, ACC-14DT exhibited the least Total Carbon loss of 47.74% while pile AMYC-3DT produced the highest carbon loss of about 73.49% (Table 4.25).

Table 4.25: Effect of feedstock composition and turning frequency on TC (%)

Feedstock	**Week**						
Turning	0	2	4	6	8	10	12
AMYC-3DT	39.83	35.12	34.73	28.31	24.53	23.93	23.98
AMYC-7DT	39.01	36.75	35.15	31.22	25.03	24.93	24.92
AMYC-14DT	38.36	36.99	34.97	31.58	27.00	27.15	27.15
ACC-3DT	37.92	34.01	33.09	31.24	28.94	28.83	28.82
ACC-7DT	37.08	30.90	30.40	29.84	27.20	26.21	26.20
ACC-14DT	37.20	35.25	31.59	32.33	30.69	29.11	29.34
ACS-3DT	37.49	34.67	34.88	31.43	29.11	28.83	28.95
ACS-7DT	35.13	34.87	33.41	31.55	31.06	25.30	25.37
ACS-14DT	35.19	34.65	34.40	30.78	30.24	25.74	25.73
LSD	3.21	1.92	1.70	2.23	2.41	2.55	2.59
p-value	0.915	0.006	0.152	0.034	0.111	0.019	0.019

LSD for comparing means at the same level of treatment (5% level of significance): 2.26

The result of these treatment reflects a significant difference (p = 0.019) in carbon (loss) at week 12. Per the relationship adopted in evaluating TC from OM their dynamics would be identical.

4.5.6 *Effect of Feedstock Composition and Turning Frequency on OM*

It can be observed from Table 4.26 that within a confidence level of 95%, treatments AMYC-7DT, AMYC-14DT, ACS-7DT and ACS-14DT produced a zero (0) order rate of mineralization of Organic Matter (OM) (See appendix E15 for a sample plot of zero order curve to predict OM loss). A first order rate of mineralization was also measured of for all 3DT turning frequencies (See appendix E16 for a sample plot of first order curve to predict OM loss) as well as ACC-7DT and ACC-14DT treatments.

Table 4.26: Summary of Organic Matter loss dynamics

TREATMENT	n	a, *a*	b, *b*	r	r^2	n.o.i.
AMYC-3DT	1	87.188	0.179	0.983	0.966	14
AMYC-7DT	0	5.533	6.026	0.962	0.926	8
AMYC-14DT	0	1.336	6.088	0.985	0.970	8
ACC-3DT	1	58.252	0.232	0.987	0.974	18
ACC-7DT	1	53.743	0.454	0.972	0.944	16
ACC-14DT	1	53.583	0.192	0.978	0.957	10
ACS-3DT	1	77.179	0.107	0.978	0.956	12
ACS-7DT	0	0.000	4.184	0.959	0.920	6
ACS-14DT	0	0.000	4.282	0.958	0.918	6

n **-** Order of mineralization rate; n.o.i – number of iteration to convergence; **a** and **b** **(wk^{-1})** represent the 1st order mineralization; ***a*** and ***b*** **(wk^{-1})** represent the 0 order mineralization.

OML (%) $= a \times (1 - e^{-bt})$; OML (%) $= a + bt$ for first-order kinetics and Zero-order kinetics respectively

The maximum mineralization potential of between 53.583 – 87.188% was recorded in treatments conforming to first order mineralization rate, of which treatment AMYC-3DT gave the highest value. Treatment ACC-7DT however, gave the highest rate of mineralization of Organic Matter or Total Carbon for this study (0.454 wk^{-1} or $0.065d^{-1}$) at $r^2 > 94.4\%$. Brito *et al*. (2008), in their study observed that turning increased the rate of OM mineralisation (k = 0.028 day^{-1}) compared to static pile composting (k = 0.009 day^{-1}) in the composting of dairy cattle slurry.

For this study, assessment of OM mineralization is evaluated as a product between the maximum potential degradation and the mineralization rate constant at 95% confidence interval (Paredes *et al*., 2000; Benito *et al*., 2009). Shi *et al.* (1999) recommended the use of the product of maximum mineralizable OM and rate of mineralization. Indeed, the minimum mineralization potential for the zero order kinetic was measured, with a high of 5.533% (AMYC-7DT) and a low of approximately 0.00 in ACS-7DT and ACS-14DT. The highest rate of mineralization measured in the zero order kinetic was linked to AMYC-7DT at r^2 of about 92.6%. Hence, it is inferred that treatment with 3DT is capable of operating at high efficiencies of Carbon or Organic Matter turnover compared to other treatment for turning frequencies in the study.

Treatment ACC-7DT had the best turnover on organic matter and potential to sanitize pathogens (Table 4.26). This indicates that a good feedstock formulation and turning regime is able to hasten degradation rate of organic matter (Robinzon *et al*., 2000). The interactive effect of feedstock and turning shows that treatment ACS-7DT was slowest in terms of organic matter turnover. The low rate of mineralization found in treatments exhibiting zero order kinetics could be attributed to the high moisture content (Das and Keener, 1997), which could be inhibiting adequate diffusion of oxygen into the piles. Moisture Content in the treatments at the active thermophilic stages or during the study did not show a clear trend in its contribution toward OM turnover.

4.5.7 ***Effect of Feedstock Composition and Turning Frequency on TN***

The TN content was variable and demonstrated significant changes ($p < 0.05$) over the composting period in this study. A significant difference ($p = 0.037$) in TN concentration at week 0 was observed in the treatments (Table 4.27). The difference existed between AMYC-7DT and that of AMYC-3DT & AMYC-14DT, ACC-3DT & ACC-7DT and ACS-7DT.

Table 4.27: Effect of feedstock composition and turning frequency on TN (%)

Feedstock	**Week**						
Turning	0	2	4	6	8	10	12
AMYC-3DT	1.61	1.62	1.28	1.63	1.26	1.20	1.33
AMYC-7DT	1.41	1.80	1.49	1.59	1.27	1.46	1.33
AMYC-14DT	1.60	1.52	1.47	1.67	1.23	1.40	1.28
ACC-3DT	1.63	1.65	1.55	1.58	1.51	1.54	1.51
ACC-7DT	1.69	1.60	1.49	1.30	1.56	1.43	1.53
ACC-14DT	1.55	1.83	1.69	1.51	1.56	1.52	1.45
ACS-3DT	1.51	1.53	1.67	1.25	1.19	1.57	1.51
ACS-7DT	1.69	1.30	1.83	1.37	1.36	1.28	1.37
ACS-14DT	1.54	1.93	1.42	1.21	1.18	1.08	1.28
LSD	0.19	0.08	0.01	0.08	0.05	0.02	0.02
p-value	0.037	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.09

The mean TN concentration ranged between 1.41-1.69 % at the start of the composting process. The interaction of turning frequency and feedstock composition produced a significant effect ($p < 0.001$) on TN in week 6 of the composting process. Between 23.83 - 43.04% TN loss occurred at this transition phase of the 6th Week of composting. This phase is also characterized by a high pH and thermophilic temperatures, which could easily induce NH_3 volatilization from the piles. At the end of the composting monitoring period, the observed mean TN loss was between 38.02 - 63.36%, with ACC-14DT and AMYC-3DT producing the highest and lowest mean losses respectively. Losses exceeding 50% was found only in AMYC treatments.

The increase in TN or its loss during composting, as reported by Liang *et al*., (2006) and Tiquia and Tam (2000), may be attributed to increase in organic N due to a concentration effect as a consequence of strong degradation of organic matter and liable through carbon dioxide or as a result of N_2 fixing from the atmosphere. Thus, an increased MC and TC contributed to the preservation of the TN in the compost (Laing *et al*., 2006; Bueno *et al*., 2008). Several studies have indicated that NH_3 volatilization increased remarkably with the increase of air supply or turning or pH (Zhang *et al*., 1994; Sundberg, 2004). Thus, TN losses evaluated for AMYC-14DT and ACS-14DT could be as a result of NH_3 volatilization resulting from a near anaerobic condition caused by high moisture content and less aeration or turning frequency (Day and Funk, 1998; Zhu, 2006).

An account of TN loss occurring in windrow or passive composting systems varied between 16–74% (Raviv *et al.*, 2004; Tiquia and Tam, 2002; Sundberg, 2005; Ogunwande *et al*., 2008). The loss of TN reduces the value of compost as a fertilizer significantly (Epstein, 1997). The presence of recalcitrant carbon sources, such as lignin in the bulking material, may have influences the level of losses in the treatments (Paredes *et al.*, 1996; Tiquia and Tam, 2002; Bernal *et al.*, 2009).

4.5.8 ***Effect of Feedstock Composition and Turning Frequency on C/N***

Generally C/N ratio in the treatment piles decreased with processing time, although there were some increments observed at various sampling weeks (Figure 4.14- 4.16).

Similar experiences have been reported in literature (Solano *et al*., 2001; Sylla *et al*., 2006). Total mean changes on C/N ratio in terms of feedstock composition and turning frequency ranged between 11.32% (increase, ACS-14DT) to -29.80% (decrease, AMYC-3DT) at the transition phase (week 6) of composting. The increases observed at week 6 for treatments ACC-7DT and all of the ACS piles, indicate that the rate at which TC reduced were much higher than that of the TN loss. At the final sampling week of composting C/N ratio experienced reduction ranging between -10.91% (ACS-7DT) to -32.28% (AMYC-7DT).

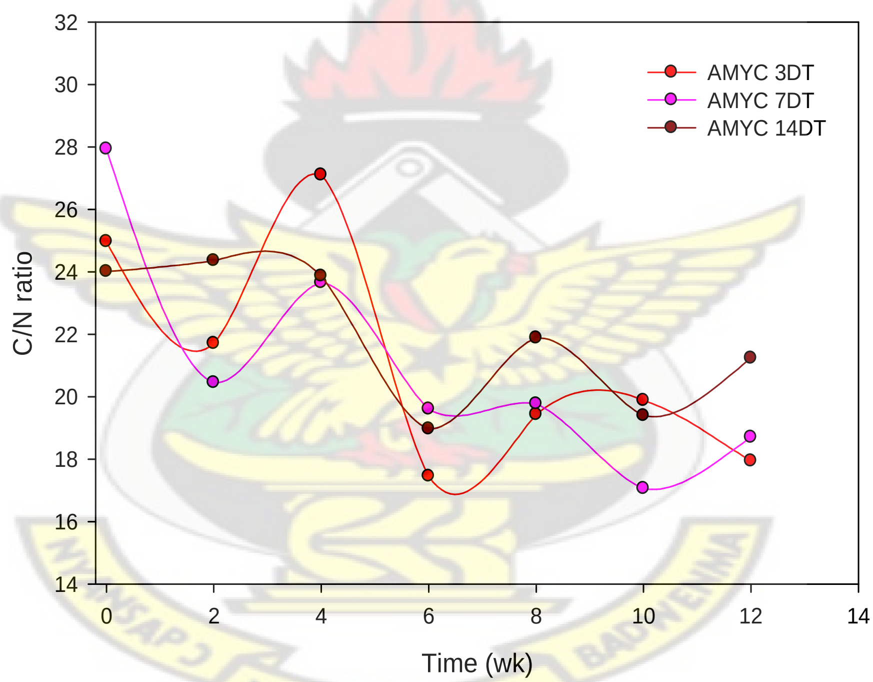


Figure 4.15: Changes in C/N ratio in pile AMYC based on turning frequency

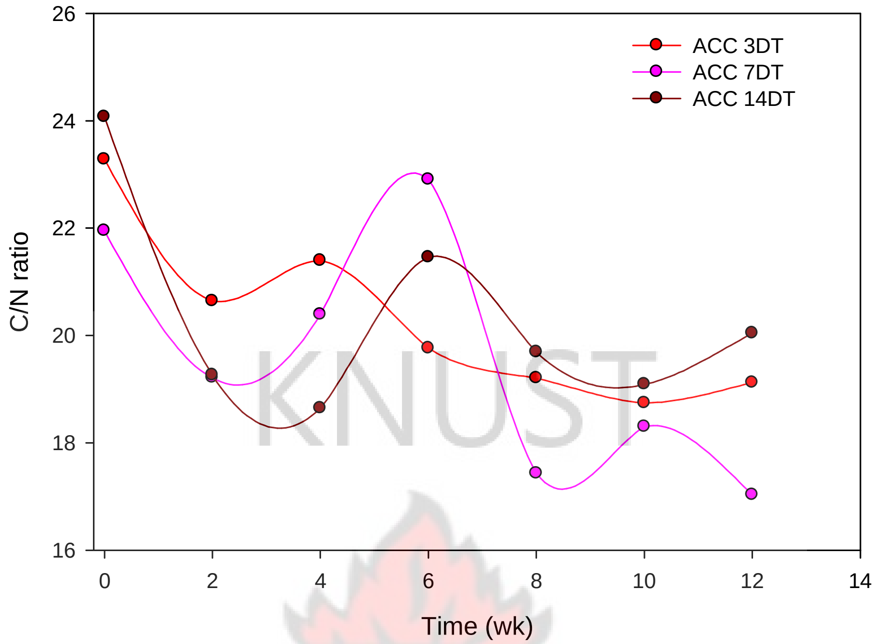


Figure 4.16: Changes in C/N ratio in pile ACC based on turning frequency

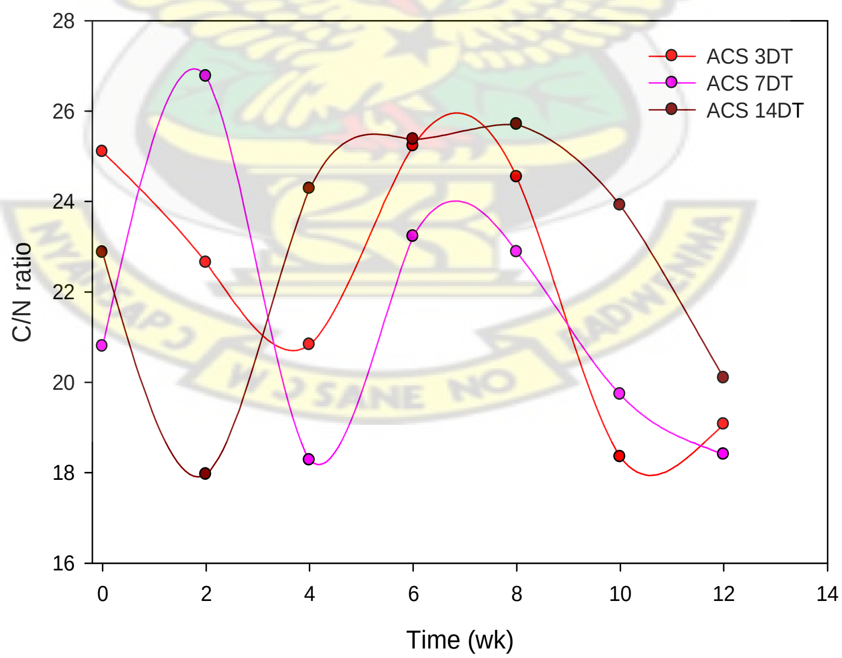


Figure 4.17: Changes in C/N ratio in pile ACS based on turning frequency

Significant differences ($p < 0.05$) observed in C/N ratio from week 2 to week 6 were largely influenced by the feedstock composition. No significant difference ($p = 0.513$) in C/N ratio was observed in Week 8 of the composting process. Thus, as materials begin to mature, the influence of feedstock composition does not play a major role in determining the evolution of its C/N ratio pathway. Although, in week 10 of composting process a significant difference ($p = 0.004$) in C/N ratio was seen in the treatments which did not continue to week 12. ANOVA performed indicated that the influence of turning frequency dominates that of feedstock composition on C/N ratio observing the interaction of feedstock composition and turning frequency during the composting of abattoir waste.

The interactive effect of feedstock compositions and turning frequency accounted for the significant differences in C/N, each factor has been noted to influence a rapid emission rate of ammonia gas during composting (Hao *et al*., 2004; Peigné and Girardin, 2004). Previous authors have reported the decreasing trend of C/N ratio during composting (Solano *et al*., 2001; Sylla *et al*., 2006). They further stated that the decreases were as a result of the mineralization of TC or OM; or the increase in TN due to relative slower mineralization of the nitrogen element. A C/N ratio below 20 is indicative of acceptable maturity (Golueke, 1981), and a ratio of 15 or less is preferable (Erhart and Burian, 1997). Because the maturity assessment criteria index recommended by California Compost Quality Council (The US Composting Council and the United States Department of Agriculture, 2001) was recorded at the beginning of the treatment (i.e. C/N < 25), it would require more than C/N to establish compost maturity or stability.

4.5.9 ***Effect of Feedstock Composition and Turning Frequency on Ca, Mg, P and K concentration***

The ANOVA on the effect of the interaction of feedstock composition and turning frequency on Mg, Ca, P and K recorded no significant variation ($p > 0.05$) in the means of the nutrients at week 0 (Table 4.28). However, a significant variation in mean was observed for Total Phosphorous (P) only at week 12. The compost pile ACS-14DT recorded the least total P value at the end of the composting process; a value two-fold less than the treatments involving AMYC. The loss of P at week 12 may be attributed to leaching. Generally, nutrient concentration increased with time, which has been attributed to the OM loss which normally increases the relative concentration of nutrient with processing time.

Table 4.28: Effect of feedstock Composition and Turning Frequency on Ca, Mg, P and K concentration in compost piles

Feedstock Turning	**Week**							
	Mg (%)		Ca (%)		P(g/kg)		K (g/kg)	
	0	12	0	12	0	12	0	12
AMYC-3DT	1.06	3.08	1.61	3.04	7.62	18.4	11.26	39.0
AMYC-7DT	0.71	1.77	1.44	3.74	7.59	20.5	15.48	42.0
AMYC-14DT	0.74	2.37	1.81	3.61	10.07	21.4	12.41	45.1
ACC-3DT	1.47	2.25	2.55	3.01	7.57	9.80	17.79	35.8
ACC-7DT	1.21	2.05	3.49	2.70	4.44	14.80	14.48	24.1
ACC-14DT	1.08	2.47	3.69	2.93	7.77	11.3	14.65	29.3
ACS-3DT	1.29	3.05	3.41	3.65	8.58	14.9	25.89	40.0
ACS-7DT	1.32	2.70	3.10	2.51	11.52	14.5	19.35	36.2
ACS-14DT	2.19	2.27	3.33	2.64	11.49	9.6	24.48	30.2
P-value	0.082	0.481	0.202	0.765	0.690	0.736	0.266	0.557
LSD	0.71	1.26	0.89	2.22	6.16	10.38	7.36	17.60

4.5.10 *Correlation of Physicochemical Parameters with Respect to Feedstock Composition*

The correlation coefficients of physicochemical parameters or transforms with respect to the interaction of feedstock composition and turning frequency are presented in Table 4.29. Contrary to the observations in the individual effects of feedstock composition and turning frequency, the interaction effect resulted in a negatively moderate correlation between temperature transforms and electrical conductivity, compared with the individual treatment effect of feedstock composition or turning frequency. Correlations between non-related parameters showed moderate to high associations in the cases of OM or MC/OM and temperature transforms.

This study revealed that, a negatively moderate correlation existed between MC/OM and the temperature transforms; yielding correlation coefficients ranging between 0.548 - 0.639. As expected, high organic matter in the feedstock provides energy for microbes to degrade more carbon to generate heat. These phenomena have been reported by Haug (1993) and Benito et al., (2003). Also noticed between MC and EC parameters is a moderate but negative relationship. Thus, an increased level of MC may influence significantly the concentration level of compost salinity (which explains the level of cation in solution). Analytically, the parameter association of non-related parameters could not produce a strong co-efficient of correlation for the interaction effect of feedstock composition and turning frequency in this study.

Table 4.29: Correlation of physicochemical parameters based on the interaction of feedstock composition and turning frequency

	ΔT	ΔT/T	T	EC	pH	MC	MC/OM	OM	TN
ΔT	1								
ΔT/T	0.9765***	1							
T	0.8508***	0.7851***	1						
EC	-0.2377	-0.246	-0.3437**	1					
pH	-0.3172*	-0.2143	-0.2452	0.117	1				
MC	0.4339***	0.4414***	0.5384***	-0.6376***	-0.1519	1			
MC/OM	-0.639***	-0.6267***	-0.5482***	0.1082	0.0877	-0.0161	1		
OM	0.7971***	0.784***	0.7748***	-0.4506***	-0.2012	0.5936***	-0.8057***	1	
TN	0.4336***	0.3993***	0.4802***	-0.2388	-0.2484*	0.5419***	-0.2904*	0.5328***	1

*, ** and *** indicates the Significant level of $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ respectively

4.5.11 ***Prediction of N Based on Feedstock Composition and Turning Frequency***

Analysis of the interactive effect of feedstock composition and turning frequency demonstrates that physicochemical parameters monitored could be used to predict the level of TN in the compost pile. The multiple regression models with group, analysed separately under a reference factor level of AMYC-3DT, explains the effect of the feedstock composition and turning frequency on nitrogen level. The independent parameters modelling the effect of interaction on TN produced varied relationships. Interaction of ACS-3DT recorded the highest co-efficient of relation amongst ΔT parameters applied; while ACS-14DT showed the lowest coefficient of relation in reference to AMYC-3DT (Table 4.30). This would imply that a unit increase in ΔT with the interaction studied would result in about 0.2874% increase to 0. 1616% decrease to the level of TN in the compost. Also, AMYC-3DT recorded the highest positive influence on TN considering the independent parameter pH while the lowest negative correlation co-efficient was realized for ACS-14DT.

Larney *et al*. (2008) reported both linear and quadratic regressions between various chemical parameters and composting time. Very few authors have reports on applying linear regression to the interactive effect of feedstock composition or turning frequency have been found (Marino *et al*., 2008; Martinez-Suller *et al*., 2008; Chen *et al*., 2009).

Table 4.30: A set of best predictive multiple-linear models relating the interactive effect of feedstock composition and turning frequency in abattoir waste composting

Treatment	$N_{treatment}$ Model Equation*	R^2	Probability
AMYC-3DT	$-8.93 + 0.0164\Delta T + 0.0398T + 1.070EC + 0.0724MC + 0.1333pH$		
AMYC-7DT	$-2.52 - 0.0156\Delta T + 0.0286T + 0.102EC + 0.0442MC - 0.0117pH$		
AMYC-14DT	$-1.11 - 0.0533\,\Delta T + 0.0472T - 0.157EC + 0.0321MC - 0.0397pH$		
ACC-3DT	$0.95 - 0.0096\,\Delta T + 0.0138T + 0.0035MC - 0.0037pH$		
ACC-7DT	$-10.97 - 0.0406\,\Delta T - 0.0792T + 0.69EC + 0.2221MC - 0.0757pH$	0.631	0.040
ACC-14DT	$3.07 + 0.015\Delta T - 0.0102T - 0.884EC + 0.0244MC - 0.1667pH$		
ACS-3DT	$6.54 + 0.2874\Delta T - 0.3322T + 1.272EC + 0.0487MC - 0.1647pH$		
ACS-7DT	$2.48 + 0.0844\Delta T - 0.1506T + 0.279EC + 0.0516MC - 0.0747pH$		
ACS-14DT	$-3.63 - 0.1616\Delta T + 0.2948T - 0.609EC - 0.0152MC - 0.2197pH$		

$$TN = constant + \Delta T + T + EC + MC + pH + Interaction\_effect(constant + \Delta T + T + EC + MC + pH$$

NB: *- The comparative regression with a common reference factor level of AMYC-3DT

This study indicates that, for the set objective, a correlation co-efficient (R^2) of 0.631 provides a significant prediction of variation in TN when considering interactive effect of feedstock composition and turning frequency (Table 4.30). Whereas, Moral *et al*. (2005) and Martinez- Suller *et al*. (2008) utilized EC, dry matter (DM), pH or specific gravity in their models, the common parameter used in study included ΔT, T, EC, MC and pH. Electrical Conductivity was not relevant in predicting TN with respect to the interaction of ACC-3DT. Literature reports of good correlation with TN on the basis of EC, dry matter (DM), pH or specific gravity (Moral *et al*., 2005; Martinez- Suller *et al*., 2008); although not with respect to interactions in treatment. The current study presents evidence of the use of physicochemical analysis to predict the nutrient value of compost. The varied relation between the parameters is an indication that turning frequency and feedstock variation may influence the composition or quality of a predictive model for TN in composting processes.

4.5.12 *Effect of Feedstock Formulation and Turning Frequency on Heavy metal Concentration Abattoir Waste Compost*

Table 4.31 shows the heavy metal concentrations in all treatments tested for the abattoir compost. Mean zinc concentrations resulting from the interaction of feedstock composition and turning frequency in the compost product recorded the highest heavy metal values between 137.84 - 217.68 mg/kg DM, while Cd, As, Co and Mo recorded values below 1.5mg/kg DM. No significant statistical difference ($p > 0.05$) in the concentration level of As, Cd, Cr, Co, Cu, Mo, Ni and Zn were observed during the study with respect to both feedstock composition and turning frequency.

Table 4.31: The effect of feedstock and turning frequency interaction on heavy metals concentrations (mg/kg DM) of compost

	AMYC-3DT	AMYC-7DT	AMYC-14DT	ACC-3DT	ACC-7DT	ACC-14DT	ACS-3DT	ACS-7DT	ACS-14DT	p-value	LSD
Cadmium (Cd)	0.082	0.06	0.069	0.381	0.455	0.521	0.139	0.338	0.14	0.306	0.209
Chromium (Cr)	4.978	2.758	2.704	2.726	4.781	3.35	4.547	2.593	4.313	0.189	2.992
Copper (Cu)	2.524	2.62	2.679	2.793	3.201	3.713	3.725	2.896	3.83	0.206	0.854
Mercury (Hg)	-	-	-	-	-	-	-	-	-	-	-
Nickel (Ni)	0.789	0.383	0.525	1.218	1.182	1.548	1.063	1.02	0.898	0.545	0.621
Lead (Pb)	2.607	1.467	1.253	1.913	2.091	1.965	2.562	2.47	2.015	0.032	0.661
Zinc (Zn)	164.536	213.872	171.973	154.425	137.839	180.833	208.597	181.836	217.681	0.125	53.38
Arsenic (As)	0.057	0.073	0.032	0.568	0.518	0.461	0.178	0.337	0.057	0.647	0.275
Cobalt(Co)	0.926	0.712	0.776	0.209	0.262	0.337	1.266	0.997	1.298	0.658	0.405
Molybdenum (Mo)	0.378	0.14	0.075	0.846	0.934	1.1	0.213	0.53	0.193	0.255	0.47
Manganese (Mn)	27.672	28.915	32.687	23.808	28.935	38.042	52.095	49.671	49.098	<0.001	4.037

However, Pb and Mn recorded significant variations ($p = 0.032$; $p < 0.001$ respectively) in mean concentrations due to the interaction of feedstock composition and turning frequencies that the compost piles were subjected to. These significant differences were largely due to feedstock utilized. The concentrations of Cu, Ni and Mn were lower than values analyzed in the cocoa pod husk sample (CPH) analyzed (Table 4.12, pg. 102). The analysis in Table 4.31 is indicative to the fact that CPH was a major contributor to heavy metal concentration in the compost produced.

Generally the interaction of feedstock composition and turning frequency regime did not influence significantly the concentration levels of heavy metals in the composting of abattoir waste, but for Pb and Mn. The analysis in this study does not exhibit any major link of heavy metal to phytotoxicity in the compost product. The heavy metal concentrations due to the interactive effect of feedstock composition and turning frequency were below the limits suggested in Day and Shaw (2001) and BSI (2005). Indeed, the source of feedstock as acknowledged by Veenken and Hameler (2002) and the process of handling Zhang *et al*. (2008) may contribute to heavy metal concentration in the final compost product.

4.6 Feedstock Characterization in River Reed Composting Experiment

In the pilot piles to test the effect of aeration system on composting process dynamics of river reed, various parameters were analysed and monitored. The characteristics of various raw materials used to formulate the piles are summarized in Table 4.33. Banana waste (BW) recorded the highest Moisture Content (MC) and Organic Matter (OM) content but had the lowest mean pH (acidic) within a range of 4.18 - 8.18 among the raw materials used. The manure components recorded the highest pH (alkaline) mean between 8.09 - 8.18. As expected, bulk density for clay was highest (~1,258.82 kg/m^3) and the lowest bulk density was recorded for rice husk (RH).

Electrical Conductivity of manure was several orders of magnitude greater than the others. This is in consonance with Ko *et al.'s* (2008), observations that EC values of animal manure composts were higher than those of other organic waste (plant) composts. Total Carbon concentration was highest in RH and lowest in clay. The highest Total Nitrogen (TN) concentration was observed in Cocoa Seed Husk (CSH), probably due to its high initial OM and lipid contents. However, the lowest was measured in the clay (soil) sample, emphasising the poor quality of soil in the area.

Ammonium concentration was highest in Poultry Manure (PM). The relative low NH_4^+ concentration in the initial CM feedstock could be attributed its dryness (MC < 40%) and the method of handling before it was used for composting. It was observed that generally, PM was kept in sacks and in forty-foot containers to preserve it from the excessive exposure to the elements of the weather, whiles other raw materials were to a large extent exposed to the weather. Thus, N was relatively preserved in PM as compared to CM because of the pre-handling measures adopted at the site. Nitrate concentration was highest in RR component and lowest in the clayey soil.

Table 4.32: Physicochemical characteristics of raw materials used in the formulation of river reed composting piles

Parameter	RR	PM	CM	CSH	RH	BW	Clay
Composition (w/w)	75%	1%	4%	1%	4%	5%	~10%
MC (%, wb)	75.03	12.98	38.22	18.46	19.00	84.06	10.18
	(1.04)	(0.28)	(0.61)	(0.73)	(0.15)	(2.05)	(0.2)
OM	86.18	61.41	35.32	87.37	74.44	88.80	5.24
	(2.98)	(1.32)	(1.41)	(2.36)	(1.11)	(2.31)	(0.06)
Bulk Density(kg/m^3)	270.20	533.33	805.00	494.12	192.16	617.26	1,258.82
	(7.63)	(10.14)	(8.25)	(6.21)	(4.50)	(5.51)	(2.62)
pH	7.14	8.18	8.09	7.14	6.34	4.18	6.58
	(0.090)	(0.115)	(0.07)	(0.02)	(0.16)	(0.05)	(0.04)
EC (dS/m)	0.24	6.70	6.70	2.5	0.53	0.31	0.18
	(0.00)	(0.07)	(0.02)	(0.04)	(0.01)	(0.02)	(0.00)
TC (%)	36.84	33.30	27.33	37.69	34.11	34.94	1.96
	(1.04)	(0.03)	(0.86)	(0.17)	(2.09)	(1.99)	(0.06)
TKN (%)	1.30	2.38	0.67	2.55	0.36	1.23	0.034
	(0.03)	(0.07)	(0.05)	(0.07)	(0.05)	(0.03)	(0.01)
NH_4^+(g/kgDM)	5.18	12.03	1.48	4.03	1.06	1.14	0.87
	(0.08)	(0.7)	(0.05)	(0.4)	(0.6)	(0.06)	(0.02)
NO_3^- (mg/kgDM)	295.82	218.47	238.91	257.81	132.81(	147.65	90.23
	(2.80)	(0.48)	(0.35)	(0.56)	0.21)	(0.77)	(0.27)
P (%)	0.14	0.87	0.23	0.33	0.16	0.18	0.07
	(0.03)	(0.05)	(0.04)	(0.05)	(0.03)	(0.02)	(0.00)
K (%)	0.50	0.70	0.75	2.75	0.85	3.33	0.15
	(0.06)	(0.07)	(0.05)	(0.03)	(0.06)	(0.13)	(0.03)

RR-River Reed; PM- Poultry Manure; CM- Cow Manure; CSH- Cocoa Seed Husk; RH-Rice Husk; BW-Banana Waste. Values in parenthesis represent the standard deviation of three replicates. The composition of the feedstock is on percentage weight-by weight basis.

The highest potential contributor of P in the final product is the PM material, recording a value of about 0.87%. Potassium concentrations analyzed in the initial materials showed that BW (about. 3.33%) and CSH (about 2.72%) had in many folds a higher constituent of the element compared to other raw materials used.

4.7 Temperature Profile: River Reed Composting Experiment

Figure (4.17 -20) describes temperature characteristics observed during the composting of river reed from the Volta Lake in Ghana (Temperature readings with time are presented in appendix H1). The solid vertical line in the temperature profiles denotes the period of turning the entire pile; whereas the broken line denotes the reshaping of the piles (in the case of the passive aeration composting system). Initial average temperatures in the piles after construction ranged from 52.1^{o}C to 65.7^{o}C. Reference temperatures monitored along the temperature time profile were at 40^{o}C (lowest thermophilic limit) and 55^{o}C (lowest disinfection limit).

Maximum decomposition of biodegradable solid waste has been reported to occur at temperatures between 55 - 70^{o}C (Epstein, 1997). However, less frequent mixing in larger piles could account for the high temperatures recorded for a longer time (Jackson and Line, 1998; Meunchang *et al.*, 2005), as in the case of DAT and HV treatments. The excessive cooling of the FA pile by day 21 was due to higher aeration rate from the centrifugal blower used; where the timer had been set to activate aeration for 2 minutes and deactivate aeration for every 15 minutes sequentially within the pile. Hence the period of aeration was adjusted to 1 minute activation and 30 minutes deactivation.

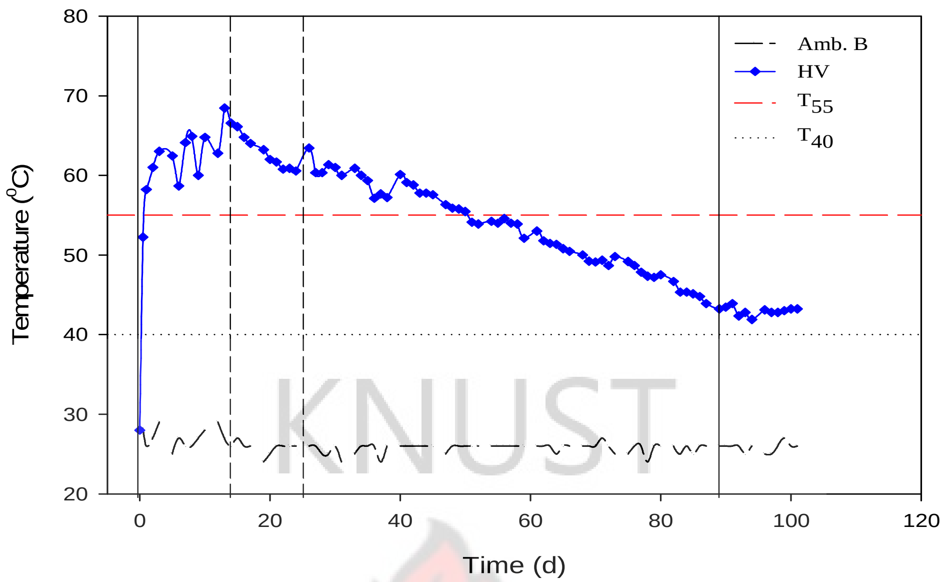


Figure 4.18: Temperature profile of the DAT aeration system

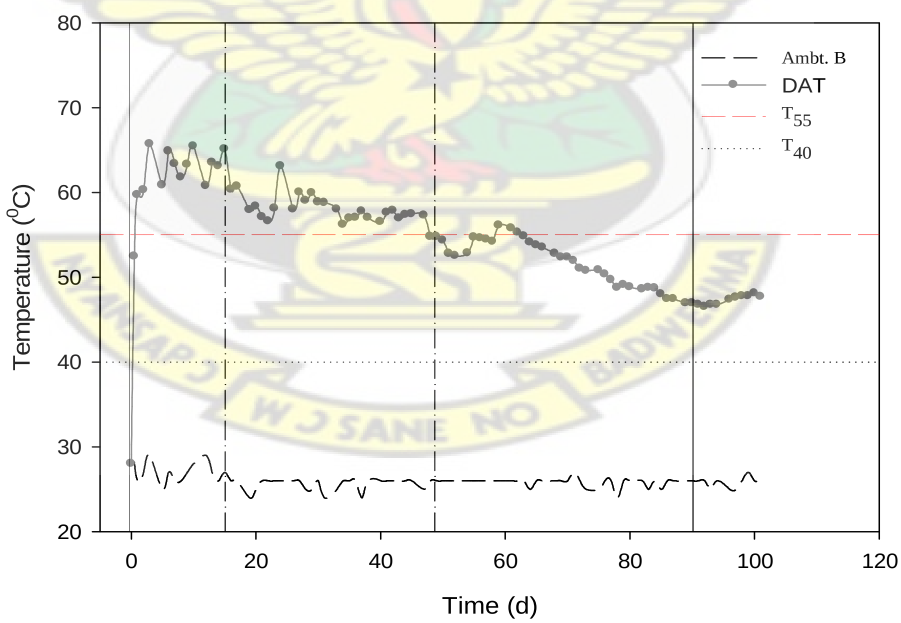


Figure 4.19: Temperature profile of the HV aeration system

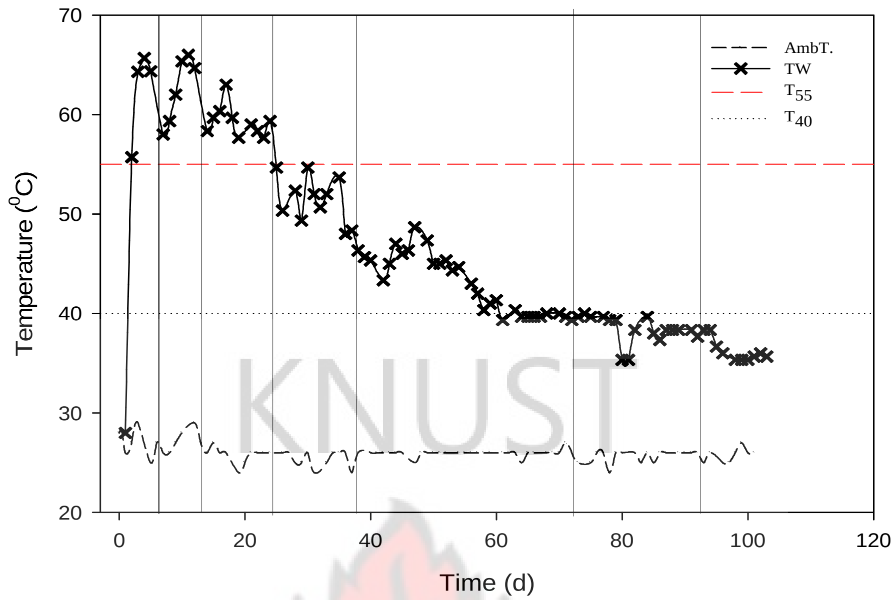


Figure 4.20: Temperature profile of the TW aeration system

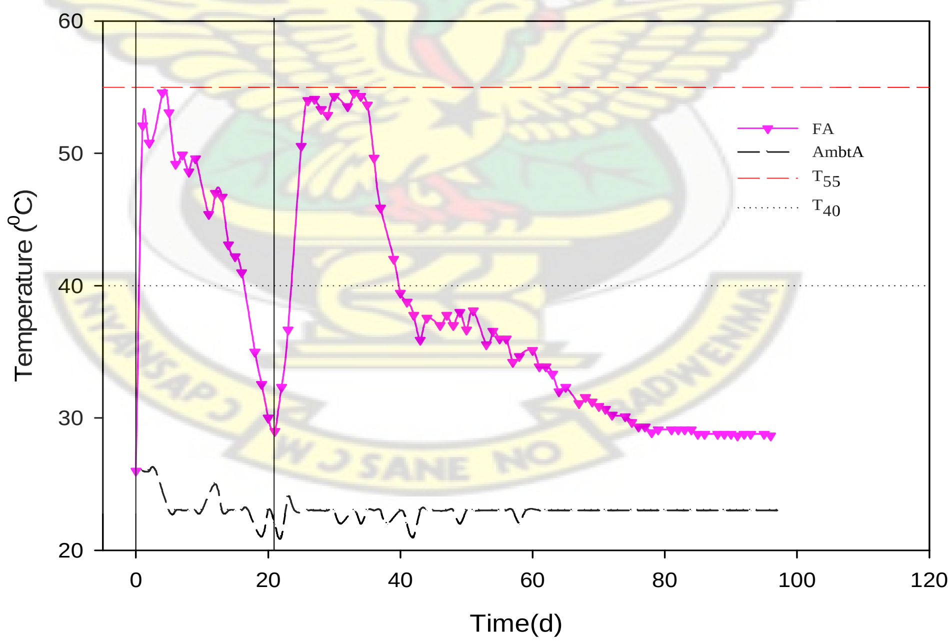


Figure 4.21: Temperature profile of the FA aeration system

Peak temperature (Table 4.33) was lowest in the FA treatment, compared to the passive aeration treatments (DAT and HV) and TW. Areas bounded by the curve and a 40^{o}C baseline (A_{40}) and areas bounded by the curve and a 55^{o}C baseline (A_{55}) were evaluated to give a quantitative description of the composting temperature profiles.

Table 4.33: Average temperature characteristics

Indicators	Unit	DAT	HV	TW	FA
Initial	^{o}C	52.2	52.2	65.7	52.10
Peak Temperature	^{o}C	65.7	68.4	66.0	54.60
Time to reach peak	d	4	13	9	4
Period above 55 ^{o}C, t_{55}	d	51	57	22	-
Period above 40 ^{o}C, t_{40}	d	>103	>103	59	31
Area above the 40^{o}C, A_{40}	^{o}C·d	1,470.8	1,435.0	722.9	261.5
Area above the 55^{o}C, A_{55}	^{o}C·d	221.2	290.3	133.6	0

The MATLAB file used in calculating the area under the temperature profile is described in Appendix D1. The values for A_{40} and A_{55} estimated for the composting of river reed under the four aeration technologies (DAT, HV, TW and FA) for 14 weeks (Table 4.32) agree with temperature-time profile characteristics reported for full-scale windrow and forced-aeration systems by Mason and Milke (2005). Time at or above the 40^{o}C reference was highest in passive aerated (DAT & HV) composting system (>103days), whilst that of the turned windrow (TW) and forced-aeration treatments (FA) recorded times of 59 and 31 days respectively. The maximum rate of temperature increase was evaluated at 36.7 $^o C\cdot d^{-1}$, which was observed in treatment DAT; with a maximum rate of temperature decrease observed in TW as -5.7 $^o C\cdot d^{-1}$. Values recorded for A_{55} ranged from 0 - 290.3^{o}C·d. However, the thermodynamic characteristics of treatment FA could not satisfy a full scale forced-aerated pile system according to the criteria of Mason and Milke (2005), since a minimum (A_{55}) of 26 $^{o}C \cdot d$ and t55 of more than 10days was not achieved. The time period (t_{55}) in the profiles, showed a more sustained thermophilic temperature in the passive aeration and turned-windrow treatments than the forced-aeration treatment.

A non-linear regression model by the Yu *et al.* (2008) was fitted to the observed data to describe the microbial influence to temperature characteristic in the composting pile (Appendix D2). The temperature under mesophilic microbial activity was found to be in the order of DAT = HV > FA > TW. The time to attain maximum microbial contributions to mesophilic heating was less than a day for all treatments (Table 4.34). The maximum mesophilic co-efficient (k_m) recorded was about the same values, 0.99 d^{-1} for all four treatments. Also, it was observed that the time within which maximum mesophilic heating rate occurred coincided with the time when maximum thermophilic heating occurred in the case of treatment TW. Thermophilic activity which is represented by 'k_t' was highest in treatment HV (0.999 d^{-1}) and lowest in treatment DAT (0.063 d^{-1}). However, the modelled maximum time for thermophilic heating was about days 34, 10 and 24 respectively (Table 4.34) for treatments DAT, HV and FA. According to Yu *et al*. (2009), dominant microbial activity phase, whether as thermophilic or mesophilic, could be compared using the maximum co-efficient rate (i.e. k_m or k_t). A higher k_m than k_t indicates a greater mesophilic activity in the treatment pile and vice versa. The river reed composting was therefore dominated by mesophilic activity. The dominance of mesophilic activity could be due to the easily degradable organic materials such as sugars, proteins and organic acids, in the feedstock pile (Sundberg *et al*., 2004). Values obtained from the model corroborated with the decline in temperatures observed in Figure 4.21.

Table 4.34: Non-linear regression parameter values for temperature-time serie in composting piles

Parameters		Initials	DAT	HV	TW	FA
T_0	^{0}C	20	28.255	26.588	32.222	20.000
T_M	^{0}C	10	40.000	40.000	23.028	35.196
k_M	d^{-1}	0.01	0.999	0.999	0.999	0.990
t_M	d	1	0.106	0.002	0.000	0.000
T_T	^{0}C	10	23.046	2.572	20.903	33.655
k_T	d^{-1}	0.01	0.063	0.999	0.999	0.734
t_T	d	1	34.164	10.247	0.000	23.644
T_C	^{0}C	40	48.852	42.376	40.944	60.000
k_C	d^{-1}	0.05	0.035	0.019	0.039	0.068
t_C	d	30	32.439	56.036	12.295	20.697
r			0.943	0.972	0.961	0.972
r^2			0.888	0.945	0.924	0.944
No. of Iteration			34.0	27	8.0	21.0

The highest temperature decline was observed in FA with a maximum potential decline of 60^{o}C (y_c) and a maximum cooling rate co-efficient (k_c) of 0.068d^{-1}. The main cause of temperature decrease is attributed to excessive aeration and dryness of the FA pile (Haug, 1993; Larsen and McCartney, 2000; Ahn *et al.*, 2007; Mason, 2007), thus, preventing the pile from operating at the thermophilic conditions required for optimum rates of decomposition. The time of maximum cooling rate (t_c) of about 20.7 days occurring three days earlier than the time of maximum thermophilic rate occurrence) and the high cooling potential (y_c) of about 60^{0}C attest to the conditions observed (Figure 4.21 (d) and Table 4.34).

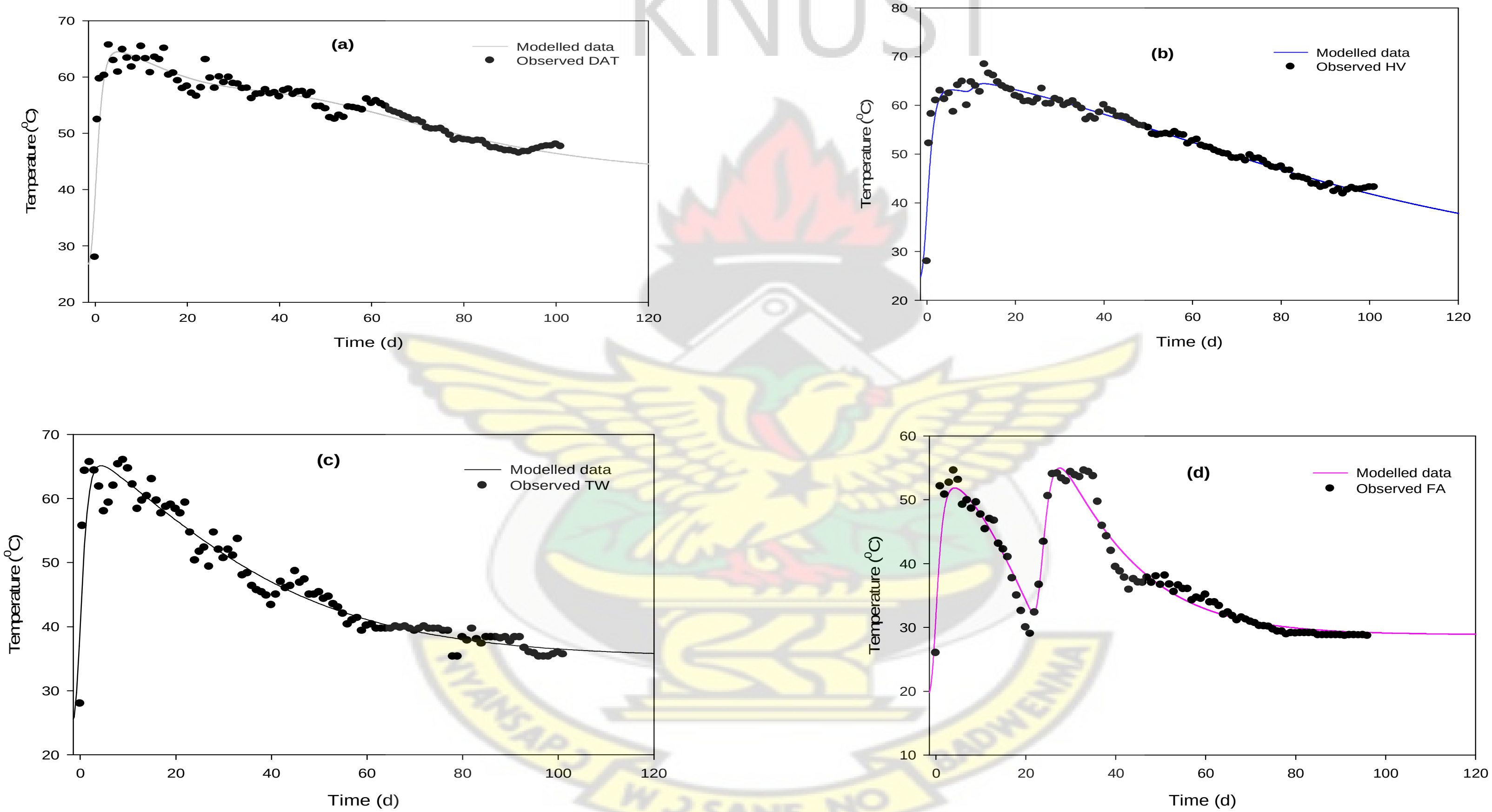


Figure 4.22: A non-linear regression to predict temperature in the selected composting aeration system pile

4.8 Evolution of Physicochemical Parameters in the Composting of River Reed

4.8.1 *Electrical Conductivity (EC) Evolution in the Compost Piles*

Electrical Conductivity reflects the degree of salinity in the composting product, which indicates its possible phytotoxic/phyto-inhibitory effects on the growth of plants as fertilizer (Lin, 2008; Huang *et al.*, 2004). Figure 4.22 shows a similar pattern of change in EC for all the four composting treatments. From an initial value of 1.03 - 1.47dSm^{-1} the piles settled with a final EC ranging between 2.28 - 2.96 dSm^{-1}. Generally, it was observed that piles with frequent or expected higher rate of aeration recorded higher EC values compared to passively aerated system. Salinity values more than doubled after week 3, for the passively aerated systems. It, however, took about 8 - 9 weeks for EC levels to double in frequently aerated piles.

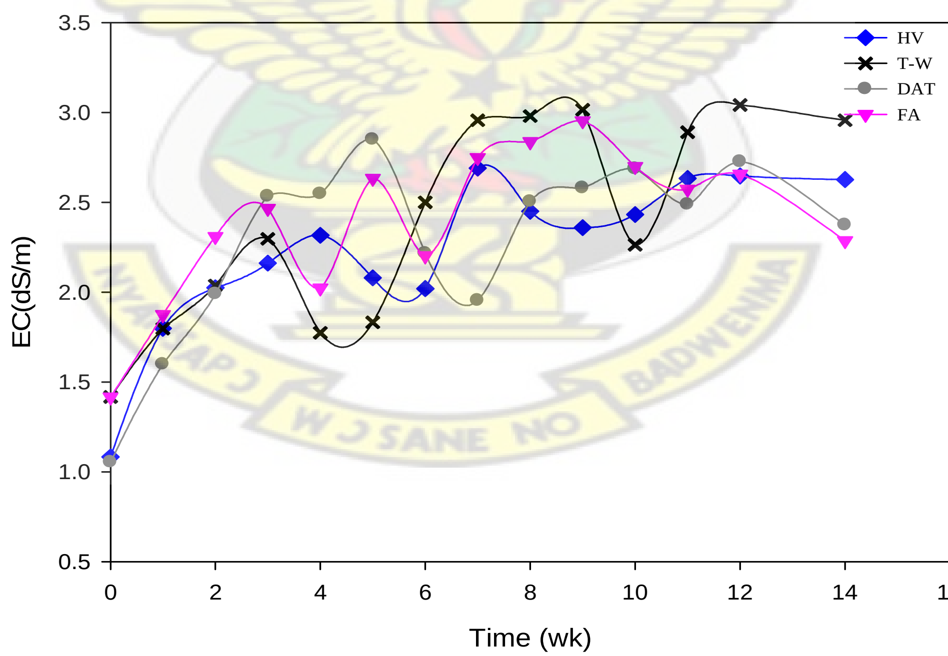


Figure 4.23: Changes in EC during composting of river reed

Electrical conductivity at the transitional phase of week 7 revealed a significant effect ($p = 0.010$, LSD = 0.480; Appendix H2) due to the system of aeration. This difference was noted mainly with DAT compared to the others (HV, TW and FA) at the transition phase. Zameer *et al.* (2010) observed that EC in treatment could decrease with increase in moisture content during the composting process. This link was better observed after the active phase of the study when DAT had relatively higher moisture content. Generally, EC values of the treatments did not show significant difference ($p < 0.05$) after week 8 through until week 14 when a significant change ($p = 0.019$) was observed amongst treatments (Figure 4.22). It was observed that piles with frequent or expected higher rate of aeration (FA or TW) recorded significant higher EC values compared to passively aerated system while composting river reed with other agro-waste. The OM mineralization of treatment at thermophilic phases contributed to the general increase in EC; which followed a similar pathway as the OM mineralization.

Gómez-Brandón *et al.* (2008) explained the phenomena as being the result of the mineralization or concentration effect of OM with respect to other present nutrients in the treatments. Thus, these relate to a high concentration of soluble ion or matter and indicative of a high concentration of TN as observed in this study (Zmora-Nahum *et al.*, 2007; Figure 4.30, page 166). The study also corroborates the assertion that, the release of mineral salts such as potassium, ammonium and like ions could have influenced such occurrences during composting (Campbell *et al.*, 1997; Larney *et al*., 2008). Baeta-Hall *et al.* (2005) observed that decreasing OM and pH tends to increase EC with composting time. The EC of composting product did not exceed the limit of < $4.0 dSm^{-1}$ (Rao Bhamidimarri and Pandey, 1996; Soumaré *et al*., 2002). The results of this study indicate that the compost may not need any dilution with soils or composts with low EC for agricultural purposes. Thus, on the basis of EC river reed compost is suitable for direct application to plants/crops.

4.8.2 *pH and Carbon Dioxide Evolution in the Compost Piles*

The initial pH recorded for this experiment was 7.69 for DAT and HV, and 7.79 for TW and FA samples. The pH values obtained during the composting process ranged between 7.27 and 8.87 (Appendix H3). These were within the recommend range of 6.0 - 9.0 for optimum composting (Haug, 1993; Metcalf and Eddy, 2003; Sundberg *et al*., 2004). The FA treatment, which was subjected to a higher aeration regime, recorded significantly lower pH values ($p \leq 0.05$) than all the other treatments (Figure 4.23 - 4.26) at most stages of the composting period. According to Tiquia *et al*. (2002), the piles revealed conditions suitable for ammonia volatilization (i.e. pH >7.5).

In the transitional phase of week 7 a significant change ($p = 0.004$, LSD 0.211) was observed in pH, with TW < DAT < HV and FA treatment systems, with corresponding values of 8.133, 7.667, 7.667 and 7.933. However, there was no significant difference ($p \leq 0.05$) in pH within the treatments at the end of the composting process. The feedstock used in this study did not experience the usual sharp decrease of pH prior to or at the thermophilic temperature observed during composting of food waste or municipal solid waste (Sundberg, 2005).

The gradual decrease in pH for the four composting treatments could be due to the volatilization of ammonia, the release of H^+ from microbial nitrification, the decomposition of OM or production of organic and inorganic acids (H_2CO_3), and the release of carbon dioxide during the composting process as similarly observed by several authors (Inbar *et al*., 1993; Wong *et al*., 2001; Zhang and He, 2006; Saludes *et al*., 2008). Significant decrease ($p < 0.05$) in pH is explained by the slower nitrification (i.e. oxidizing NH_4^+ to NO_3^- by nitrifying bacteria) which causes the release of hydrogen ion (H^+); thus, causing the pH decreases in the piles (Sylla *et al*., 2006). The characteristic of the graphs indicates that pH decreases were preceded or coincided with CO_2 (g) increases generally (Yañez *et al*., 2009; Figure 4.23 pH/CO2).

In the transitional phase of week 7 a significant change ($p = 0.027$, LSD 0.945) in CO_2 concentration was observed, with TW < DAT < HV and FA treatment systems at concentrations (v/v %) of 4.67, 5.00, 6.00 and 6.00 respectively. Eklind and Kirchmann (2000) observed that, the decomposition of organic matter and production of organic acids and the release of carbon dioxide during the composting process facilitate the decrease in pH as was observed in this study. Thus, in the presence of adequate moisture, CO_2 is likely to form weak bicarbonate when bio-oxidation of the pile is not intense. Such occurrence is noted to promote the activity of autotrophic nitrification bacteria that are capable of consuming bicarbonates as a form of carbon (Cáceres *et al*., 2006). Thus, as shown in Figure 4.25, TW treatment demonstrated a more stable CO_2 concentration compared to any other treatment studied, indicating a suitable bio-oxidation process. More so, the reshaping, turning or system of aeration of the pile, is considered to contribute to the dynamics of pH and CO_2 due to their influence on temperature and microbial biomass. Thus, the dilution of pile CO_2 by atmospheric air could account for such decreases in pile pH values.

Generally, increases in pH during composting has been linked to the biodegradation of the organic acids, mineralization of organic compound or the solubilisation of ammonia (Paredes *et al*., 2000; Wong *et al*., 2001; Sanchez-

Monedero *et al*., 2001; Sundberg *et al*., 2004). Higher pH values were observed in passive piles compared to the active ones (TW and FA pile). An increase in pH during composting has been reported in other studies (Sundberg *et al*., 2004; Tognetti *et al*., 2007; Gil *et al*., 2008).

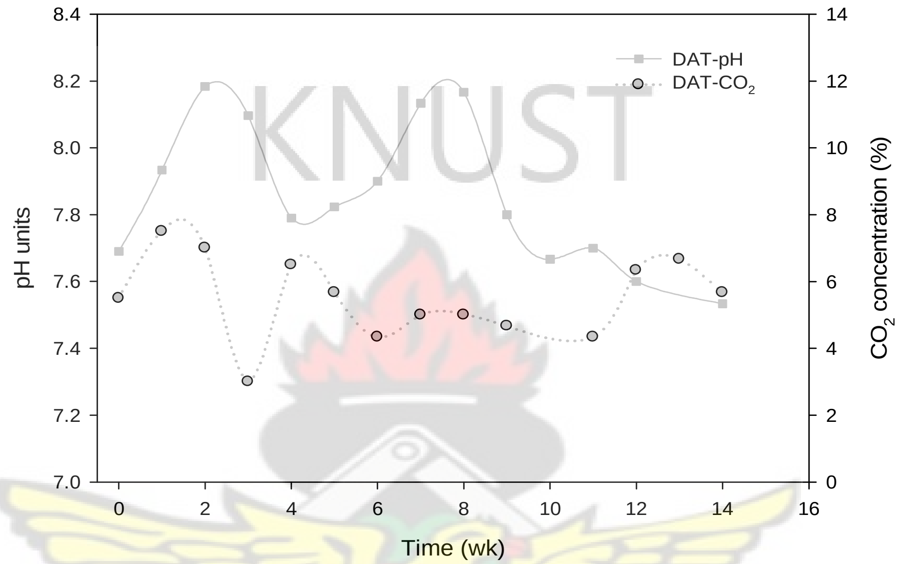


Figure 4.24: Changes in pH and CO2 concentration in DAT pile

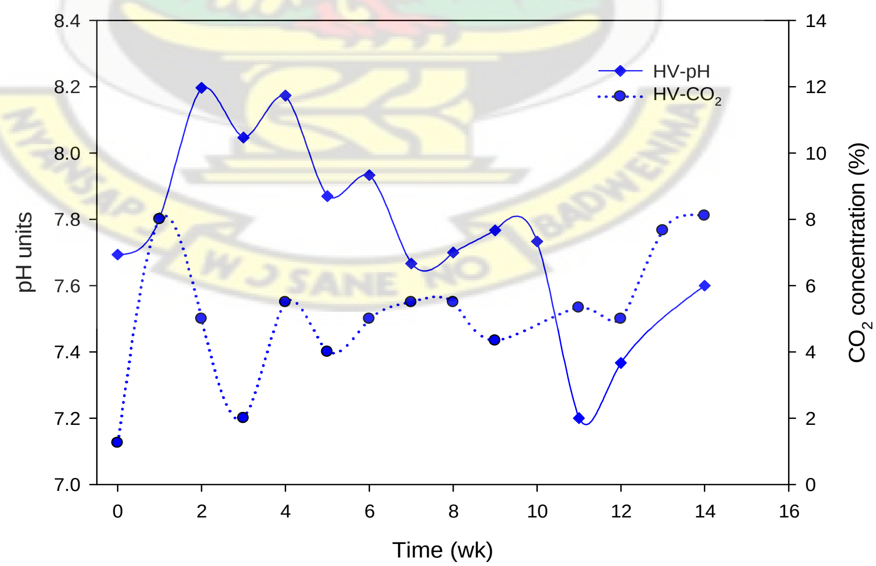


Figure 4.25: Changes in pH and CO2 concentration in HV pile

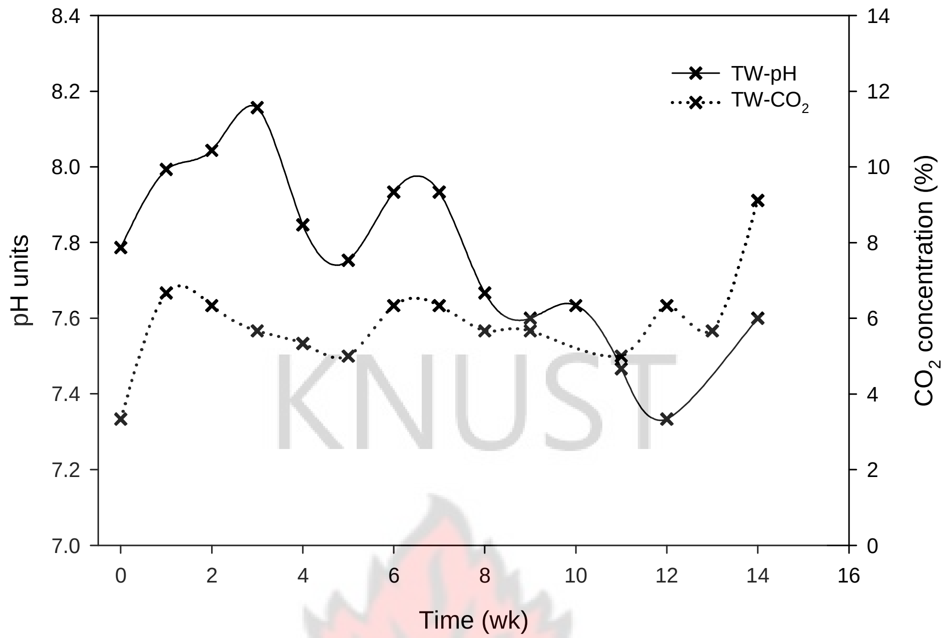


Figure 4.26: Changes in pH and CO2 concentration in TW pile

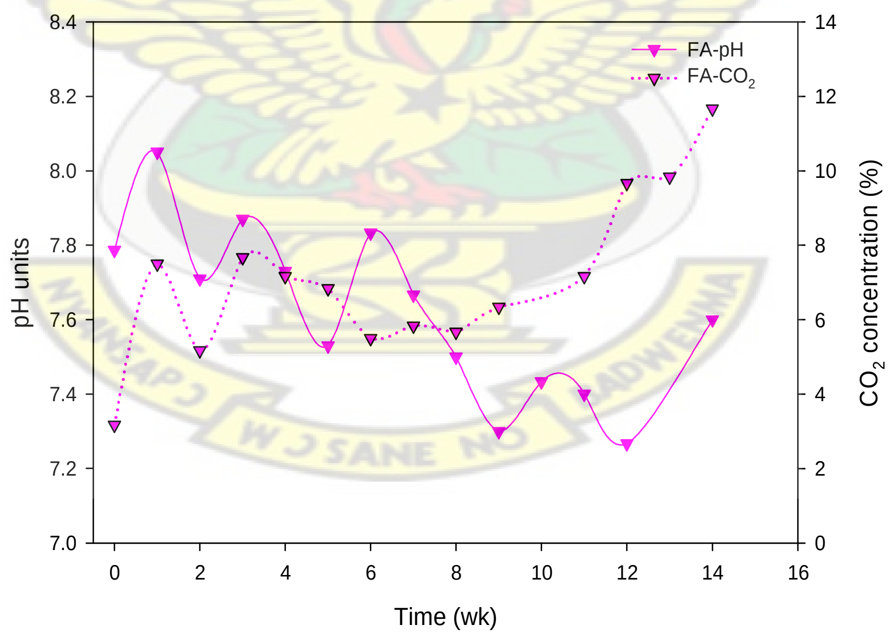


Figure 4.27: Changes in pH and CO2 concentration in FA pile

Sundberg *et al*. (2004) and Gil *et al*. (2008) associated higher pH with ammonification, a process which fosters the solubilisation of Ammonia leading to the formation of Ammonium, occasioning an increase in pile pH value. These findings were confirmed in this study, because in all the piles constructed the pH shape generally reflected the TN profile at the active composting period (Figure 4.30, page. 166).

Furthermore, percentage volume of CO_2 (g) measured increased in the latter stages of the composting process; which is not normally expected. This is explained by the increase in TN during the maturing period (weeks 8 to 14, Figure 4.30, page. 166). This observation is explained to be a major source of influence on microbial growth and activity (Meunchang *et al*., 2005). It is reckoned that microbial growth was hastened due to the possible fixation of Nitrogen (Moldes *et al*., 2007); however these microbes may also be immobilized at a similar rate converting their dead cells as carbon source which is utilized quickly to release CO_2 (g). The observed increases in CO_2 (g) generally for all aeration treatment systems support this phenomena. Ryckeboer *et al*. (2003) and Kutsanedzie (2010) found that temperature affects microbial survival during composting and thus influences decomposition and the release of gases.

4.8.3 ***Evolution of Moisture Content in the Compost Piles***

Moisture Content monitored during the composting process ranged from 55.67 - 71.00% (wet basis) during the active composting phase (i.e. the first 6-weeks, mostly characterized with high thermophilic temperatures); and 45.67 - 60.33% during the stabilization phase (Figure 4.27, Appendix H4). The highest moisture content was observed in treatment TW (week 1), while the lowest occurred in week 9 of the same treatment. Mean differences in MC observed during the composting process showed significant difference (p = 0.036) between treatments in week 8. This difference was occasioned by the differences in the aeration regimes after the beginning of the maturation process in week 7. The difference is due to the low MC recorded for TW compared to the passive aerated piles (DAT and HV).

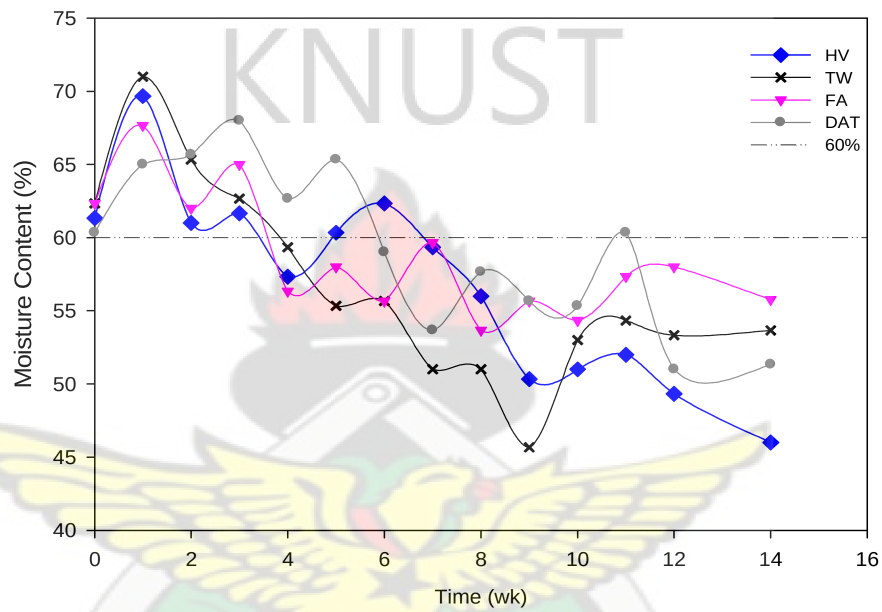


Figure 4.28: Moisture Content level of treatment pile

Although there was a general decrease in MC value during the composting process, watering of the piles accounted for most increases in MC in treatments. The prime phenomena accounting for moisture loss is evaporation, which has been cited to represent about 70% of heat loss in the composting system (Haug, 1993; Schaub and Leonard, 1996; Robinzon *et al*., 2000; Mason, 2007). Complete turning of the piles contributed to the higher rate of moisture loss (Robinzon *et al*., 2000; Nelson *et al*., 2006; Kader *et al*., 2007).

4.8.4 ***Total Carbon and Organic Matter Turnover in Compost Piles***

The analysis of variance showed Total Carbon (TC) and Organic Matter (OM) turn over to differ among the treatments under the aeration systems. Total Carbon did not differ significantly amongst the treatment at the initial week of the composting process. The only significant difference of TC in treatments at the active thermophilic stage was at week 3; which coincided with relatively high moisture content for treatment DAT compared with HV and FA (Figure 4.27, Appendix H5). Total Carbon loss (TC Loss) by the transition stage of week 7 demonstrated that the passive aerated systems (DAT and HV) have been able to achieve more than 50% of the degradation of carbon in the piles; whereas, the actively aerated systems produced values of 38.62% and 24.62% in treatment TW and FA respectively. Thus a significant effect ($p = 0.042$) on TC concentration due to aeration was observed in FA with respect to DAT and HV at week 7. The TC loss with respect to organic matter at week 14 is ranked as HV > DAT > TW > FA (Appendix H10) with mean values ranging between 50.17 - 64.91%, with no significant difference in TC concentration with treatment. Thus, maturity of the piles is further examined with respect to the degradation of OM.

Organic Matter changed from initial values of 54.41 - 54.52% on dry matter basis to between 28.68 - 39.10% dry matter basis at the end of the composting period (Appendix H6). Generally, OM content decreased with time during the composting process. An examination of percentage OM and OM–loss evolution during the composting process showed a significant difference in week 4 and through the transitional phase for most treatments (Appendix H11). A marked difference in OM was also observed in Week 7 week between treatments ($p = 0.046$). The study revealed that the slow rate of organic matter decomposition with respect to FA compared to passive systems of aeration or a mechanically turned system influenced the marked differences in Organic Matter (OM). Beck-Friis *et al*. (2003) attributed the degradation of OM and TC to bio-oxidation of the pile resulting in the release of CO_2. By the transition phase treatments had achieved above the 50% of the organic matter loss. Factors such as temperature and pH contributed to the marked difference observed in OM concentration. These factors have been reported to affect the process efficiency or OM turnover during composting (Haug, 1993; Sundberg *et al*., 2004; Bueno *et al*., 2008; Bernal *et al*., 2009). At the final stage of composting, a marked difference ($p = 0.011$) in OM was obtained between the treatments. The concentration of OM at the 14th week of composting could be ranked as HV $<$ DAT $<$ TW $<$ FA with values of 28.68%, 33.79%, 34.26% and 39.10% respectively. Sartaj *et al*. (1997) reported that passive aeration had a higher composting rate compared to the active aeration systems in their study of manure slurry composting. Nelson *et al*. (2006) and Szanto *et al*. (2007) reported that turning and forced-aeration in static piles have a higher tendency to causing drying or early cooling of treatment piles. Conversely, the domes or piping ducts formed in the composting piles were effective in producing a better or comparable OM mineralization rate as supported by Fernandez and Sartaj (1997), Patni *et al*. (2001), Sylla *et al*. (2003), Zhu *et al*. (2004) and Sylla *et al*. (2006).

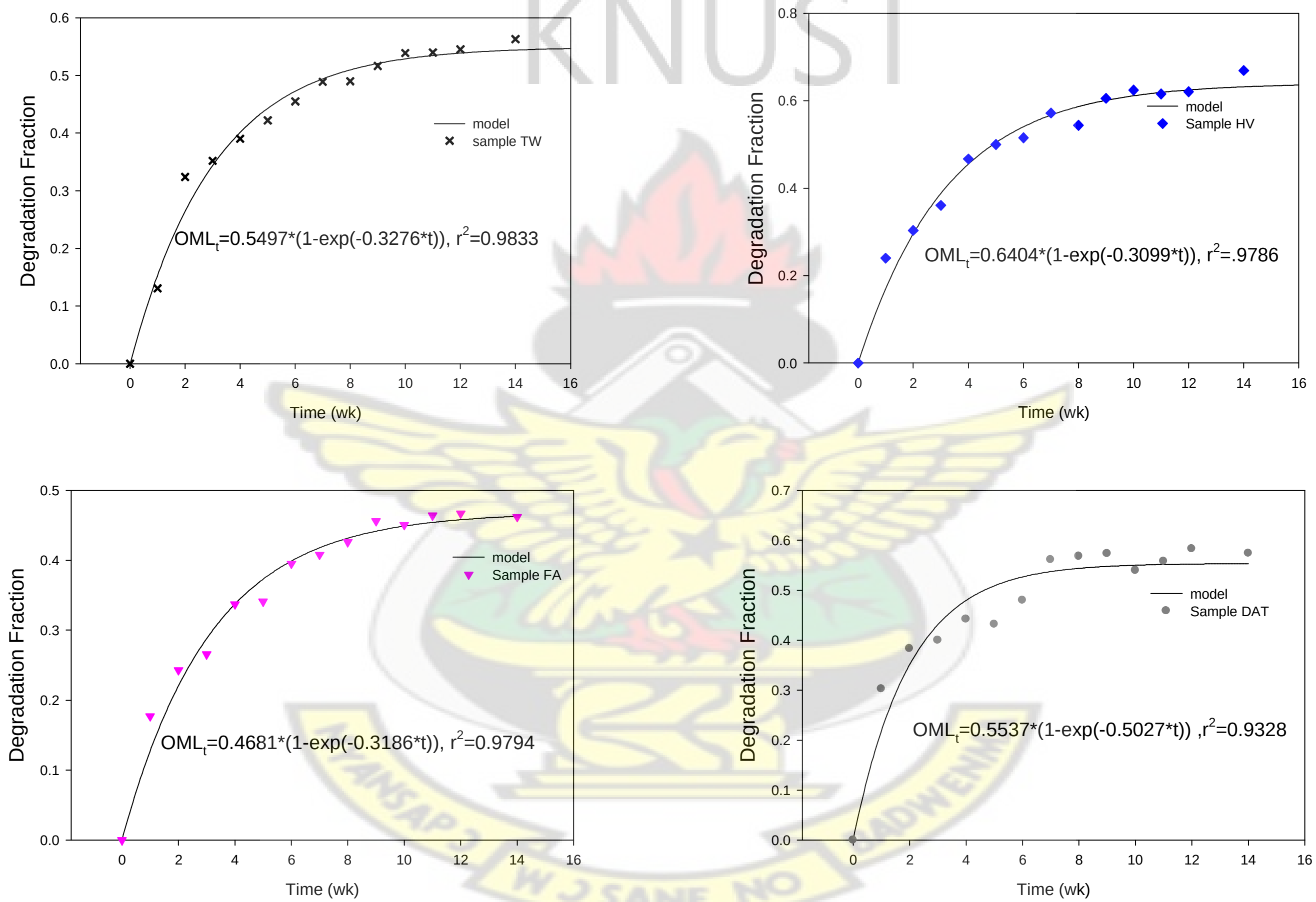


Figure 4.29: Degradation of Organic Matter (d.m. basis) under different aeration system

Figure 4.28, describes the highest potential maximum OM loss or degradation recorded in treatment as: HV (64.04%) compared to DAT (55.37%), TW (54.97%) and FA (46.81%) in decreasing order. The highest rate of OM loss was measured in DAT (0.503wk^{-1}), compared to TW (0.328Wk^{-1}), FA (0.319wk^{-1}) and HV (0.310wk^{-1}) in a decreasing order. The first order kinetics is also used to examine the rate of OM mineralization or turnover based on the experience of Larney *et al*. (2008), Paredes *et al*. (2002) and Benito *et al*. (2009). Thus the multiplication of the maximum degradation (OML_0) and the rate constant (k) reveals that treatment DAT was a more favourable treatment compared to the other aerated systems. Thus order of highest rate of OM turnover can be described as DAT > HV > TW > FA.

4.8.5 *Evolution of Carbon-Nitrogen (C/N) Ratio in Composting Piles*

Composting commenced in the four piles with an initial C/N ratio of between 24.71 and 27.5 (Appendix H7). This range is indicative of a suitable nutrient balance for the composting process (Haug, 1993; NRAES, 1992; Bernal *et al*., 2009). The initial C/N recorded significantly a lower mean value in FA than the other piles. This could be attributed to the extra mixing or shredding that the feedstock for FA was subjected to. Generally, C/N ratio of all the treatments decreased during the composting period (Figure 4.29). Carbon-Nitrogen ratio decreased significantly ($p < 0.001$) with composting process time; such that at the fourteenth week of composting, all the piles had achieved more than 50% reduction in C/N ratio. Most of the reduction occurred in the thermophilic phase of the composting process; especially within the first 2-5 weeks of composting. These dynamics are explained by the substantial changes in the TN and TC during the composting process.

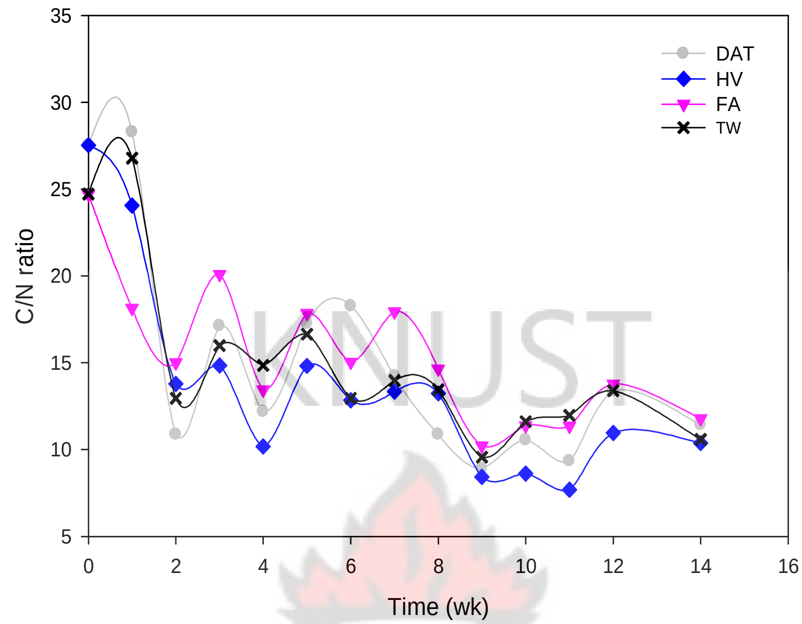


Figure 4.30: Changes in C/N ratio in piles

The final C/N ratio of the treatments ranged from 10.38 - 11.78 with a trend of HV < TW < DAT < FA. It was also established that the amount of TC loss was markedly higher than the Total N concentrations based on organic matter levels during the composting process. At the end of the composting process, TC loss of about 50.17% - 64.91% was observed and ranked as HV > DAT > TW > FA; whereas TN values ranged from -5.03% to 8.51% ranked as FA > TW > DAT > HV (Appendix H5 and H8).

The C/N ratio is traditionally used as an indicator of compost maturity (Epstein, 1997; Bernal *et al.*, 1998; Larney and Hao, 2007). The C/N ratio decrease was due to mineralization of the substrates present in the raw materials initially used in the composting piles (Solano *et al.*, 2001). The relevance of the C/N ratio lies in the fact that a decrease in the ratio implies an increase in the degree of humification of organic matter. A C/N ratio below 20 is indicative of acceptable maturity (Lin, 2008; Bernal *et al*., 2009). The US Composting Council and the United States Department of Agriculture (2001) recommends C/N ratio of ≤ 25 as part of the indicators of compost maturity. The treatments were able to achieve such levels of C/N ration within the composting period.

4.8.6 *Evolution of Total Nitrogen in Composting Piles*

Total Nitrogen in compost as affected by aeration system is presented in Figure 4.30 (Appendix H8). Total Nitrogen exhibited a fluctuating trend during the composting period. This component concentration ranged from 0.92 - 0.97% during the initial stages of the composting process (week 0); with no significant difference between the treatments. However, after week 1 all treatments had TN values ≥ 1.00%. An assessment of the aeration mechanism demonstrated that the loss/gain calculated on the means revealed a range of 18.41% loss to a 5.91% gain at the transition stage of the composting process (Appendix H9).

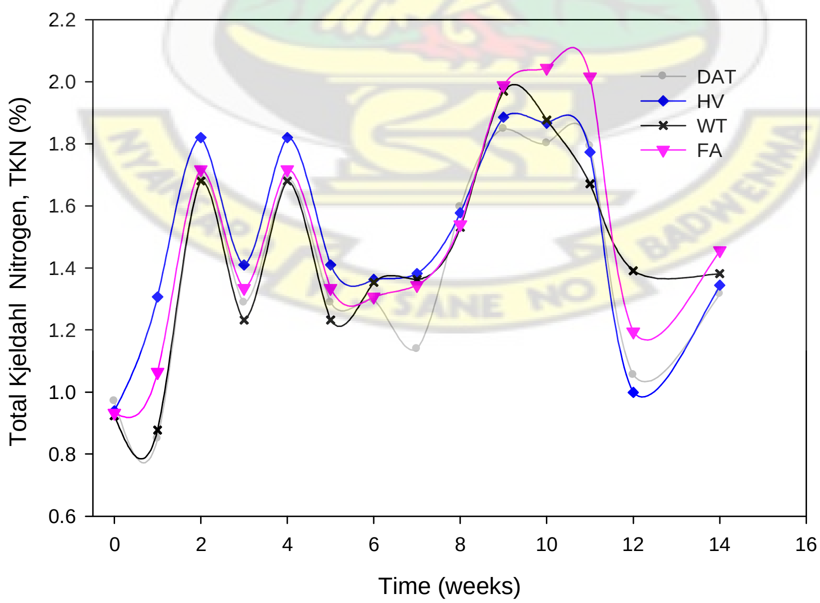


Figure 4.31: Total Nitrogen dynamics during composting

These increments in the TN concentration of the compost piles could be attributed to the greater loss of carbon compared with N during composting as similarly observed by Bernal *et al*. (1996) and Paredes *et al*. (2000).

It was noted that although nitrogen fixation during composting is less frequent it has been reported in some cases (Paredes *et al*., 2000; Hatayama *et al*., 2005; Beauchamp *et al*., 2006; Cayuela *et al*., 2009). Cayuela *et al*. (2009) reported that, increase in TN during composting could be attributed to increase in oxidation of non-nitrogenous organic materials and partially to the N_2 - fixation by non-symbiotic nitrogen fixers as indexed by the increase in organic nitrogen. The sinusoidal trend of N-concentration in the treatment piles implies that biotic or abiotic microbial immobilization of nitrogen in the piles was possible (Esptein, 1997; Moldes *et al*., 2007). Also, Brito *et al*. (2008) observed an increase in TN with decreasing OM during the composting of the solid fraction of dairy cattle slurry. This was attributed to the small pile size, turning effect and the relatively higher dry matter.

Elevated nitrogen loss on ashless basis was observed in treatment DAT (6.62%) and HV (8.51%) at the end of the composting period, a phenomenon which was also observed by other authors (Paredes *et al*. 2000; Meunchang *et al*. 2005). However, treatment TW and FA recorded gains of about 3.43% and 5.03% respectively by the end of the composting period. Nearly 50% of the TC was lost compared to less than 10% of the TN in the final compost; which is comparable to other experiences in composting by Meunchang *et al*. (2005). Indeed, the basis for the loss in TN could be attributed to the mode of aeration of the pile, thermophilic temperature development, pH of piles, and OM degradation (Bernal *et al*., 1996; Paredes *et al*., 2000; Beck-Friis *et al*. 2001). Also, the process of denitrification to NO_X or N_2 may account for some of the TN loss realised in the experiment, as was reported by Tiquia *et al*. (2002). According to Bernal *et al*. (2009) apart from the composition of the initial mixture, the composting conditions such as temperature development and aeration method (turning frequency or aeration strategy) are considered the main factors influencing TN-loss. Beck-Friis *et al*. (2001) observed that significant ammonia emissions started when thermophilic temperatures (> 45^0C) and high pH (about pH of 9) coexisted in the compost environment, resulting in a total loss of nitrogen within 24 – 33% of the initial nitrogen content. It is worth noting that, the moisture content regime applied to the piles did not necessitate a high loss in TN. The study also corroborates the findings of Yañez *et al*. (2009), who maintained moisture content above 60% at the thermophilic phase which resulted in controlling significant TN losses. Though, thermophilic temperatures were sustained for lengthy periods, especially in DAT and HV, the net N - concentration in the piles only experienced a loss less than 10% of the initial concentration. This and the effect of immobilization or nitrogen fixation could be influenced by the commercial "SoilTech Solution STARTER" inoculum used at the beginning of the composting processes (Kutsanedzie, 2008).

4.8.7 ***Effect of Aeration System on Ammonium and Nitrate Dynamics***

Ammonium ion (NH_4^+-N) generally decreased as composting progressed to week 14 (Table 4.35). Concentrations of NH_4^+-N decreased from initial values of 3.74 - 3.89g/kg DM to a range of 1.32 - 1.85g/kg DM at the end of the composting process. The highest concentration of ammonium was observed at the periods with the highest OM degradation. This observation is also supported by Sànchez-Monedero *et al*. (2001) and Zhu *et al.* (2005).

Table 4.35: Effect of aeration system on ammonium dynamics during the composting process

Treatment	Ammonium ion (NH_4^+) concentration, g/kg DM													
Sampling weeks	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
DAT	3.74	3.34	2.1	1.77	1.56	2.01	2.96	1.96	2.01	1.00	1.29	2.50	1.28	1.55
HV	3.74	2.60	1.16	2.17	1.37	1.86	1.72	2.22	1.66	0.77	0.96	1.38	1.34	1.35
TW	3.89	3.02	1.40	1.39	1.79	1.19	0.92	1.41	1.60	0.98	1.05	1.79	1.56	1.85
FA	3.89	2.58	1.35	2.08	1.75	1.79	1.66	2.02	1.71	1.11	1.20	1.53	1.53	1.32
LSD	0.58	1.41	1.67	0.63	1.23	1.35	1.47	0.72	0.43	0.45	0.62	1.10	0.74	0.45
F-test	1.000	0.541	0.410	0.077	0.830	0.517	0.070	0.132	0.192	0.389	0.597	0.164	0.744	0.086

LSD for comparing means at the same level of treatment (5% level of significance): 1.61

Table 4.36: Effect of aeration system on nitrate dynamics during the composting process

Treatment	Nitrate ion (NO_3^-) concentration, g/kg DM													
Sampling weeks	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
DAT	0.27	0.35	0.29	0.25	0.26	0.39	0.38	0.38	0.34	0.72	0.54	0.45	0.79	0.79
HV	0.27	0.39	0.22	0.34	0.24	0.40	0.53	0.72	0.44	0.83	0.44	0.30	0.63	0.63
TW	0.31	0.36	0.26	0.24	0.31	0.40	0.67	0.38	0.52	0.39	0.53	0.35	0.60	0.60
FA	0.31	0.41	0.23	0.38	0.43	0.38	0.65	0.36	0. 35	0.39	0.39	0.37	0.65	0.65
LSD	0.17	0.24	0.11	0.07	0.10	0.14	0.26	0.20	0.21	0.48	0.21	0.36	0.28	0.28
F-test	0.905	0.919	0.487	0.006	0.004	0.954	0.115	0.013	0.217	0.150	0.335	0.766	0.910	0.421

LSD for comparing means at the same level of treatment (5% level of significance): 0.21

Aeration systems caused a loss, with respect to OM only, of more than 70% at the final week of sampling. Nonetheless, aeration system did not have significant effect on the concentration of ammonium ion at the end of the composting process. Both NH_4^+-N and NO_3^--N concentration showed marked changes, generally decreases and increases respectively, during the composting period.

The nitrate ion concentration in the pile increased from an initial concentration range of 0.271 - 0.307g/kg DM to 0.599 - 0.793g/kg DM. The calculated gain, with respect to OM only, recorded a range of between 34.76 - 101.57%, ranked as TW < FA < HV < DAT. Thus, nitrification may be more intense in the passive aerated piles compared to the active piles. This process of transformation from ammonium to nitrate was intense after the thermophilic phase, as recounted by Sànchez-Monedero *et al*. (2001) and Gao *et al*. (2010).

The study also shows an early start in mineralization and subsequent nitrification (Illmer *et al*., 2007). A dramatic decline in NH_4^+-N ion did not correspond to a rapid increase in NO_3^--N. A reason being that thermophilic temperatures dominated in most of the treatment, which tends to inhibit the activities of nitrifying bacteria (Sànchez-Monedero *et al*., 2001). This decreasing trend in NH_4^+-N guaranteed that ammonification was ending and could be used as a criterion of compost maturity (Paredes *et al*., 2000). The decrease in NH_4^+ concentrations was attributed to the combined effects of immobilization/denitrifying microorganism, mineralization/ nitrification, or NH_3 volatilization (Tiquia and Tam, 2002; Meunchang *et al*., 2005; Eklind and Kirchmann, 2000; Càceres *et al*., 2006; Illmer *et al*., 2007). However, the final values of NH_4^+ were higher than the recommended value proposed by Zucconi and De Bertoldi (1987) as < 0.40g/kg DM. The final compost recorded ammonium concentration of about 1.32 - 1.85g/kg DM. Szanto *et al.* (2007) attributed the incomplete conversion of NH_4^+ in the treatment to the lack of oxygen. It also assumed that, methanotrophs could be capable of oxidizing NH_4^+ through methane (CH_4) oxidizing bacteria at thermophilic temperature since nitrifying bacteria may not be very active at such temperatures.

The NO_3^--N content in the four piles kept a general growth path during the composting process (Table 4.36, Appendix H12). Nitrate at the start of the experiment ranged from 0.27 - 0.31g/kg DM and recorded concentrations of about 0.6 - 0.79g/kg DM at the end of the composting process. It could be inferred that the thermophilic phase caused an inhibition effect on nitrifying bacteria in the compost pile, hence no significant increase in NO_3^--N content was observed at the start of the composting process.

Nitrification in the piles started about the third week of the composting process, with concentration differences of ammonium ions dropping significantly from an initial range of 3.74 - 3.89g/kg DM to 1.39 - 2.1g/kg DM. Nitrification was significantly higher ($p < 0.05$) in treatments which were characterized by their design or were considered to have a better vertical distribution of air; especially in the case of treatment FA. This finding is also supported by the finding of Sylla *et al*. (2006) which realized that horizontally piped passive piles demonstrated a higher nitrate formation during the composting process. Nitrate dynamics in the piles compared very well with the turning or reshaping (with or without the removal of channels or chimneys) periods indicated by the temperature characteristics (Figure 4.17- 4.20). For example, treatment FA indicates that between day-20 and day-28, nitrate concentration increased significantly ($p < 0.01$). Hence, it is tenable to suggest that, upon the introduction of air, turning, or reshaping of the piles nitrate concentration increased. Bernal *et al*. (2009) have also suggested that the nitrification process is greatly influenced by pH, temeperature and C/N ratio.

The characteristic temperature and pH variation in piles contributed to the marked difference in nitrate concentration of the compost at week 3. Indeed, at this characteristic thermophilic phase, the treatment FA recorded a significantly different ($p < 0.05$) nitrate concentration, temperature and pH reading. The relation indicates that at high temperatures or pH condition, nitrate values would demonstrate lower concentrations (Sànchez-Monedero *et al*., 2001). The suspected excessive aeration of treatment FA explains the relatively low temperature and changes in pH values. The high pH about week 3 and the temperature confirms the slow nitrification experienced in the treatments, especially with respect to the FA treatment. Smårs *et al*., (2002) and Sundberg *et al.*, (2004) associated higher pH with ammonification in the composting process. The transition phase of week 7 recorded similar related phenomena in the treatments. The aeration system or strategy did not significantly affect the nitrate concentration at the end of the composting process. However, nitrification and nitrate concentration increased towards the end of the treatment with temperature values close to mesophilic ranges and lower pH values. The later explains the conversion of ammonium (NH_4^+) to nitrate (NO_3^-) with the release of hydrogen (H^+) ions that tends to lower pH values.

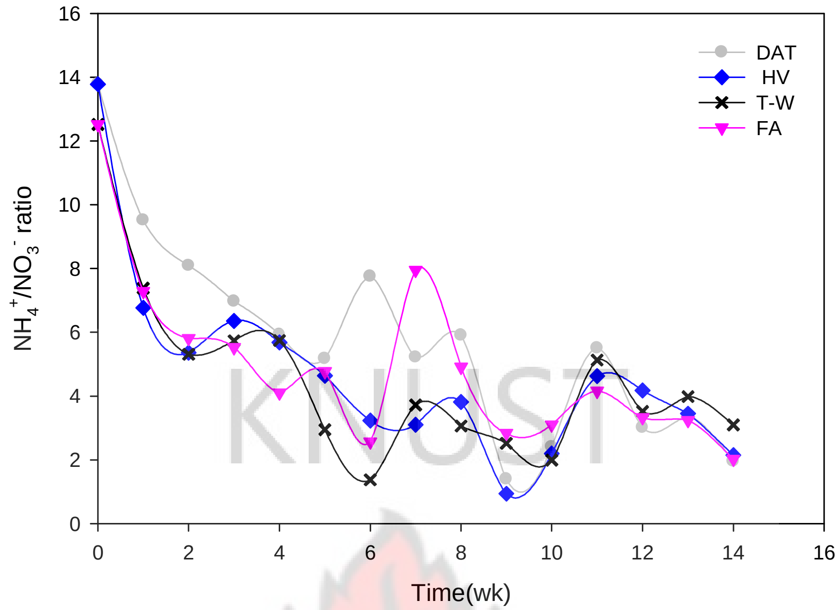


Figure 4.32: Changes in ammonium - nitrate ratios during composting

The ammonium-nitrate ratio was seen to decrease significantly from the initial 12.52 - 13.78 range to between 1.95 - 3.10 ranges at the final week of composting (Figure 4.31). By the account of the influence of feedstock or aeration system the ammonium- nitrate dynamics may vary (Díaz *et al*., 2002; Tiquia *et al*., 2002; Wang *et al*., 2004; Kaboré *et al*., 2010). The experiment did not achieve the < 0.16 maturity limit proposed by Bernal *et al*., (1996) or Bernal *et al*., (2009). It may take some additional weeks of curing to attain this indicator of maturity of the composting treatments. Various authors have reported that the NH_4^+/NO_3^- ratio is a clear indicator of nitrification and maturity (Bernal *et al*., 1996; Sànchez-Monedero *et al*., 2001; Tiquia *et al*., 2002; Bernal *et al*., 2009). Szanto *et al*. (2007) observed a NH_4^+/NO_3^- ratio of about 0.5 and 0.31 for turned and static composting systems respectively after 118days. More so, Zhu *et al*. (2004) also witnessed an even higher NH_4^+/NO_3^- ratio (4.18 - 8.22) in characterizing the performance of three aeration systems for swine manure composting. Benito *et al*. (2009) recommended a

NH_4^+/NO_3^- range of 0.5 - 3.0 as an indication of compost maturity, after composting green waste and spent horse litter for 190 days. The US Composting Council and the United States Department of Agriculture (2001) also recommended an ammonium to nitrate ratio of 2 as an indication of maturity. The indicator established by Benito *et al*. (2009), the US Composting Council and the United States Department of Agriculture (2001) suits this study and can be used as an indicator for maturity for the treatments. Thus, treatment DAT has been able to attain these limits; while treatment HV and FA were only able to obtain values within the limits set by Brito *et al*. (2009). Treatment TW just exceeded the limit proposed by Brito *et al*. (2009); an indication that the pile may require some additional time to mature with respect to ammonium to nitrate ratio although the system had been frequently turned.

4.8.8 *Effect of Aeration System on P and K concentration*

Potassium concentration generally decreased from an intial of 1.13 - 1.23% of dry matter to a final sampling concentration of 0.79 - 0.88% of dry matter (Table 4.37). Largely, the study did not show any significant effect of aeration mechanism on potassium concentration during the composting process . The marked change is as a result of aeration mechanism observed at the transition phase of week 7. The analysis of treatment, indicates that, DAT has a significantly lower TK concentration compared to treatment HV, TW or FA. Increases in potassiun concentration during the composting period could be attributed the mineralization of organic matter in the treatment piles. Tiquia and Tam (2002) related increase in Total K and P to losses in C, H, N and O in the treatments as CO_2, H_2O and NH_3. Significant statistical differences ($p < 0.05$) in potassium concentration was observed in all treatments. A decrease in Potassium can be attributed to leaching since the K^+ ion is very soluble and mobile (Tumuhairwe *et al*., 2009) and the enhanced microflora or microbial activities in the composting material as Potassium is very much essential for their metabolic activity (Kumar *et al*., 2009) . The later may cause either an adsorption or assimilation of available fractions of Potassium (Garg *et al*., 2006).

The observation of a high Potassium level during composting or in compost is likely to originate from the source of substrate, and in most cases occurs as a woody material (Suzuki *et al*., 2004). Various Authors have associated increases in P or K during composting to the high rates of carbon loss, which occurs as a result of organic matter mineralization (Gupta *et al*., 2007; Suthar *et al*., 2010). Tiquia *et al*. (2002) reported a not-significant loss for P and K during the composting of pig manure and corn stalk depending on the pile turning regime or construction method.

Phosphorus was monitored in all the treatment piles. Initial concentrations ranged between 4.37 - 4.67% of DM. The results, as captured in Table 4.38 (Appendix H13), suggests that the mechanism of aeration significantly affects the concentration of phosphorous during the composting process. The turned windrow (TW) treatment showed a high TP value compared with the other treatments during the active phase of composting (week 7). This can be partly attributed to the high mixing and a better uniform feedstock distribution that can be achieved with this aeration mechanism. The analyzed results indicate that treatment TW largely had higher phosphorous level compared to treatment DAT, HV and FA during the composting process. Thus, substrates (poultry manure and cocoa seed husk) containing relatively higher TP values are more uniform distributed is samples collected for analysis, as a result of turning in treatment TW.

Table 4.37: Effect of aeration system on Potassium concentration during the composting process

Treatment	**Amount of Percentage Potassium, K (%)**													
Sampling weeks	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
DAT	1.13	1.57	1.83	1.53	0.93	1.98	1.42	1.13	1.37	1.87	1.47	1.23	0.72	0.79
HV	1.13	1.87	2.20	1.60	1.40	0.93	1.33	1.43	1.27	1.30	1.13	1.13	0.67	0.81
TW	1.23	1.50	2.00	2.17	1.60	1.47	1.43	1.53	1.27	1.47	1.13	1.00	0.95	0.88
FA	1.23	2.30	1.86	1.63	1.27	1.64	1.47	1.57	1.30	1.50	1.20	1.37	0.72	0.86
LSD	0.12	1.16	0.36	0.94	1.06	2.12	0.21	0.21	0.38	1.49	0.34	0.56	0.22	0.14
F-test	0.117	0.394	0.155	0.403	0.523	0.691	0.514	0.008	0.905	0.819	0.146	0.484	0.077	0.408

LSD for comparing means at the same level of treatment (5% level of significance): 0.75

Table 4.38: Effect of aeration system on phosphorus concentration during the composting process

Treatment	**Amount of Phosphorous, P (%, DM)**													
Sampling weeks	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
DAT	4.37	2.27	3.36	2.67	3.58	2.88	3.78	5.04	3.95	4.15	6.46	3.55	3.03	2.07
HV	4.37	2.80	3.86	3.33	2.45	3.18	3.96	4.90	4.95	2.56	3.66	3.67	4.64	1.85
TW	4.67	4.57	4.35	5.00	4.89	4.61	6.83	6.42	5.50	5.18	6.98	4.17	4.85	2.02
FA	4.67	3.17	3.41	2.70	2.65	2.39	4.45	5.64	5.54	3.97	3.84	5.99	1.65	2.14
LSD	1.45	0.51	1.56	1.40	1.96	2.38	1.42	2.84	2.65	2.51	2.98	2.18	1.56	0.85
F-test	0.912	<0.001	0.441	0.020	0.074	0.227	0.006	0.580	0.480	0.190	0.069	0.104	0.007	0.860

LSD for comparing means at the same level of treatment (5% level of significance):1.82

Mixing allows for better matrix uniformity allowing nutrient that may be percolating to the bottom of the pile to mix well again. The final compost piles recorded TP concentration between 1.85 - 2.14% of DM, where FA > DAT > TW > HV. There were no observed significant differences in TP at the final treatment sampling date of week 14. The recorded TP concentrations declined at the final sampling stage; which is possibly as a result of phosphate leaching in soluble organic solutes. The reduction in TP concentration to about 52.63 - 57.67% on dry matter basis was higher than values reported by Tiquia *et al*. (2002) which ranged between 23 - 42% for pig manure composting. This is corroborated by the findings of Larney *et al*. (2006). Again, like TN, phosphorous concentration fluctuated according to reshaping or turning or aeration mechanism. It could be realized that a decrease in TP value was prompted by reshaping or turning or moisture adjustments to the treatments during the composting process.

Different dynamics of TP concentration increases (Sommer, 2001; Tai and He, 2007) or decreases (Tiquia *et al*., 2002; Parkinson *et al*., 2004; Ogunwande *et al*., 2008) during composting have been reported in literature. Phosphorous is a less mobile nutrient as it is able to form strong bonds with organic matter and insoluble phosphate complexes with calcium and magnesium at high pH (Tumuhairwe *et al*., 2009). Suthar *et al*. (2010) acknowledged that the high levels of phosphorous in various forms during composting could be by the influence of enzyme phosphatise or P-solubilising microorganism (microflora) present in the compost matrix. However, the reduction in TP content during the study is explained as the possible effect of leaching or a slower rate of mineralization relative to Organic Matter (OM) for the treatment piles (Zhang and He, 2006; Huang *et al*., 2004).

4.8.9 *Correlation of Physicochemical Parameters*

The results of correlation coefficients (r), of the variables are presented in Table 4.39. Correlation analysis is a measure of the degree of association between two variables. As suggested by Swinscow (1997), absolute values of *r* between 0.0 – 0.19 are regarded as very weak; 0.2 - 0.39 as weak; 0.4 - 0.59 as moderate; 0.6 - 0.79 as strong and 0.8 - 1.0 as very strong. The correlation matrix of parameters indicated that Total TP was largely weak in correlating with other parameters investigated. However, a fairly good association was observed between Total Potassium concentration and temperature and its transforms (T, ΔT, and $\Delta T/T$) with correlation co-efficient (r) of 0.644 ($p < 0.050$), 0.657 ($p < 0.050$) and 0.675 ($p < 0.010$) respectively. Total Potassium in the piles also recorded a good positive correlation with MC, pH and OM; resulting in r = 0.587 (at $p < 0.050$), 0.798 (at $p < 0.001$) and 0.578 (at $p < 0.050$) respectively. The correlation of TN to temperature and its transforms yielded a negative and weak relationship.

Particularly in MC, apart for the moderately negative correlation observed with respect to TN, all other parameters examined demonstrated a strong to very strong correlation relationship with MC. Thus, increasing MC content during composting would result in decreasing EC and NO_3^- levels; however, the opposite was observed for other parameters monitored. Other comparative parameters correlated with temperature and its transforms, such as EC showed significantly strong negative co-efficient ($r = -0.846$; $p < 0.001$) with the temperature (T) of the pile. Also, a significantly strong and positive correlation ($r = 0.802$; $p < 0.001$) was established in relating ΔT to pH of the treatment piles. The compost pH revealed a positive correlation with parameters such as the temperature transforms TK, MC, NH_4^+/NO_3^-, OM, and TC (Table 4.39); while a negative correlation was evaluated for EC and NO_3^-. Moisture content produced a significantly positive strong ($r = 0.89$; $p < 0.001$) correlation with temperature (T).

Indeed, a significantly strong positive correlation was observed in Ammonium (NH_4^+) concentration and its ratio with corresponding nitrates (NH_4^+/NO_3^-) as was also reported by Tiquia *et al*. (1998). The report of Tiquia *et al*. (1998) was further reinforced with the observation of a significantly strong and negative correlation established in relating nitrate concentrations with temperature and its transforms. Tiquia *et al*. (1998) and Szanto *et al*. (2007) in their studies utilized temperature to predict the concentrations of other pertinent parameters during composting, due to the good correlations established. The correlation also corroborates the finding of Sànchez-Monedero *et al.* (2001), that nitrate ion concentration was positively correlated with EC ($r = +0.664$), but negatively correlated with pH ($r = -0.57$).

Organic Matter (OM) and TC concentration showed significantly strong and positive correlations with temperature and its transforms as was also observed by Tiquia *et al.* (1998). Nonetheless, TN concentration showed a weak and negative correlation with temperature and its transforms for this study. Other effective correlations identified are presented in Table 4.39. The significant differences in temperature development at the bio-oxidation stage and the inductive passive aerations led by temperature differences relative to ambient air temperatures could be attributed to the different aeration systems implemented in this study (Solano *et al*., 2001). These phenomena observed could help predict or explain the dynamics of some critical parameters needful for assessing compost maturity.

Table 4.39: Correlation between physicochemical parameters observed during river reed composting

	C/N	ΔT	ΔT/T	EC	MC	NH_4^+	NH_4/ NO_3	NO_3^-	OM	T	TC	TN	pH
C/N	1												
ΔT	0.493	1											
ΔT/T	0.51	0.991^{X}	1										
EC	-0.405	-0.833^{X}	-0.798^{X}	1									
MC	0.618*	0.881^{X}	0.859^{X}	-0.789^{X}	1								
NH_4^+	0.572*	0.582*	0.53	-0.587*	0.618*	1							
NH_4^+/NO_3^-	0.557*	0.757$^{\#}$	0.691$^{\#}$	-0.728$^{\#}$	0.876^{X}	0.759$^{\#}$	1						
NO_3^-	-0.3	-0.744$^{\#}$	-0.684$^{\#}$	0.664$^{\#}$	-0.834^{X}	-0.543*	-0.905^{X}	1					
OM	0.601*	0.93^{X}	0.895^{X}	-0.833^{X}	0.912^{X}	0.684$^{\#}$	0.858^{X}	-0.801^{X}	1				
T	0.528	0.996^{X}	0.982^{X}	-0.846^{X}	0.89^{X}	0.578*	0.774^{X}	-0.752$^{\#}$	0.947^{X}	1			
TC	0.429	0.851^{X}	0.807^{X}	-0.807^{X}	0.807^{X}	0.574*	0.838^{X}	-0.77^{X}	0.842^{X}	0.859^{X}	1		
TN	-0.949^{X}	-0.317	-0.337	0.343	-0.427	-0.499	-0.405	0.119	-0.431	-0.361	-0.251	1	
pH	0.414	0.802^{X}	0.802^{X}	-0.604*	0.758$^{\#}$	0.481	0.607*	-0.57*	0.78^{X}	0.785^{X}	0.697$^{\#}$	-0.194	1

*, $^{\#}$ and ^{X} indicates the Significant level of $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ respectively

4.8.10 ***Predicting Total N, P and K in compost matrix***

The variability of feedstock (plant material, livestock manure, and inoculants) may significantly affect the prediction models constructed to rapidly estimate chemical or nutrient content in substrates. Rapid, clean and low cost prediction models would enable compost producers to quantify concentration of parameters in feedstock and aid in optimizing feedstock or substrates during composting. Although a couple of authors have used a simple linear regression or to predict nutrient in manure or compost (Tiquia *et al*., 1998; Moral *et al*., 2005; Chen *et al*., 2008) recent submissions reveal that multiple regression trends to increase the accuracy of predictions (Yang *et al*., 2006). Tiquia *et al.* (1998) and Chanda *et al.* (2010) utilized temperature or time in predicting contents of the compost substrate.

Because the treatments were ascertained to be influenced by convective and diffusive heat transfers (through passive aeration, Sylla *et al*., 2006), which are noted to influence nutrient losses or microbial behaviour, temperature and its transforms are used in explaining these phenomena in the construction of the model. Physicochemical parameters considered include EC, pH, MC, OM, MC/OM and T and its selected transforms. Thus, the physicochemical properties observed during composting and used in the construction of the models are reported in Table 4.40. The results presented are part of a large array of several models tested predictions using the physicochemical parameters.

Table 4.40: Regression equations for nutrients in the composting of river reed

Treatment	DV	Modelled Equation	R^2	F
TW	TN	$20.94 + 0.1097MC - 7.24\frac{MC}{OM} - 0.3549 \cdot OM - 6.05\frac{\Delta T}{T} + 0.1325 \cdot \Delta T - 0.5389 \cdot EC$	0.997	0.040
	TP	$-214.05 - 1.6393MC + 64.86\frac{MC}{OM} + 1.2269 \cdot OM + 194.64\frac{\Delta T}{T} + 4.7521 \cdot T - 6.4733 \cdot \Delta T$	1.00	0.009
	TK	$25.58 + 0.4541MC - 17.856\frac{MC}{OM} - 0.5563 \cdot OM - 7.292\frac{\Delta T}{T} + 0.06933 \cdot \Delta T - 0.2377 \cdot EC$	1.000	0.013
DAT	TN	$6.56 + 0.460MC - 7.30\frac{MC}{OM} - 0.2737 \cdot OM - 35.05\frac{\Delta T}{T} + 0.1059 \cdot T + 1.190 \cdot EC$	0.916	0.204
	TP	$-83.38 - 2.3621 \cdot MC + 1.7983 \cdot OM + 12.96\frac{\Delta T}{T} + 0.9893 \cdot \Delta T + 10.606 \cdot pH$	0.999	0.020
	TK	$-14.172 - 0.32303 \cdot MC + 0.10605 \cdot OM - 4.876\frac{MC}{OM} + 0.23482 \cdot T + 2.288 \cdot EC + 2.4452 \cdot pH$	1.000	0.012
HV	TN	$113.5 + 1.445 \cdot MC - 54.5\frac{MC}{OM} - 2.348 \cdot OM - 7.12\frac{\Delta T}{T} - 8.00 \cdot EC$	0.979	0.015
	TP	$264.02 + 2.1501 \cdot MC - 82.02\frac{MC}{OM} - 3.5705 \cdot OM + 0.23649 \cdot T - 13.601 \cdot EC - 10.981 \cdot pH$	1.000	0.016
	TK	$97.0 + 1.410 \cdot MC - 2.132 \cdot OM - 50.2\frac{MC}{OM} - 28.69\frac{\Delta T}{T} + 0.1979 \cdot T - 6.30 \cdot EC$	0.983	0.091
FA	TN	$321.36 + 3.6180 \cdot MC - 166.78\frac{MC}{OM} - 4.6566 \cdot OM - 0.14836 \cdot \Delta T - 11.365 \cdot pH - 6.3242 \cdot EC$	1.00	0.015
	TP	$-3.481 \cdot EC - 0.2505 \cdot OM - 22.48\frac{MC}{OM} + 47.50\frac{\Delta T}{T} - 0.7897 \cdot \Delta T - 6.463 \cdot pH + 96.14$	0.997	0.039
	TK	$0.200 \cdot EC - 1.135 \cdot OM + 0.940 \cdot MC - 40.44\frac{MC}{OM} - 0.2756 \cdot \Delta T + 0.2573 \cdot T + 44.26$	0.977	0.107

DV – Dependent variable; F- F probability; Number of sample (n) used in each analysis - 21samples; R^2: co-efficient of determination

The coefficient of determinations (R^2) ranging from 0.916 - 1.000 was obtained for the selected models used in predicting TN. The best regressions for TN showed significant differences ($p < 0.05$), but for treatment DAT (Table 4.40). Total

Phosphorous (TP) predicted with the physicochemical parameters showed a significant difference for all treatments considered. A very good coefficient of determination (R^2) ranging from 0.997 - 1.000 was obtained for the treatments. Also, the analysis conducted for TK prediction models indicated significant difference ($p < 0.05$) in WT and DAT treatments. No significant differences in TK were observed in the proposed models for treatment HV and FA Table 4.40. Typically, the temperature transformation effect revealed a decreasing trend for TN. However because of the aeration effect exhibited by treatment FA, which ensured a higher aeration of the pile, the temperature transform was limited to temperature difference and not the ratio of temperature difference and ambient temperature. Notably, treatment DAT recorded the highest effect of temperature transform during the prediction of TN concentration; indicating that a unit change in the ratio of temperature difference to ambient temperature may result in TN loss of about 35.05%.

Total Potassium concentration prediction was heavily influenced by the moisture content to organic matter ratio parameter. This parameter has a decreasing effect on the Potassium concentrations. Thus, a unit increase in this ratio would result in between 4.876% to 50.02 % decrease in TK, all other parameters kept constant, depending on the aeration treatment that the substrate is subjected to. As reported in other single or two-factored regression model analysis, EC was a strong predictor of TN and other nutrient parameters in the constructed models (Moral *et al*., 2005; Yang *et al*., 2006; Chen *et al*., 2008). In this study, depending on the influence of aeration technology on physicochemical parameters, the dependency of a factor(s) could have an increasing or decreasing effect on the response variable. Findings by Chanda *et al.* (2010) corroborate this position, that different phases of composting could influence nutrient concentration prediction. Tiquia and Tam (2002) employed quadratic regression to explain various properties during composting of poultry manure. However, the coefficient of determinations (r^2) reported in their experiment were in most cases less than 0.45.

4.8.11 *Heavy Metal Concentration in Compost*

The presence of heavy metals in the finished compost constitutes a very important problem from an agricultural and environmental point of view. As indicated by Richard and Woodbury (1992), data from both experimental trials and operating facilities indicate that the lowest levels of contaminants are achieved by targeting materials that are less susceptible to heavy contamination (agricultural biomass, yard trimmings, and some manures or food waste) or source-separation of compostable product, especially with MSW. This emphasises the fact that, the feedstock (raw material) used in composting could significantly influence the level of contaminants (heavy metals) identified in final compost. Furthermore, the total metal concentration in compost is important in controlling crop uptake of labile elements, like Zn and Cu, which increases with increasing total content of these elements in compost. Nonetheless, Smith (2009) reported little evidence of phytotoxic effects, or accumulations of metals in crop tissues that may pose a risk to human health, from application of MSW-composts to soil.

Table 4.41: Heavy metal analysis of river reed compost quality

Parameter	LECC	LC	TW	DAT	HV	FA	Clay	RR
					mg/kg of DM^{ø}			
Manganese (Mn)	-	-	0.44	0.43	0.40	0.40	0.34	0.40
Cadmium (Cd)	0.7	1.0	1.93	2.00	2.10	1.82	2.65	0.83
Chromium (Cr)	50	50	10.91	11.98	10.44	10.53	10.9	4.84
Copper (Cu)	25	60	12.86	14.34	16.94	14.83	11.53	6.14
Mercury (Hg)	0.3	0.2	ND	ND	ND	ND	ND	ND
Nickel (Ni)	10	20	6.42	7.67	5.65	7.20	8.43	4.51
Lead (Pb)	65	100	4.99	7.32	5.24	3.98	7.13	2.86
Zinc (Zn)	75	200	197.34	258.67	294.33	250.54	201.33	243.47
Arsenic (As)	5	15	0.82	0.81	1.12	0.33	0.36	0.50
Cobalt (Co)	-	-	5.38	5.70	3.74	4.80	9.82	2.08
Molybdenum (Mo)	-	-	2.62	3.06	2.09	2.33	4.82	1.06

LECC- Limit for 'Extra Clean' Compost; LC-Limit for Compost, by the Dutch standard, the strikethrough indicates observations exceeding the Limit for 'Extra Clean' Compost; ø-mean of four replicates analysed in ICP-OES

Clay gave the highest contribution of Cd, Cr, Cu, Pb and Co. However, river reed showed the highest levels in Zn, with difference within 13.20 -2 8.66% in comparison with clay. Table 4.40, also shows that Zn, Cu and Cr are the elements present in the largest amounts. However, Cd and Zn exceeded the concentration for the Dutch Limit for 'Extra Clean' Compost (LECC). Clay, from Table 4.40, is reflected as the major contributor of Cd; while river reed (RR) could be the main contributor of Zn elements in the treatment piles. Nevertheless, these elements occur naturally in the feedstock.

The study have demystified the key sources to high concentration of some heavy metal content which impacts on quality of compost produced from the VREL composting facility. These were identified as the river reed and clay which served as part of the main substrates used by the facility and was adopted for the study. Thus, heavy metal quality of compost in this experiment was mainly influenced by feedstock (clay and river reed) than of the method of aeration. Process efficiency relative to organic matter turnover was much superior with the passive aerated composting systems (DAT or HV); compared to the active systems of mechanical tuning (TW) and Forced-aerated (FA) systems. However, conservation of Total Nitrogen favoured treatments TW and FA, compared to DAT and HV, although the difference was not very significant ($p<0.05$). Thus, overall, treatment DAT had a better process efficiency compared to other treatments.

CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS

This Chapter puts forward the findings from this study addressing the research questions highlighting the major contribution that has been made to the body of knowledge on composting and also some recommendations for future studies. This study was undertaken to examine the effect of feedstock formulation, turning frequency, and aeration mechanisms on process efficiency of windrow composting of abattoir waste and river reed. From examined literature and studies on this field critical factors that promoted or limited the successful operations of community and large scale composting facilities, such as in developing countries like Ghana have been highlighted. These also exposed the need to investigate the effect of the choice of feedstock composition and aeration mechanism on the process efficiency of composting of abattoir waste and river reed which are deemed as less investigated compostable wastes. Also, the need to predict compost nutrient content rapidly without necessarily conducting expensive laboratory analysis, which has not been widely reported on was investigated. The study addressed some critical gaps in the knowledge of composting process efficiency (rate of decomposition, nutrient conservation or compost quality, and sanitizing potential) on abattoir waste and river reed by answering these questions:

1. Does feedstock formulation significantly affect the process efficiency during the windrow composting of abattoir waste?
2. Does turning frequency significantly affect the process efficiency during the windrow composting of abattoir waste?
3. Does the interactive effect of feedstock formulation and turning frequency have any significant effect on process efficiency during the windrow composting of abattoir waste?

4. Does the mechanism of aeration of river reed compost pile have any significant effect on the process efficiency?
5. To what extent can physicochemical parameters be used to estimate nutrient content of piles during composting?

Thus, one would need to examine the sanitization potential ($T \geq 55^0C$), salinity, heavy metal limits, nitrogen conservation, and organic matter degradation or mineralization to draw a conclusion on which treatments satisfied a better process efficiency.

5.1 Effect of Feedstock Composition on the Process Dynamics and Nutrient Content during Abattoir Waste Composting

Composting of abattoir waste was successfully conducted to achieve maturity (Temperature, C/N and OM especially) within a period of about 90days, with main findings as follows:

- Abattoir waste composted as AMYC (with source separated market waste, corn straw/cob and yard trimmings) demonstrated a better sanitization potential, based on temperature, compared to the other feedstock studied. Thus, Feedstock composition influenced temperature development, with feedstock AMYC recording the highest peak temperature of 61.7^0C; and recording the highest sanitization potential (55^oC for about 4days; and temperature-time profile area above 55^oC of 8.73 $^oC \cdot d$). Characterizing composting through the development of temperature-time profile show that feedstock composition significantly influences the temperature dynamics. Furthermore, feedstock with seemingly less lignin content demonstrated a better sustained thermophilic temperature that could sanitize the compost.

- The most crucial factors influencing temperature development are Total Nitrogen (TN), Organic Matter (OM) and Moisture Content (MC), as was observed in the correlation analysis. The study also established that, Electrical Conductivity (EC) was negatively and significantly correlated to temperature with respect to analysing the effect of feedstock on process efficiency.
- The order of kinetic degradation of organic matter in the compost was of first-order for feedstock ACC (comprising abattoir waste, corn straw/cob and cocoa pod husk); while feedstock ACS (comprising abattoir waste, cocoa pod husk and sawmill waste) and AMYC (consisting of abattoir waste, source separated market waste, corn straw/cob and yard trimming waste), was of a zero-order with the former showing a higher rate constant. Also, evaluated nitrogen loss during composting was between 41.8-58.35% (ash free basis), with AMYC emerging with the highest value. Whereas, in terms nitrogen value conserving the compost ACS may serve a better feedstock compared to AMYC and ACC.
- The compost produced relative to feedstock composition indicated a clean compost quality acceptable by many standards (BSI, 2005; Day and Shaw, 2001). The level of TN, P, K in the final compost was within acceptable range for plant application (having mean values ranging as follows: 1.32-1.50% TN, 1.20-2.01% TP; and 2.97-4.20% TK). Furthermore, the electrical conductivity analysed from produced compost did not exceed the recommended phytotoxicity limit of 4 mS/cm.

The application of this conclusion serves to give any User a guide to optimize on which parameter best answers his/her particular need apart for compost sanitization. Thus, in this very study, because AMYC was the only feedstock which was characteristic of sanitizing potential pathogens, it is selected as the primary and optimal choice for composting; although it's marked with a lower nitrogen conservation and organic matter mineralization rates.

5.2 Effect of Turning Frequency on the Process Dynamics and Nutrient Content during Abattoir Waste Composting

The process efficiency of the composting of abattoir waste under the three turning regimes studied can be concluded as follows:

- The sanitization potential of treatment 3DT was much more remarkable than the other treatments (55^{o}C for about 2days; and temperature-time profile area above 55^{o}C of 6.10 ^{o}C·d). Based on the size of this pile, thermophilic regime were better achieved in piles turned about three days (3DT) apart as compared to turning seven day (7DT) and fourteen days (14DT) apart. Therefore, it can be said that frequently, in this case three days apart, turned piles produce better sanitized compost compared to less frequently turned piles. Nonetheless, the piles could not sustain their temperatures over the 55^{0}C reference; because the results also points to the fact that frequent turning (3DT) of the piles after they have reached their peak values facilitate cooling than bio-oxidation.
- Electrical Conductivity increased with turning frequency; however, the salinity (EC) of the final compost for all treatment was less than the salinity limit value suitable for agriculture application.
- Increased turning frequency facilitated a higher rate of organic matter decomposition or bio-oxidation; thus treatment 3DT was able to better stabilize the organic matter or carbon in the piles.

- More so, turning on a weekly (7DT) or fortnightly (14DT) basis ensured a better TN conservation in the compost pile, with the latter demonstrating a higher propensity for TN conservation. The TN loss on ash-free basis was less than 50% for all the treatments.
- The macro-nutrients of Nitrogen, Phosphorous and Potassium were within an acceptable range for agricultural allocation (1.34-1.45% TN; 1.41-1.66% TP; and 3.41-3.83%TK). Heavy metal concentrations were within the limits suitable for agricultural purposes and could act as micro nutrients in the soil. Generally, a frequent turning regime did not influence significantly the levels of heavy metals concentration during the composting of abattoir waste.

The application of these findings is that, turning frequency significantly affects the process efficiency during windrow composting of abattoir waste. Thus, a three day turning frequency (3DT) achieved a better process efficiency comparing turning frequencies, although its Nitrogen conservation was the lowest amount treatment. The 3DT treatment had a better sensitization potential, organic matter mineralization or stabilization, and nutrients quality were comparable to other treatments.

5.3 Effect of Aeration Mechanism on Process Dynamics and Nutrient Quality for the Windrow Composting of River Reed

The study evaluated aeration mechanisms (two passive; mechanically turned and forced-aeration) for windrow composting system, which produced these findings:

- The passive aeration system designed at full scale showed prolonged thermophilic temperatures as compared to the mechanically aerated composting system. Compost sanitization was better achieved in passive composting systems (DAT and HV) than in mechanically Turned Windrow

(TW) and Forced Aerated (FA) systems. These recorded temperatures above 55^0C than in the forced-aeration system.

- The river reed compost quality proved to be suitable for agricultural use with respect to its salinity (EC < 3.5mS/cm) and pH values (7.5-8.2).
- The method of aeration system significantly affected the turnover on organic matter during composting. Aeration systems examined showed that river reed composting under DAT (passive aeration) yielded a much superior organic matter turnover compared to other treatments.
- The process efficiency in relation to Total Nitrogen turnover showed clear signs of nitrogen fixation. The investigation suggests that conservation of nitrogen during river reed composting favoured mechanically turned windrow (TW) piles. This aeration mechanism had a significant influence on the nitrification of the compost piles, as maturity indicator (NH_4^+/NO_3^- <3.5) was better achieved with aeration systems ranked as DAT, HV, FA and TW respectively; in the river reed composting process.
- Phytotoxicity contribution as from heavy metal concentration in the final compost was only noticed in Zn and Cd (according the Dutch Standard Limit for compost), which were intrinsic in river reed and clay used in the initial feedstock formulation. The phytotoxicity of Cd was still persistent when even compared with BSI (2005). Thus, VREL or other initiatives should be mindful to reduce the soil or river reed content setting up composting pile; since they are major contributors of Zn and Cd concentration to final compost quality.
- This study provides the basis to support the conviction that using a single parameter such as Temperature, pH, EC, OM loss, TN Loss, or C/N ratio as a

maturity index of compost made from river reed is insufficient. Temperature, EC, OM Loss, TN loss C/N, NH_4^+/NO_3^- are important parameters that can be used as maturity and process efficiency indicators, in river reed composting. Also, findings from the study suggest that compost maturity should be assessed by measuring two or more compost parameters, and that parameters of compost maturity for river reed need to satisfy the following threshold values consistent with literature at full-scale composting: NH_4^+/NO_3^- ratio < 3.5, C/N ratio < 15; stable OM Loss, Temperature < 50^0C. Thus, treatment DAT had a better process efficiency compared to other treatments.

5.4 Effect of Feedstock Composition and Turning frequency on the Process Dynamics and Nutrient Content during Abattoir Waste Composting

The process efficiency observed when both feedstock composition and turning frequency were considered for the composting of abattoir waste could be concluded as follows:

- Feedstock AMYC with all three turning frequencies demonstrated better pathogen sanitization potential compared to other treatments.
- The study revealed that, the interactive effect of feedstock composition and turning frequency influenced monitored parameters such as Temperature, EC, pH, OM, TN. The recommended phytotoxicity limits could not be sustained in feedstock containing market waste (AMYC) that was turned three days (3DT) and seven days (7DT) apart (4.23mS/cm and 4.44mS/cm respectively). This was due to the intrinsic properties of market waste which had high Electrical Conductivity (EC) values compared to other feedstock inputs.

- Treatment ACC-7DT recorded the highest bio-oxidation rate of compost through organic matter degradation. Thus, indicating that a good combination of feedstock formulation and turning regime is needed to hasten the degradation rate of organic matter.
- Conservation of TN was better in treatments of ACC and ACS, than in those of AMYC. The presence of recalcitrant carbon sources as bulking material, such as lignin, may have influences the level of losses in the treatments. The treatments were able to produce compost with nutrient quality ranging from 1.28-1.53% TN, 1.13-2.14% TP and 2.41-4.51%TK, which is considered very suitable for agricultural application.
- The heavy metal levels in the final composts were within the acceptable limits for agricultural application.

5.5 Estimation of nutrient content of piles during composting using physicochemical Parameters

Prediction models were successfully formulated to predict Total Nitrogen concentrations (TN) during composting using physicochemical parameters that are easy to measure. Four to five parameters such as EC, pH, OM, MC, MC/OM, T, ΔT, or ΔT/T were utilized to fit the models to predict concentrations of TN, TK or TP during the composting process.

- A predictive model to predict TN during composting of abattoir waste, based on feedstock composition, was established with very strong coefficient of determination R^2 ranging from 0.879 - 0.99. This means that TN could be computed easily during such a composting process when process temperature, pH, Organic Matter content (OM), Moisture Content (MC) and Electrical Conductivity (EC) are known.

- A near perfect predictive model, with coefficient of determination $R^2 > 0.99$, was modelled for the prediction of TN during composting, with respect to turning frequency on abattoir waste. These models depending on the turning regime could utilize some five of the physicochemical parameters such pH, EC, T, ΔT, ΔT/T, MC, OM, or MC/OM to fit the model.
- The study on abattoir waste composting was also able to relate to nitrogen concentration with parameters such as: ΔT, T, EC, MC and pH at R^2 of 0.63 considering both feedstock composition and turning frequency; while using treatment AMYC-3DT as a reference treatment.
- The coefficient of determinations (R^2) ranging from 0.916 - 1.000 were obtained for the selected models used in predicting TN during river reed composting with respect to the different aeration mechanisms studied. A very good coefficient of determination (R^2) ranging from 0.997 - 1.000 was obtained for the prediction of TP and TK during the composting of river reed.

Composting process efficiency is influenced by feedstock composition, turning frequency and aeration mechanism selected for examination, and an appropriate maturity criteria and predictive models have been identified to estimate essential nutrients such as Total Nitrogen during composting.

5.6 Contribution to Knowledge

This comprehensive study allowed for the comparison of some major composting experiences in Ghana, the dynamics of feedstock composition and turning frequency on abattoir waste composting, dynamics of aeration mechanism during river reed composting, and formulation of nutrient prediction models based on physicochemical process parameters. The study concludes that the most common aeration mechanism of aerating composting piles is by mechanical turning; which could be replaced or supported by passively aerated system. The research work undertaken added to contemporary knowledge regarding the evaluation of process efficient (sanitization potential, organic matter turnover, nitrogen turnover and nutrient quality) during composting of less utilized feedstock such as abattoir waste and river reed. The study revealed feedstock formulations have a significant impact in achieving optimal process efficiency during composting; likewise the turning frequency and their combined treatments. Thus, this study has classified the development of maturity and nutrients dynamics during composting, which can be utilized in setting standards for composting operations; and have assessed the final products for both agricultural and environmental benefits. The work validates the assertion that simple aeration systems could be used to manage composting processes to reflect the performances in other mechanically managed facilities. Also, the study have been able to adopt less demanding monitoring parameters to develop models that predict macro-nutrient content (TN, TP and TK) during the composting of abattoir waste or river reed with similar feedstock composition or aeration mechanism.

5.7 Recommendations for Future Studies

This study has provided a good insight into the process dynamics of less studied feedstock (abattoir waste and river reed) and the effect of turning frequency or aeration mechanism on composting process efficiency. However, the studies also identified some related issues that need to be addressed to progress research in this area, and have been highlighted as follows:

1. Further studies should be considered for similar feedstock to assess the microbial activity under different turning frequencies or aeration mechanism. This would enable process Managers to identify the behaviour of microorganism as a pathogen or beneficial organism.
2. The impact of applying compost products on soils and crops, from the studied feedstock, are yet to be comprehensively considered. Thus, there is a need to conduct such studies on different crops to ascertain their impact on crop; as sole compost product or enriched with mineral fertilizer.
3. There is potential to further improve and validate predictive models on macro- nutrient for field treatment trials.
4. Furthermore, a Life Cycle Analysis (LCA) on composting aeration mechanism (mechanical tuned, passive and forced-aeration technologies) considering their environmental impact and economic costs would help in formulating decision making tools to facilitate effective planning of such system in urban or .rural communities. These also exposes the need to further examine the condition for a commercially viability composting facility by comparing their underlines financial indicators and condition under which they operate. their operations

The use of dewatered faecal sludge as an amendment material for composting river reed could be investigated to replace poultry manure which may not be easily accessible and could be costly to sustain farmers or operators seeking to compost river reed.

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APPENDICES

Appendix A: Composting Facility Questionnaire

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

(College of Engineering)

Faculty of Mechanical and Agricultural Engineering

Department of Agricultural Engineering

COMPOSTING PLANTS IN GHANA

Questionnaire survey:

Name of Institution:…………………………………………………………………………………

Location:……………………………………………………………………………….............

Tel:…………………………………………………………………………………………

Date:…………………………..……………………………………………………...…………

Contact of Institution :(*Name of Interviewee, position*):

Name:…………………………………………………………………………………….......

Position:…………………………………..…………………………………………………

COMPOSTING PLANTS IN GHANA. ***Questionnaire Survey***	
Questionnaire ID:	Date:
This structured questionnaire is been used as part of a research **composting plants in Ghana**. It is part of a department's project in the Faculty of Agriculture, KNUST and will be very pleased if you can gladly assist. The data collected will be treated with utmost confidentiality. The data collected will be treated without personal information revealed, and results will be presented as group data. **You may attach any important formation that could be useful to this research** (pictures, documents etc). You may involve an official in your organization to make contribute to this questionnaire Thank you for your cooperation and participation in this important exercise	

COMPOSITION
1. Why the choice for composting? a. Waste treatment method ☐ b. Product development(organic fertilizer) ☐ c. Both ☐ d. Research/ Fact finding ☐ e. Others……………………………………………………………………………………………………
2. Is composting the most appropriate method to treat your waste? a. Yes ☐ b. No ☐ c. Comments ……………………………………………
3. What materials (organic waste) are used to prepare your compost? a. Solid waste (domestic and market wastes) ☐ b. Horticultural and agricultural waste: garden refuse, leaf litter, cut grass ☐ c. Agro-industrial waste: Palm waste, abattoirs waste, breweries waste etc ☐ d. Sludge and bio-solid: human faecal matter ☐ 4. Others……………………………………………………………………………………………………….
5. What percentage of your material feedstock is produced within your facility for composting? a. Composition from facility (%) …………… b. Composition from outside facility (%) …………... Total 100%
6. Where is the source of your feedstock for composting? a. Farms ☐ b. Processing and agro based industries ☐ c. Septic tanks and treatment plants ☐ d. Homes, institutions and commercial centers ☐ e. Others…………………………………………………………………………………

2

…….

7. Does your facility pre-treat feedstock material before using for composting? (e.g. sorting, shredding, cutting)

a. Yes ☐

b. No ☐

If yes please

specify……………………………………………………………………………..……

8. Which competing uses affect your feedstock availability?

a. Damping on landfills ☐ b. Soil amendment ☐

c. Feeding livestock ☐ d. Fuel ☐

e.

Others…………………………………………………………………………………… ……...

9. What is the composition of your initial compost pile?

Substrate (% v/v) or (%w/w)

a…………………………………………… …………… ……………

b…………………………………………… …………… ……………

c…………………………………………… …………… ……………

d…………………………………………… …………… ……………

e…………………………………………… ……………

3

DEMAND
10. Who is interested in your compost? a. Urban and peri-urban farm facilities ☐ b. Real estate ☐ c. Landscape design ☐ d. Horticulture ☐ e. In-house ☐
11. What is their experience and/ or perception of the product? a. Excellent ☐ b. Very good ☐ c. Good ☐ d. Fair ☐ e. Poor ☐
12. What is the quality of your product?

	(%)	(g/kg)
C	……………	……………
N	……………	……………
P	……………	……………
K	……………	……………
Ca	……………	……………
Mg	……………	……………
pH	……………	……………
Organic Matter (%)	……………	……………
Others	……………	……………
	……………	……………

13. Is your facility able to meet the demand for compost supply? a. Yes ☐ b. No ☐
14. Are there special constraints to compost use related to cultural aspects? a. Taboos ☐ b. Gender ☐ c. Compost marketing ☐ d. Handling ☐ e. Quality ☐

4

PROCESSING

15. What processing parameters do you use to monitor the composting process?

a. Temperature ☐ b. Carbon dioxide ☐

c. Oxygen ☐ d. Moisture content ☐

16. What strategy and equipment do you use to aerate your compost pile?

a. Turner ☐ e. Pipes(pvc) ☐

b. Blower ☐

c. Front loader ☐

d. Shovel/ fork ☐

17. What is the frequency of aeration or turning?

a. Daily ☐ b. Monthly ☐

c. Weekly ☐ d. Other ……………

18. How long does it take for your compost to mature?

a. Within 2 months ☐ b. Within 3 months ☐

c. Within 4 months ☐ d. Within 5 months ☐

19. What is your installed capacity for compost production?

a. 10 tonnes per week ☐ b. Within 10 -20 tonnes per week ☐

c. Within 20-30 tonnes per week ☐ d. More than 40 tonnes per week ☐

20. How much compost is produced?

b. Less than 60 tonnes per week ☐ b. Less than 30 tonnes per week ☐

c. Less than 15 tonnes per week ☐ d. 5 tonnes per week ☐

Others………………………………………………………………………………………

21. Equipments	Purpose	Capacity
Turner ☐		
Front Loader ☐		
Sieve Drum ☐		
Shredder ☐		
Pipes ☐		
others		

5

22. Equipment	Fuel consumed per week GH¢	Electricity consumed per week	GH¢
Turner			
Front Loader			
Sieve Drum			
Shredder			
Pipes			
others			

ECONOMICS

23. What is the average cost per month of energy (**electricity**) being used at the composting facility?

a. GH¢ 60 per month ☐ b. Less than GH¢ 80 per month ☐

c. Less than GH¢ 100 per month ☐ d. Less than GH¢ 120 per month ☐

Others...

24. What is the average cost per month of energy (**fuel**) being used at the composting facility?

b. GH¢ 60 per month ☐ b. Less than GH¢ 80 per month ☐

c. Less than GH¢ 100 per month ☐ d. Less than GH¢ 120 per month ☐

Others...

25. What is the average cost of **collecting feedstock material** to the composting facility?

c. GH¢20 per week ☐ b. Less than GH¢ 40 per week ☐

c. Less than GH¢ 60 per week ☐ d. Less than GH¢ 80 per week ☐

Others...

26. What is the average cost of **operating the Composting system**? (labour, utilities)

a. about GH¢50 per week ☐ b. Less than GH¢ 100 per week ☐

c. Less than GH¢ 150 per week ☐ d. about GH¢ 200 per week ☐

Others...
....

27. How much compost are you able to sell outside your facility?

a. 5 tonnes per week ☐ b. Less than 10 tonnes per week ☐

c. Less than 20 tonnes per week ☐ d. 40 tonnes per week ☐

Others...

28. Tonnes produced per year	Production cost, Gh¢ per tonne	Price compost, Gh¢ per tonne

29. Do you have a market or a potential market for your compost?

a. Yes ☐

b. No ☐

Comments...
....

30. Does you facility justify the need for municipal subsides for compost producers in Ghana?

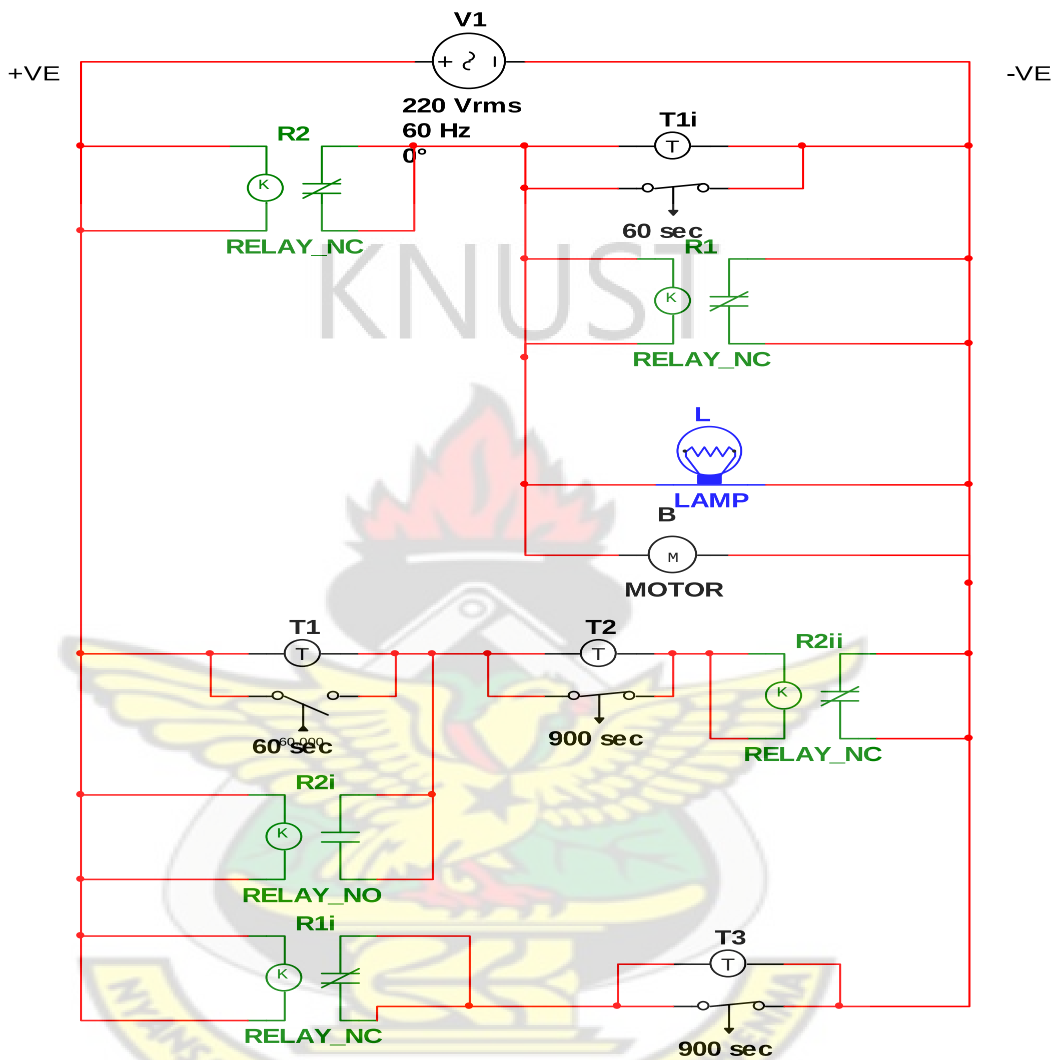
a. Yes ☐

b. No ☐

Comments
....

Appendix B: Electrical Control Circuit For Forced Aeration Experiment

SIMULATED CIRCUIT



SPECIFICATIONS OF COMPONENTS

- Two (2) Relays (MP-2) - Sungho (Korea)– (200/220VAC 60Hz, 200VAC, 50Hz)
- Two (2) pieces of Fuji Super Timer Multi-range (ST3P), Fuji (Japan) - 200-220V 50/60Hz (No. B23K)

- Terminal Bar
- Green illuminated pilot lamp (PR30P-2) Sungho (Korea) –(220V/6.3V)
- Socket Switch (30A)
- Plug (U.K Standards)- BS506- 15A 250V
- Pump specification: Dietz-motoren KG, type-WN 13T, Power - 0.4 kW, Static pressure -550Pa, V_{max} – 18m^3/min

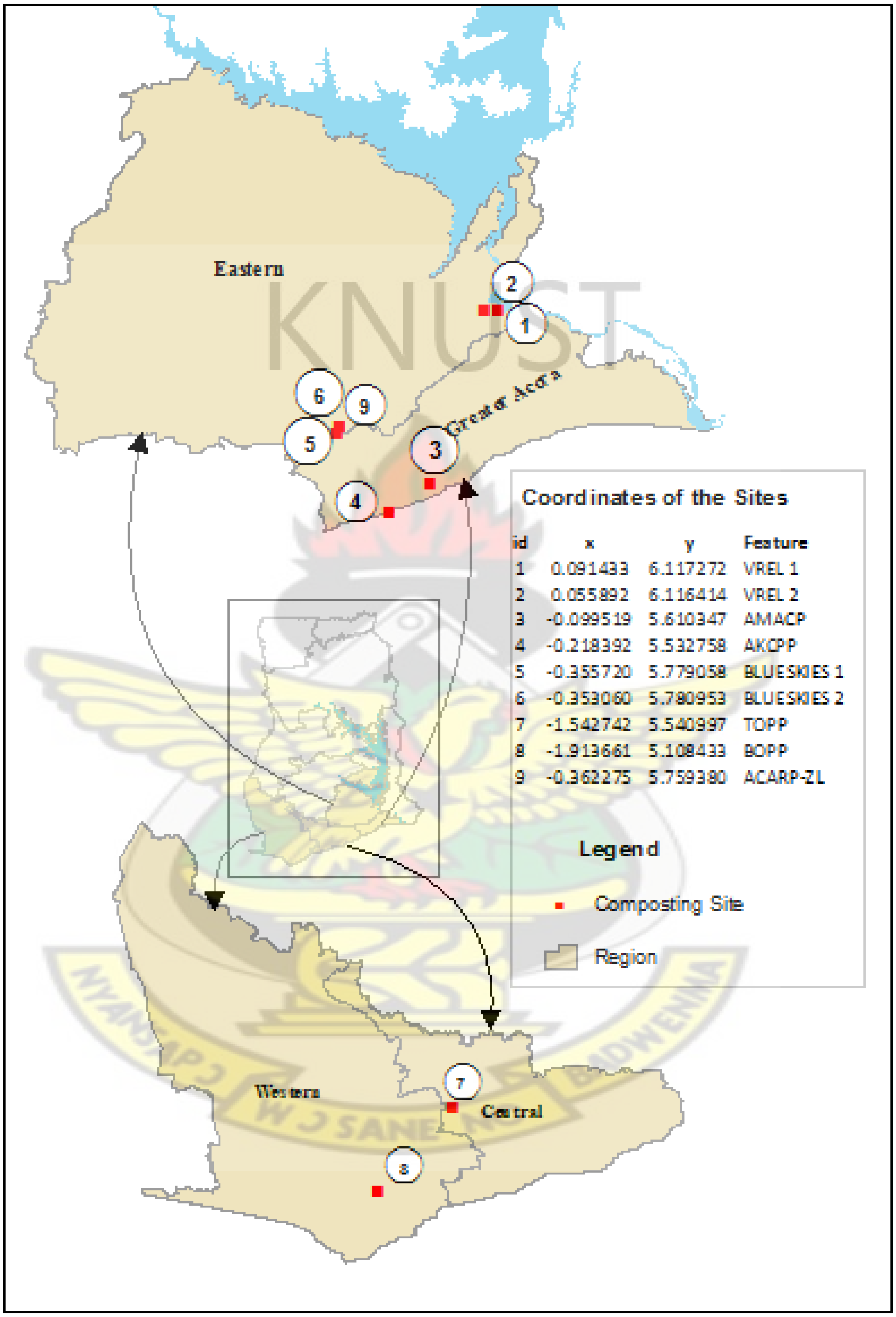
OPERATION OF CIRCUIT

When the switch to the circuit is closed, current flows through the contacts of the Relay-R2 which is normally closed to the coils of Timer - T1 at node (7&2) and Relay-R1 at nodes (7&2). The light comes on and the blower also starts operating.

After **1 minute**, the coil of Timer-T1 energizes to close its normally open contact between nodes (1&3) and (8&6). This current reaches Relay-R2 coil which energizes simultaneously closing its contact between (8&6) and (1&3) nodes. Also opening its normally closed contact R2 between (1& 4) and (8&5) nodes. This de-energizes the coils of T1 & R1. Also, the light and the blower go off for 15minute. Hitherto, the opened normally closed contact of Relay-R1 between nodes (1&4) and (8&5) closes as Relay-R1 is de-energized.

After 15 minutes the current reaching the coil of Timer-T2 energizes it, opening its normally closed contact between the (1&4) and (8&5) nodes. This de-energizes the Relay-R2 which closes its contact between the (1&4) nodes. This energizes Relay-R1 which intern opens its normally closed contact between the nodes (1&4) and (8&5). This de-energizes the coil Timer-T2. The whole process then gets repeated.

Appendix C: Geographical Locations of Surveyed Composting Facilities



Appendix D: Modelling Composting Temperature-Time Profile

Appendix D1: Determination of Reference Areas under the Temperature -Time Profile during Composting Using A MATLAB Routine Adopted From Mason (2007, Pp 345-6)

```
%Area Under a Temperature curve
%a script file to determine A40 and A55 from experimental data
%method: determine T*deltat where deltat is the temperature logging
% interval (1 d in these experiments)
%assumption: deltat is spread equally on either side of the logging time
% T=input('enter temperature profile name : '
% int=input('enter interval for temperature rate (day): ');
%enter fixed data
%T=[51.167 71.16706 71.86451 71.73276 68.6321 57.32602...
 %  52.76008 57.41103 61.56305 63.1924 60.40106 61.6599...
 %  63.16077 61.78376 52.72936 48.87814 54.58861 58.68638...
 %  61.2949 62.48706 62.08674 63.01238 62.55331 62.36137...
 %  62.8254 63.50834 58.5218 47.61474 50.16854 52.10331...
 %  54.48345 56.53913 57.41138 56.89938 55.38827 56.91789...
 %  58.11171 58.38066 57.81851 58.2856 57.91259 57.30546 56.42119];

 T=[27.00  53.33   52.33   55.33   56.67   52.33   52.33   51.33...
   44.00  44.00   42.00   43.33   45.33   41.33   43.00   45.00...
   43.33  41.67   45.00   44.67   41.67   41.67   41.33   42.00...
   40.67  48.33   41.00   50.00   46.67   44.67   44.00   40.33...
   40.00  39.00   42.00   40.33   35.33   36.00   36.00   41.00...
   40.67  40.33   33.33   33.00   32.67   33.00   32.67   32.33...
```

```
    30.33  30.29   30.00   29.67   28.67   28.33   28.00   28.33...
    27.33  29.00   29.67   29.33   28.33   28.67   28.71   28.33...
    28.00  29.33   28.00   28.33   28.33   28.00   27.67   28.33...
    27.72  27.58   28.00   26.00   27.95   28.00   27.47   27.41...
    27.46  27.31   27.31   28.33   26.00   27.60   26.67];
int=1;%interval (1 d in these experiments)
deltat=1; %(d)
%calculate temperature interval >40
T40=T-40;
%eliminate negative values
[i,j]=find(T40 < 0);
if length(i)>0
for m=1:size(i);
T40(i(m),j(m))=0;
end
end
%calculate individual areas
areas40=T40.*deltat./1; %C.days
%calculate total area
A40=max(cumsum(areas40))%C.days
%calculate temperature interval >55
T55=T-55;
%eliminate negative values
[k,l]=find(T55 < 0);
if length(k)>0
```

```
for m=1:size(k);

T55(k(m),l(m))=0;

end

end

%calculate individual area

areas55=T55.*deltat./1; %C.days

%calculate total area

A55=max(cumsum(areas55))%C.days

%calculate maximum rates of temperature change

n=1:int:(size(T,2)-int);

deltat=(T(n+int)-T(n));

deltatmax=max(deltat);

deltatmin=min(deltat);

Tratemax=deltatmax/int %C/d; max rate of increase

Tratemin=deltatmin/int %C/d; max rate of decrease
```

Appendix D2: Modelling Temperature -Time Profile in Composting System: Using the Dynamic Fit Wizard of Sigma plot 10.0

Equation:

f=y0+yhm*exp (-exp (-km*(x-tm))) +yht*exp (-exp (-kt*(x-tt))) -

… yc*exp(-exp(-kc*(x-tc)))

fit f to y

'Yu sigmoid, asymptotic growth curves and a decay curve for temperature profile'

'yo: ambient temperature'

'yhm: heating potential of the mesophilic stage'

'yht: heating potential of the thermophilic stage'

'yc: cooling potential'

'tm: time when maximum mesophilic heating rate occurs'

'th: time when maximum thermophilic heating rate occurs'

'tc: time when maximum cooling rate occurs'

'km: maximum mesophilic microbial kinetic coefficient'

'kt: maximum thermophilic microbial kinetic coefficient'

'kc: maximum cooling coefficient'

Variable:

x=col(1) ' Time period'

y=col(2) ' Temperature at any state of time'

Initial Parameter:

y0 = 20 ' {{MinRange: 0}} {{MaxRange: 30}}

yhm = 10 ' {{MinRange: 0}} {{MaxRange: 40}}

km = 0.01 ' {{MinRange: 0}} {{MaxRange: 1}}

tm = 1 ' {{MinRange: 0}} {{MaxRange: 40}}

yht = 10 ' {{MinRange: 0}} {{MaxRange: 70}}

kt = 0.01 ' {{MinRange: 0}} {{MaxRange: 1}}

tt = 1 ' {{MinRange: 0}} {{MaxRange: 70}}

yc = 10 ' {{MinRange: 0}} {{MaxRange: 40}}

kc = 0.05 ' {{MinRange: 0}} {{MaxRange: 1}}

tc = 30 ' {{MinRange: 0}} {{MaxRange: 40}}

Constrains:

tm>0.0001; tt>0.0001; tc>0.0001

tc>tt; tt>tm;

y0>0.0001; y0<35.0

yhm<40; yhm>0.1

km<1.0; km>0.0001

km<1.0; yht<40

yht>1; kt<1.0

kt>0; yc>1

kc<1.0; kc>0

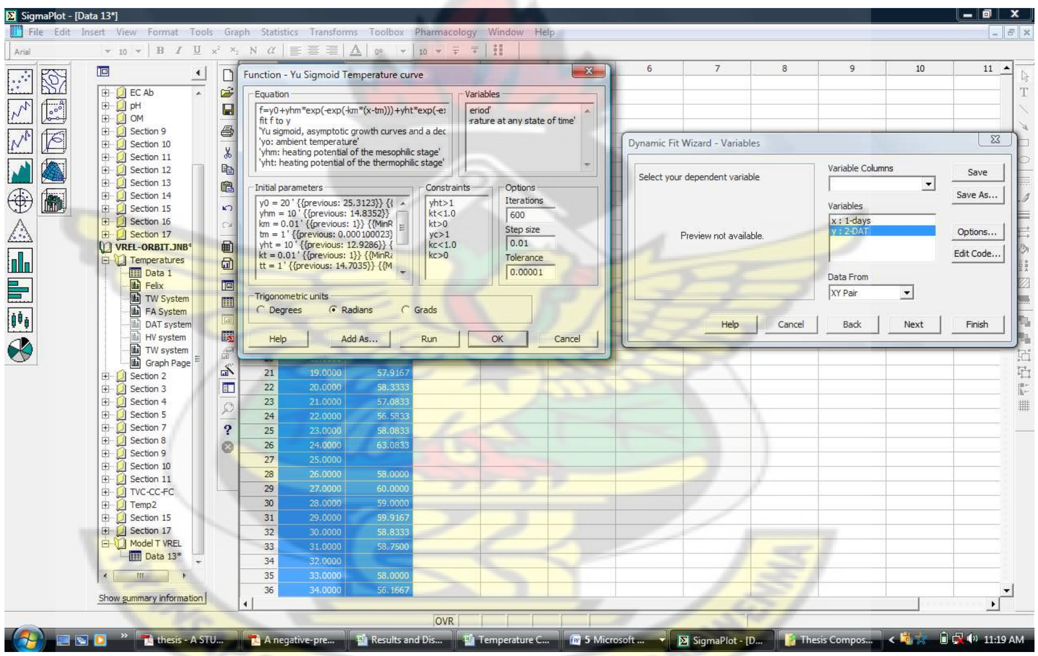


Figure A1. A print-screen of Dynamic fit Wizard regression in Sigmaplot 10.0

Appendix E: Results of Abattoir Waste Composting

Appendix E1: Evaluated Temperature Profile Characterization Based on Feedstock Formulation

Factors		AMYC	ACC	ACS
Initial Temperature	^{o}C	52.67	48.87	34.97
Peak Temperature	^{o}C	58.13	51.53	44.97
Time to reach peak	d	3	4.33	13.33
Period above 55 ^{o}C, t_{55}	d	4	0	0
Period above 40 ^{o}C, t_{40}	d	30.67	24	12.67
Area above the 55^{o}C, A_{55}	$^{0}C \cdot d$	8.73	0	0
Area above the 40^{o}C, A_{40}	$^{0}C \cdot d$	214.5	141.47	12

Appendix E2: Evaluated Temperature Profile Characterization Based on Turning Frequency

Factors		3DT	7DT	14DT
Initial Temperature	^{0}C	45.10	45.43	45.97
Peak Temperature	^{0}C	53.67	48.87	52.10
Time to reach peak	d	8.33	2.67	9.67
Period above 55 ^{0}C, t_{55}	d	1.67	1.67	0.67
Period above 40 ^{0}C, t_{40}	d	22.67	20.33	24.33
Area above the 55^{0}C, A_{55}	$^{0}C \cdot d$	6.10	2.10	0.53
Area above the 40^{0}C, A_{40}	$^{0}C \cdot d$	150.67	107.07	110.23

Appendix E3: Effect of Feedstock on Electrical Conductivity (EC, mS/cm)

Feedstock	Week						
	0	2	4	6	8	10	12
AMYC	2.13	2.43	2.84	3.24	2.84	3.38	3.95
ACC	1.89	1.64	1.37	1.84	1.87	2.07	2.31
ACS	1.64	1.52	1.65	1.90	1.78	2.16	2.36
LSD	0.01	0.04	0.00	0.00	0.00	0.00	0.00
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.01

Appendix E4: Effect of Turning Frequency on Electrical Conductivity (EC, mS/cm)

Turning Frequency	Week 0	2	4	6	8	10	12
3DT	1.69	1.87	1.97	2.59	2.77	2.99	3.46
7DT	1.82	1.83	1.94	2.25	1.82	2.37	2.76
14DT	2.15	1.89	1.95	2.14	1.90	2.25	2.40
LSD	0.01	0.04	0.00	0.00	0.00	0.00	0.00
p-value	<0.001	0.01	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.01

Appendix E5: Effect of feedstock composition on pH during composting

Feedstock	Week 0	2	4	6	8	10	12
AMYC	7.28	7.18	9.47	9.46	8.89	7.97	7.99
ACC	7.38	6.99	9.25	9.16	8.64	7.64	7.69
ACS	7.32	7.23	9.16	9.50	8.86	7.96	7.95
LSD	0.02	0.01	0.02	0.12	0.01	0.04	0.03
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.02

Appendix E6: Effect of turning frequency on pH during composting

Turning Frequency	Week 0	2	4	6	8	10	12
3DT	7.37	7.16	9.41	9.55	8.89	7.96	7.92
7DT	7.30	7.07	9.17	9.33	8.75	7.86	7.84
14DT	7.31	7.17	9.30	9.24	8.76	7.75	7.87
LSD	0.02	0.01	0.02	0.12	0.01	0.04	0.03
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.02

Appendix E7: Effect of feedstock on moisture content (MC, %)

Feedstock	Week						
	0	2	4	6	8	10	12
AMYC	65.72	71.44	63.89	66.98	63.25	61.93	57.59
ACC	76.37	74.70	74.29	70.66	67.59	66.67	63.59
ACS	75.81	68.03	70.90	68.29	64.49	65.74	61.76
LSD	2.21	0.85	0.13	1.07	0.62	0.28	0.26
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.05

Appendix E8: Effect of turning frequency on moisture content

Turning Frequency	Week						
	0	2	4	6	8	10	12
3DT	71.90	67.21	66.79	64.87	60.43	60.74	54.75
7DT	71.81	71.67	70.14	68.30	66.70	65.88	62.97
14DT	74.19	75.29	72.14	72.76	68.20	67.73	65.22
LSD	2.21	0.85	0.13	1.07	0.62	0.28	0.26
p-value	0.061	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance): 0.05

Appendix E9: Effect of feedstock composition on Total Nitrogen (TN,%)

Feedstock	Week						
	0	2	4	6	8	10	12
AMYC	1.54	1.65	1.41	1.63	1.25	1.36	1.32
ACC	1.62	1.70	1.58	1.46	1.54	1.50	1.50
ACS	1.58	1.59	1.64	1.28	1.24	1.31	1.39
LSD	0.11	0.04	0.01	0.05	0.03	0.01	0.01
p-value	0.326	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment ($p<0.05$):0.05

Appendix E10: Effect of turning frequency on TN (%)

Turning Frequency	Week 0	2	4	6	8	10	12
3DT	1.58	1.60	1.50	1.49	1.32	1.44	1.45
7DT	1.60	1.57	1.60	1.42	1.40	1.39	1.42
14DT	1.57	1.76	1.53	1.46	1.32	1.33	1.34
LSD	0.11	0.04	0.01	0.05	0.03	0.01	0.01
p-value	0.821	<0.001	<0.001	0.042	<0.001	<0.001	<0.001

LSD for comparing means at the same level of treatment (5% level of significance):0.05

Appendix E11: Percentage Nitrogen Loss (ash-free basis) with Respect to Feedstock Formulation

Treatment	Week 0	2	4	6	8	10	12
AMYC	0.00	9.12	27.60	32.11	56.60	53.07	58.35
ACC	0.00	14.86	26.71	33.88	36.22	39.96	41.92
ACS	0.00	5.44	4.87	35.21	40.08	44.64	41.80

Appendix E12: Percentage Nitrogen Loss (ash-free basis) with Respect to Turning Frequency

Treatment	Week 0	2	4	6	8	10	12
3DT	0.00	18.00	24.51	37.07	50.00	46.11	49.87
7DT	0.00	15.78	18.90	34.42	42.82	47.68	46.23
14DT	0.00	-4.53	17.72	28.58	41.17	45.02	48.04

Appendix E13: Percentage Carbon Loss (ash-free basis) with Respect to Feedstock Formulation

Treatment	Week 0	2	4	6	8	10	12
AMYC	0.00	21.21	29.26	50.14	65.07	65.53	68.47
ACC	0.00	27.57	36.33	38.92	48.08	51.37	52.83
ACS	0.00	9.20	12.71	30.46	35.98	50.54	50.89

Appendix E14: Percentage Carbon Loss (ash-free basis) with Respect to Turning Frequency

Treatment	Week						
	0	2	4	6	8	10	12
3DT	0.00	27.06	29.14	47.33	57.12	58.13	61.25
7DT	0.00	20.87	27.82	38.47	51.07	58.60	58.33
14DT	0.00	10.01	23.04	34.35	44.45	51.95	54.81

Appendix E15: Percentage OM Loss (ash-free basis) with Respect to Feedstock Formulation

Treatment	Week						
	0	2	4	6	8	10	12
AMYC	0	21.23	29.26	50.15	65.08	65.54	71.90
ACC	0	27.57	36.32	38.92	48.08	51.37	54.45
ACS	0	9.18	12.70	30.44	35.97	50.53	51.47

Appendix E16: Percentage OM Loss (ash-free basis) with Respect to Turning Frequency

Treatment	Week						
	0	2	4	6	8	10	12
3DT	0.00	27.07	29.14	47.33	57.12	58.14	64.54
7DT	0.00	20.89	27.85	38.48	51.08	58.62	58.10
14DT	0.00	10.00	23.04	34.34	44.44	51.94	57.91

Appendix E17: Percentage Nitrogen Loss (ash-free basis) with Respect to Interaction Treatment

Treatment	Week						
	0	2	4	6	8	10	12
AMYC-3DT	0.00	23.68	40.87	43.04	61.51	64.05	63.63
AMYC-7DT	0.00	-11.52	15.27	24.74	52.46	45.52	50.95
AMYC-14DT	0.00	12.35	23.97	26.31	54.73	48.17	59.85
ACC-3DT	0.00	17.94	26.22	30.72	39.73	38.79	44.08
ACC-7DT	0.00	29.97	36.12	45.53	40.92	47.74	44.09
ACC-14DT	0.00	-6.25	17.50	23.83	26.70	32.99	38.02
ACS-3DT	0.00	13.01	4.05	38.86	47.08	30.93	38.24
ACS-7DT	0.00	24.05	0.49	31.48	33.40	49.63	44.49
ACS-14DT	0.00	-21.93	11.38	35.93	38.89	52.79	43.42

Appendix E18: Percentage Carbon Loss (ash-free basis) with Respect to Interaction Treatment

Treatment	Week						
	0	2	4	6	8	10	12
AMYC 3DT	0.00	33.12	35.15	60.01	69.71	71.02	73.49
AMYC 7DT	0.00	17.70	27.75	46.59	66.13	66.38	66.78
AMYC 14DT	0.00	11.03	24.56	41.88	58.55	58.08	64.47
ACC 3DT	0.00	27.29	32.29	41.12	50.35	50.75	54.12
ACC 7DT	0.00	38.36	40.60	43.02	53.05	56.34	56.36
ACC 14DT	0.00	14.72	35.75	32.05	39.91	46.53	47.74
ACS 3DT	0.00	20.60	19.28	38.09	47.86	48.92	52.31
ACS 7DT	0.00	2.00	12.60	24.09	26.83	52.10	50.54
ACS 14DT	0.00	4.20	6.04	28.68	31.46	50.76	50.23

Appendix E19: Percentage OM Loss (ash-free basis) with Respect to Interaction Treatment

Treatment	Week						
	0	2	4	6	8	10	12
AMYC 3DT	0.00	33.13	35.15	60.01	69.72	71.01	76.80
AMYC 7DT	0.00	17.71	27.76	46.59	66.14	66.38	67.24
AMYC 14DT	0.00	11.03	24.57	41.88	58.56	58.07	70.95
ACC 3DT	0.00	27.29	32.29	41.12	50.36	50.75	57.12
ACC 7DT	0.00	38.36	40.59	43.02	53.05	56.35	56.35
ACC 14DT	0.00	14.70	35.75	32.05	39.91	46.53	49.57
ACS 3DT	0.00	20.61	19.30	38.10	47.87	48.93	55.73
ACS 7DT	0.00	1.98	12.61	24.08	26.82	52.11	49.03
ACS 14DT	0.00	4.20	6.04	28.66	31.44	50.76	49.58

Appendix E20: Kinetics of N-loss in Feedstock AMYC

$\mathbf{NL_t = NL_{max} + kt}$ (Zero Order)	Values	Std. Error	p-value
Regression, R^2	0.9262	6.9652	0.0005
Coefficient (NL_{max}),%	2.5541	4.7460	0.6136
Rate coefficient (k), wk^{-1}	5.2133	0.6582	0.0005
Product of coefficients (AMYC)	-		

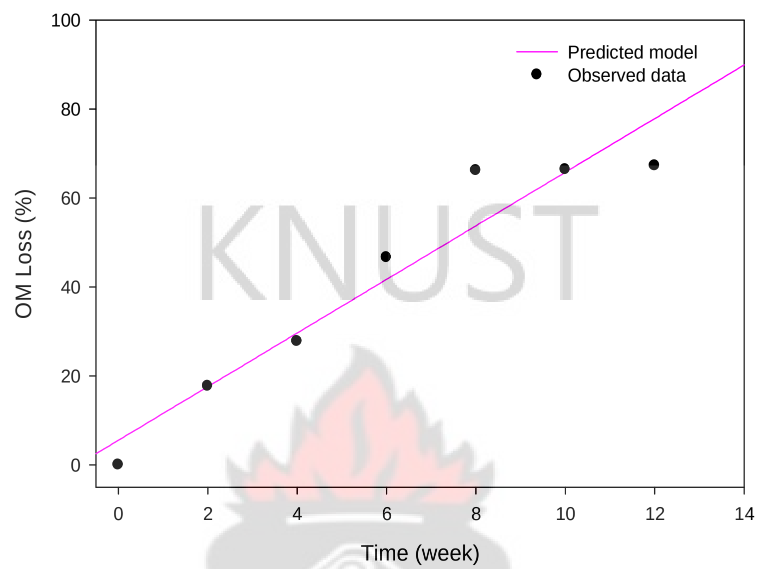
Appendix E21: Kinetics of N-loss in Feedstock ACC

$\mathbf{NL_t = NL_{max}(1 - e^{-kt})}$	Values	Std. Error	p-value
Regression, R^2	0.9976	0.8150	<0.0001
Coefficient (NL_{max}),%	45.1629	1.1463	<0.0001
Rate coefficient (k), wk^{-1}	0.2166	0.0137	<0.0001
Product of coefficients (ACC)	9.7823		

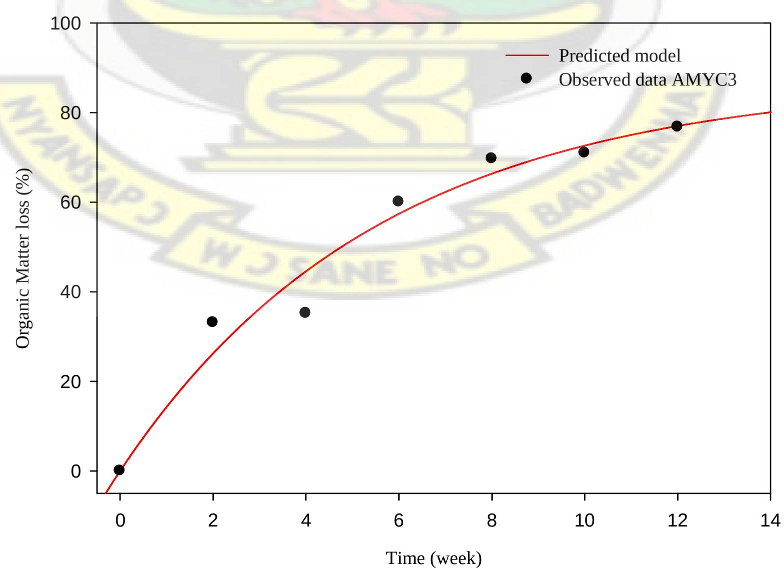
Appendix E22: Kinetics of N-loss in Feedstock ACS

$\mathbf{NL_t = NL_0 + kt}$	Values	Std. Error	p-value
Regression, R^2	0.8462	8.6121	0.0030
Coefficient (NL_{max}),%	-1.0310	5.8682	0.8674
Rate coefficient (k), wk^{-1}	4.2682	0.8138	0.0033
Product of coefficients (ACS)	-		

Appendix E23: Fitted Zero Order Curve to the Predict Organic Matter Loss in Treatment AMYC-7DT



Appendix E24: Fitted 1st Order Curve to Predict Organic Matter Loss in Treatment AMYC-3DT



Appendix F: Sample Statistical Analysis (Anova)

Sample Analysis of Variance using GENSTAT statistical software

```
720  "General Treatment Structure (in Randomized Blocks)."
 721  BLOCK reps
 722  TREATMENTS feed*turning
 723  COVARIATE "No Covariate"
 724     ANOVA   [PRINT=aovtable,information,means,%cv;   FACT=32;
FPROB=yes; PSE=diff,lsd,means;\
 725   LSDLEVEL=5] N_wk12
```



```
***** Analysis of variance *****
Variate: N_wk12
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
reps stratum               2 0.00041321 0.00020661    2.55
reps.*Units* stratum
feed                       2 0.15455955 0.07727978  954.53  <.001
turning                    2 0.06118793 0.03059396  377.88  <.001
feed.turning               4 0.03742791 0.00935698  115.57  <.001
Residual                  16 0.00129538 0.00008096

Total                     26 0.25488399

* MESSAGE: the following units have large residuals.

reps 1     *units* 4          0.0158   s.e. 0.0069
reps 2     *units* 4         -0.0193   s.e. 0.0069
reps 3     *units* 7          0.0161   s.e. 0.0069

***** Tables of means *****
Variate: N_wk12

Grand mean:  1.4015
    feed        1        2        3
           1.3155   1.4996   1.3893


  turning        1        2        3
           1.4515   1.4154   1.3374
```

feed	turning	1	2	3
1		1.3344	1.3331	1.2790
2		1.5079	1.5386	1.4523
3		1.5122	1.3747	1.2810

*** Standard errors of means ***

Table	feed	turning	feed turning
rep.	9	9	3
d.f.	16	16	16
e.s.e.	0.00300	0.00300	0.00519

*** Standard errors of differences of means ***

Table	feed	turning	feed turning
rep.	9	9	3
d.f.	16	16	16
s.e.d.	0.00424	0.00424	0.00735

*** Least significant differences of means (5% level) ***

Table	feed	turning	feed turning
rep.	9	9	3
d.f.	16	16	16
l.s.d.	0.00899	0.00899	0.01557

***** Stratum standard errors and coefficients of variation *****

Variate: N_wk12

Stratum	d.f.	s.e.	cv%
reps	2	0.00479	0.3
reps.*Units*	16	0.00900	0.6

```
726  "General Treatment Structure (in Randomized Blocks)."
 727  BLOCK reps
 728  TREATMENTS feed*turning
 729  COVARIATE "No Covariate"
 730     ANOVA   [PRINT=aovtable,information,means,%cv;   FACT=32;
FPROB=yes; PSE=diff,lsd,means;\
 731   LSDLEVEL=5] OM_wk0

731.................................................................
...............
```



```
***** Analysis of variance *****
Variate: OM_wk0
Source of variation     d.f.        s.s.        m.s.    v.r.  F pr.
reps stratum               2       22.74       11.37    0.99
reps.*Units* stratum
feed                       2      148.12       74.06    6.43  0.009
turning                    2       40.88       20.44    1.78  0.201
feed.turning               4       10.75        2.69    0.23  0.915
Residual                  16      184.18       11.51

Total                     26      406.67


* MESSAGE: the following units have large residuals.
reps 1     *units* 8            5.25   s.e. 2.61

***** Tables of means *****
Variate: OM_wk0
Grand mean  68.57
     feed        1        2        3
             71.50    68.44    65.76
  turning        1        2        3
             70.30    67.85    67.56
     feed  turning        1        2        3
        1             72.89    71.39    70.20
        2             69.39    67.86    68.07
        3             68.62    64.28    64.39
```

*** Standard errors of means ***

Table	feed	turning	feed turning
rep.	9	9	3
d.f.	16	16	16
e.s.e.	1.131	1.131	1.959

*** Standard errors of differences of means ***

Table	feed	turning	feed turning
rep.	9	9	3
d.f.	16	16	16
s.e.d.	1.599	1.599	2.770

*** Least significant differences of means (5% level) ***

Table	feed	turning	feed turning
rep.	9	9	3
d.f.	16	16	16
l.s.d.	3.391	3.391	5.873

***** Stratum standard errors and coefficients of variation *****

Variate: OM_wk0

Stratum	d.f.	s.e.	cv%
reps	2	1.124	1.6
reps.*Units*	16	3.393	4.9

```
"One-way ANOVA (no Blocking)."
BLOCK "No Blocking"
TREATMENTS TRTS
COVARIATE "No Covariate"
ANOVA [PRINT=aovtable,information,means,%cv; CONTRASTS=7; FPROB=yes; PSE=diff,lsd,\
means; LSDLEVEL=5] T_14
```

Analysis of variance

Variate: T_14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TRTS	3	689.667	229.889	176.09	<.001
Residual	8	10.444	1.306		
Total	11	700.111			

Tables of means

Variate: T_14

Grand mean: 39.17

TRTS	DAT	FA	T	W
	49.11	28.78	42.78	36.00

Standard errors of means

Table	TRTS
rep.	3
d.f.	8
e.s.e.	0.660

Standard errors of differences of means

Table	TRTS
rep.	3
d.f.	8
s.e.d.	0.933

Least significant differences of means (5% level)

Table	TRTS
rep.	3
d.f.	8
l.s.d.	2.151

Stratum standard errors and coefficients of variation

Variate: T_14

d.f.	s.e.	cv%
8	1.143	2.9

Appendix G: Sample Regression Analysis

Appendix G1: Nonlinear Regression Analysis of Abattoir Waste Composting Feedstock AMYC Determining the Organic Matter Kinetics

Data Source: Data 1 in Notebook1
Equation: Exponential Rise to Maximum, Single, 2 Parameter
f=a*(1-exp(-b*x))

R	Rsqr	Adj Rsqr	Standard Error of Estimate
0.9870	0.9743	0.9691	4.6536

	Coefficient	Std. Error	t	P	VIF
a	92.4325	16.0525	5.7581	0.0022	23.5772<
b	0.1243	0.0383	3.2488	0.0227	23.5772<

Analysis of Variance:

Uncorrected for the mean of the observations:

	DF	SS	MS
Regression	2	16929.1640	8464.5820
Residual	5	108.2801	21.6560
Total	7	17037.4442	2433.9206

Corrected for the mean of the observations:

	DF	SS	MS	F	P
Regression	1	4098.5930	4098.5930	189.2588	<0.0001
Residual	5	108.2801	21.6560		
Total	6	4206.8731	701.1455		

Statistical Tests:

PRESS 267.2230

Durbin-Watson Statistic 2.0381 Passed

Normality Test Passed (P = 0.8640)

K-S Statistic = 0.2138 Significance Level = 0.8640

Constant Variance Test Passed (P = 0.4383)

Power of performed test with alpha = 0.0500: 0.9989

APPENDIX G2: Sample Multi Linear Regression to Predict Nutrient Parameters during Composting (Abattoir Waste Composting Turning Frequency - 14DT)

Response variate: N

Fitted terms: Constant, pH, OM, T, %_T_T, MC

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	5	0.15669956	0.03133991	723.77	0.028
Residual	1	0.00004330	0.00004330		
Total	6	0.15674286	0.02612381		

Percentage variance accounted for 99.8

Standard error of observations is estimated to be 0.00658.

Estimates of parameters

Parameter	estimate	s.e.	t(1)	t pr.
Constant	-0.707	0.141	-5.02	0.125
pH	-0.06138	0.00337	-18.20	0.035
OM	-0.05563	0.00317	-17.52	0.036
T	0.00641	0.00191	3.36	0.184
%_T_T	1.2820	0.0643	19.95	0.032
MC	0.07630	0.00336	22.72	0.028

Appendix H: Results of River Reed Composting

Appendix H1: The Effect of Aeration System on Temperatures Measured during Composting

Treatment	Temperature (^{0}C)														
Sampling weeks	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
DAT	56.3	63.9	68.8	59.9	61.2	59.8	58.9	56.7	55.8	56.7	53.4	50.8	50.0	47.9	49.1
HV	52.2	64.1	66.6	61.7	60.3	59.3	58.8	55.8	54.0	51.4	49.1	47.6	45.3	43.9	42.8
WT	65.7	66.0	59.7	54.7	50.7	45.7	46.3	44.3	41.3	39.7	40.0	35.3	38.3	36.7	36.0
FA	52.1	48.6	42.2	32.3	52.9	49.7	35.9	36.7	34.2	32.0	30.7	28.9	28.8	28.8	28.8
LSD	21.8	19.5	13.8	9.4	9.9	12.6	8.3	6.6	6.0	3.9	3.2	5.1	2.5	1.9	2.2
F-test	0.478	0.217	0.008	<.001	0.092	0.076	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

LSD for comparing means at the same level of treatment (5% level of significance): 8.24

Appendix H2: The Effect of Aeration System on Electrical Conductivity, EC (dS/m) during composting

Treatment	Electrical Conductivity, EC (dS/m)													
Sampling weeks	0	1	2	3	4	5	6	7	8	9	10	11	12	14
DAT	1.05	1.60	1.99	2.53	2.55	2.85	2.22	1.95	2.50	2.58	2.69	2.49	2.73	2.37
HV	1.08	1.80	2.03	2.16	2.32	2.08	2.20	2.69	2.45	2.36	2.43	2.63	2.65	2.63
WT	1.42	1.80	2.04	2.30	1.77	1.83	2.50	2.96	2.98	3.02	2.26	2.89	3.04	2.96
FA	1.42	1.88	2.31	2.47	2.02	2.63	2.20	2.75	2.84	2.95	2.70	2.57	2.66	2.29
LSD	0.51	0.31	0.69	0.36	0.80	0.56	0.68	0.48	0.43	0.57	0.65	0.40	0.47	0.38
F-test	0.231	0.252	0.670	0.143	0.195	0.014	0.449	0.010	0.064	0.085	0.369	0.187	0.232	0.019

LSD for comparing means at the same level of treatment (5% level of significance): 0.48

Appendix H3: The Effect of Aeration System on Acidity or Alkalinity Measured as pH during Composting

Treatment	pH units													
Sampling weeks	0	1	2	3	4	5	6	7	8	9	10	11	12	14
DAT	7.69	7.93	8.18	8.10	7.79	7.82	7.90	8.13	8.17	7.80	7.67	7.70	7.60	7.53
HV	7.69	7.80	8.20	8.05	8.17	7.87	7.93	7.67	7.70	7.77	7.73	7.20	7.37	7.60
WT	7.79	7.99	8.04	8.16	7.85	7.75	7.93	7.93	7.67	7.60	7.63	7.47	7.33	7.60
FA	7.79	8.05	7.71	8.87	7.73	7.53	7.83	7.67	7.50	7.30	7.43	7.40	7.27	7.60
LSD	0.24	0.42	0.30	0.17	0.32	0.26	0.24	0.21	0.43	0.35	0.29	0.48	0.24	0.21
T-test	0.612	0.562	0.024	0.029	0.052	0.065	0.714	0.004	0.038	0.044	0.166	0.187	0.062	0.819

LSD for comparing means at the same level of treatment (5% level of significance): 0.29

Appendix H4: The Effect of Aeration System on Moisture Content Evolution during Composting

Treatment	Percentage Moisture Content, MC (%)													
Sampling weeks	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**
DAT	60.33	65.00	65.67	68.00	62.67	65.33	59.00	53.67	57.67	55.67	55.33	60.33	51.00	51.33
HV	61.33	69.67	61.00	61.67	57.33	60.33	62.33	59.33	56.00	50.33	51.00	52.00	49.33	46.00
WT	62.33	71.00	65.33	62.67	59.33	55.33	55.67	51.00	51.00	45.67	53.00	54.33	53.33	53.67
FA	62.33	67.67	62.00	65.00	56.33	58.00	55.67	59.67	53.67	55.67	54.33	57.33	58.00	55.77
LSD	9.58	5.92	8.76	9.66	5.00	8.92	5.37	6.89	4.25	10.40	6.06	13.83	8.34	6.89
F-test	0.945	0.174	0.510	0.448	0.079	0.138	0.063	0.053	0.036	0.150	0.404	0.528	0.163	0.057

LSD for comparing means at the same level of treatment (5% level of significance): 7.05

Appendix H5: The Effect of Aeration System on Total Carbon Evolution during Composting

Treatment	Percentage of Total Carbon, TC (%)													
Sampling weeks	0	1	2	3	4	5	6	7	8	9	10	11	12	14
DAT	26.32	24.45	22.86	16.19	20.59	18.38	23.59	15.95	17.11	16.30	19.00	16.69	13.36	15.16
HV	25.57	29.84	24.94	22.42	19.61	16.67	17.46	18.36	19.87	15.83	16.11	13.33	18.96	14.03
WT	22.30	20.58	22.14	18.49	17.01	22.35	17.41	19.06	20.08	18.78	21.76	19.79	16.73	14.46
FA	22.56	22.39	17.69	22.72	25.93	19.48	19.62	24.10	22.13	20.17	22.87	21.72	20.45	16.72
LSD	18.27	9.15	8.19	4.43	7.76	6.44	5.28	5.23	7.66	6.74	5.22	5.95	8.86	7.37
F-test	0.925	0.056	0.272	0.030	0.134	0.277	0.084	0.042	0.507	0.414	0.069	0.054	0.319	0.820

LSD for comparing means at the same level of treatment (5% level of significance): 7.53

Appendix H6: The Effect of Aeration System on Organic Matter Evolution during Composting

Treatment	Percentage Organic Matter, OM (%)													
Sampling weeks	0	1	2	3	4	5	6	7	8	9	10	11	12	14
DAT	54.41	45.48	40.88	43.97	38.33	40.07	37.9	34.43	34.10	33.20	35.19	35.24	29.75	33.79
HV	54.41	47.09	44.58	43.36	39.02	36.65	32.8	35.24	34.39	32.07	30.91	31.48	31.02	28.68
WT	54.52	50.96	44.22	44.66	42.19	40.85	41.2	36.67	37.85	36.64	35.54	35.50	35.20	34.26
FA	54.52	49.61	47.32	46.73	44.18	44.08	42.0	42.23	41.41	40.37	39.60	39.04	38.97	39.10
LSD	1.07	6.71	10.33	5.28	4.16	7.30	13.06	5.45	4.83	1.61	7.61	4.15	4.97	4.77
F-test	0.989	0.282	0.546	0.483	0.042	0.203	0.382	0.046	0.030	<0.001	0.147	0.025	0.014	0.011

LSD for comparing means at the same level of treatment (5% level of significance): 5.88

Appendix H7: The Effect of Aeration System on Carbon-Nitrogen during Composting

Treatment	Carbon-Nitrogen (C/N) ratio													
Sampling weeks	0	1	2	3	4	5	6	7	8	9	10	11	12	14
DAT	27.53	41.73	13.60	12.55	12.23	14.36	18.27	14.22	10.9	8.91	10.54	9.34	12.60	11.43
HV	27.53	27.11	13.58	16.18	11.14	12.00	12.84	13.34	13.2	8.43	8.62	7.69	18.96	10.38
WT	27.53	23.48	13.54	15.42	10.26	18.25	12.95	13.97	13.4	9.56	11.61	11.97	11.97	10.58
FA	24.71	21.43	10.56	16.94	15.51	14.71	15.04	17.95	14.7	10.22	11.38	11.36	17.29	11.78
LSD	0.99	20.28	5.77	6.00	5.99	5.05	5.21	3.69	7.26	3.22	2.74	4.91	7.79	4.01
F-pr.	<0.001	0.162	0.522	0.380	0.255	0.109	0.127	0.076	0.656	0.583	0.121	0.231	0.172	0.80

LSD for comparing means at the same level of treatment (5% level of significance): 6.54

Appendix H8: The Effect of Aeration System on Total Nitrogen Evolution during Composting

Treatment	Percentage Total Kjeldahl Nitrogen, TNK (%)													
Sampling weeks	0	1	2	3	4	5	6	7	8	9	10	11	12	14
DAT	0.97	0.85	1.68	1.29	1.69	1.29	1.30	1.14	1.60	1.85	1.80	1.79	1.06	1.32
HV	0.94	1.31	1.82	1.41	1.82	1.41	1.36	1.38	1.58	1.89	1.87	1.77	1.00	1.34
WT	0.92	0.88	1.68	1.23	1.68	1.23	1.35	1.36	1.53	1.97	1.88	1.67	1.39	1.38
FA	0.93	1.06	1.72	1.34	1.72	1.34	1.31	1.34	1.54	1.99	2.04	2.02	1.20	1.46
LSD	0.76	0.70	0.43	0.40	0.43	0.40	0.13	0.24	0.41	0.51	0.42	0.56	0.31	0.24
F-Test	0.999	0.420	0.851	0.743	0.851	0.743	0.559	0.139	0.975	0.890	0.572	0.530	0.075	0.564

LSD for comparing means at the same level of treatment (5% level of significance): 0.39

Appendix H9: Percentage Nitrogen Loss (ash-free basis) on Aeration System

	Treatment			
Week	**DAT**	**HV**	**TW**	**FA**
0	0.00	0.00	0.00	0.00
1	26.80	-19.90	11.93	0.29
2	-34.25	-59.44	-48.26	-47.85
3	-8.00	-20.81	-9.57	-16.48
4	-28.71	-44.90	-43.04	-39.54
5	-0.97	-8.02	-2.52	-7.28
6	1.90	1.52	-13.28	-1.85
7	18.41	-3.56	-5.91	-1.76
8	-13.78	-16.73	-21.23	-16.61
9	-29.98	-34.75	-52.99	-47.16
10	-30.59	-31.17	-43.26	-51.10
11	-30.01	-25.66	-27.50	-49.47
12	29.46	29.71	-5.64	14.14
14	6.62	8.51	-3.43	-5.03

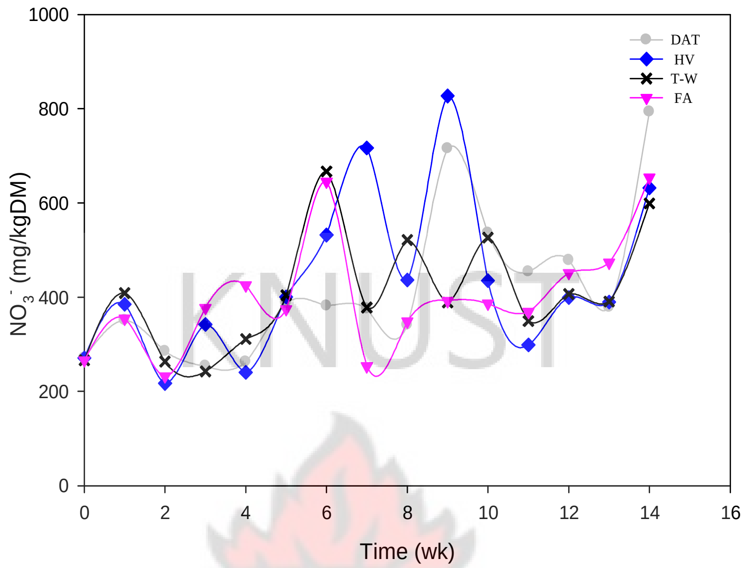
Appendix H10: Percentage Carbon Loss (ash-free basis) on Aeration System

	Treatments			
Week	**DAT**	**HV**	**TW**	**FA**
0	0.00	0.00	0.00	0.00
1	-12.14	-0.56	14.41	13.31
2	33.03	19.75	19.07	37.08
3	49.94	29.41	31.87	18.07
4	42.18	42.68	39.99	12.96
5	46.88	53.09	22.96	35.30
6	34.24	53.66	39.61	36.80
7	57.87	49.43	38.62	24.62
8	55.03	46.00	34.11	30.76
9	57.74	58.44	39.57	38.31
10	49.23	58.43	31.16	30.14
11	55.37	65.31	37.44	33.45
12	67.07	50.99	47.35	39.27
14	60.35	64.91	55.15	50.17

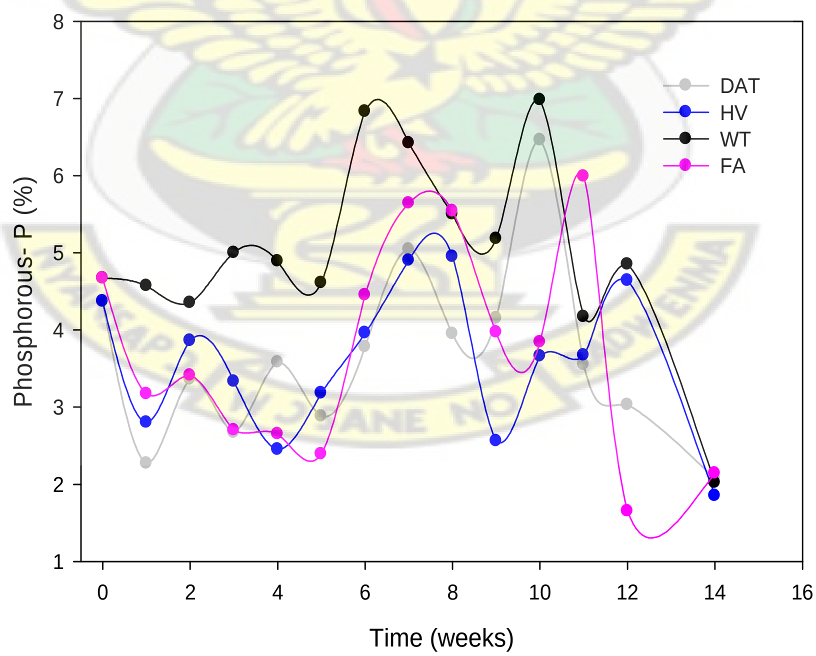
Appendix H11: Percentage OM Loss (ash-free basis) on Aeration System

	Treatment			
Week	**DAT**	**HV**	**TW**	**FA**
0	0.00	0.00	0.00	0.00
1	30.09	25.44	13.29	23.25
2	42.06	32.60	33.85	36.29
3	34.25	35.86	32.69	34.28
4	47.92	46.39	39.12	44.58
5	43.99	51.52	42.39	46.08
6	48.93	59.07	41.56	50.24
7	56.01	54.40	51.69	54.06
8	56.65	56.08	49.19	54.05
9	58.35	60.44	51.76	56.95
10	54.50	62.51	54.00	57.13
11	54.40	61.50	54.08	56.75
12	64.52	62.32	54.68	60.64
14	57.25	66.31	56.52	60.19

Appendix H12: Evolution of Nitrate during Composting Process



Appendix H13: Evolution of Available Phosphorous during Composting



Appendix I: Publications Related To Research

Appendix I1: List of Publications

Candidate's contributions to the publications: The candidate collected and analysed relevant data and wrote the papers while receiving guidance, supervision and some relevant information from co-authors for the first two conference papers. He collected and analyzed data on two composting systems presented in the paper published in the International Research Journal of Applied and Basic Sciences.

1. **Rockson, G. N. K**., & Aklaku, E. D. (2006). Evaluation of Biowaste for biogas production potential in Kumasi. In A. Bart-Plange, & A. Addo (Ed.), *Proceedings of the 3rd National Conference on Agricultural ENgineering - Engineering Ghana's Agriculture and Health for Economic Progress* (pp. 248-256). Kumasi: Ghana Society of Agricultural Engineers.
2. **Rockson, G. N. K**., Aklaku, E. D., & Quansah, C. (2008). A comparative study for co-composting of river reed in Ghana. In Proceedings of the 6th International ORBIT Conference (13 - 15th of October), Wageningen, The Netherlands
3. Kutsanedzie, F., **Rockson, G. N. K.,** Aklaku, E. D., & Achio, S. (2012) Comparisons of Compost Maturity Indicators for two Field Scale Composting Systems. *International Research Journal of Applied and Basic Sciences*. Vol. 3 (4), 713-720,