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COMPOSTING OF COFFEE HUSK and PULP and CO-DIGEST WITH OTHER ORGANIC WASTES

(THE CASE OF DALE WOREDA)

BY

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"COMPOSTING OF COFFEE HUSK and PULP WITH OTHER ORGANIC WASTES"

(THE CASE OF DALE WOREDA)

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Declaration

I, the undersigned, declare that this thesis entitled "Composting of Coffee Husk and Pulp with Other Organic Wastes " is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and that all resources of materials used for this thesis have been duly acknowledged.

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Acronyms

CD	Cow Dung
CH	Coffee Husk
CP	Coffee pulp
C:N	Carbon to Nitrogen ratio
DM	Dry Matter
dS/m	Decisiemens per meter
EC	Electrical Conductivity
EPA	Environmental Protection Agency
GI	Germination Index
MC	Moisture Content
OC	Organic carbon
OM	Organic matter
pH	Power of hydrogen
RCBD	Randomized complete block design
SNNPR	Southern Nations Nationalities and Peoples Region
TK	Total potassium
TKN	Total Kjeldahl Nitrogen
TP	Total phosphorus
US.EPA	United States Environmental Protection Authority

ABSTRACT

*Coffee processing firms generate huge amount of solid wastes (coffee pulp and husk). Because of their abundance, chemical composition and physical characteristics, these residues should be handled in an appropriate way in order to avoid environmental impact as these wastes are easily dumped in to water bodies and unsanitary landfills due to their threat to the environment. Hence, this work was undertaken to transform these waste to bio-fertilizer using windrow composting technique with the intention to alleviate environmental impacts while to produce soil conditioner. In this study, the samples were placed in (6*3) treatments in RCBD in which 6 is the treatment and 3 is the replication. coffee pulp + coffee husk (pile 1), coffee pulp + coffee husk + cow dung (pile 2), coffee pulp + coffee husk + khat waste (pile 3), coffee pulp + coffee husk + cow dung + khat waste (pile 4), coffee pulp + cow dung (pile 5) and coffee husk + cow dung (pile 6) were used to prepare compost. The compost base area was 1m^2 and 1m long (1m^{3}in volume), above 20cm height bricks bed with the composting material in layers till the height of the piles become 1m long. Essential parameters were measured during the 80 day composting. Samples were collected on days 0, 45, 80 for Physico-chemical analysis. The compost maturity tests (germination and plant bioassay) were conducted using maize (BH540). The mean physicochemical results of matured compost found within the range of acceptable limits set by most countries guidelines except total potassium content which is out of the range recommended by many countries. Mean range specific values of pH, EC, %MC, OM, TKN, TP, K and C/N ratios for matured compost were:7.85-8.2, 2.66-4.4 dS/m, 39-49.6%, 39-42.7%, 1.28-2.06%, 0.25-1.02%,0.25-1.48 and 11-20.8 respectively. While a germination index of 100%, 125%, 121%, 150%, 112.5% and 118.75% was obtained respectively which depicted the compost maturity. Parameters like OC, OM, and C/N ratio decreases throughout the composting period while other parameters like pH, EC, and plant macronutrients TN, TP and TK increases as composting process progressed till maturity.*

Comparing the compost samples, the physic-chemical characteristics, germination and plant bio-assay the compost produced by coffee residue with other organic amendment has high nutrient value which can be used effectively as bio-compost.

Key words*: coffee residue, composting, compost quality, macronutrient and Germination Index*

1. Introduction

The word “coffee” comes from the name of a region of Ethiopia where coffee was first discovered-‘Kaffa’. The name ‘Kaffa’ is inherited from the hieroglyphic nouns ‘KA’ and ‘AFA’. ‘KA’ is the name of God; ‘AFA’ is the name of earth and all plants that grow on earth. So the meaning of Koffee (Coffee) from its birth place bells on as the land or plant of God.

Botanically, coffee is belonging to the family Rubiaceae in the genus Coffea. Although the genus Coffea includes four major subsections, 66% of the world production mostly comes from Coffea arabica L. and 34% from Coffea canophora Pierre ex Froehner (robusta type) (Mekuria et al., 2004).

Ethiopia is the home and cradle of biodiversity of Arabica coffee seeds. More genetically diverse strains of C. arabica exist in Ethiopia than anywhere else in the world, which has lead botanists and scientists to agree that Ethiopia is the centre for origin, diversification and dissemination of the coffee plant (Mekuria et al., 2004).

Coffee cultivation plays a vital role both in the cultural and socio -economic life of the nation. About 25% (15 million) of the Ethiopian population depend, directly or indirectly, on coffee production, processing and marketing (Woods, 2003). Currently, Ethiopia is the leading Arabica coffee producer in Africa, the fifth largest worldwide and the tenth in coffee exports worldwide. The average annual production amounts to about 350,000 tons. The average yield is about 0.71ton/ha. Ethiopian coffee is intrinsically organic and renowned for its superior quality. Small holder farmer account for more than 95% of the total coffee produced in Ethiopia, but still traditional farming systems (UNDP, 2012). In Ethiopia, Coffee is produced under four broad production systems, i.e forest coffee (8-10%), semi forest coffee (30-35), cottage or garden coffee (50-57%) and modern coffee plantation (5%) (UNDP, 2012).

Ethiopian Coffee is processed in two different processing methods. The first one is called the dry method where the beans are dried inside the fruit. The second method called the sophisticated large scale wet method employs a more advanced technology in which the fruit is immediately removed from the beans in a serious of complex operations before the beans are dried. The aim of coffee processing (both dry and wet method) is isolating coffee beans by removing shell and mucilaginous part from the cherries. The solid residues obtained from wet and dry coffee processing is termed as coffee pulp and coffee husk respectively (Pandy et al., 2000). Dry coffee processing method is the oldest, simplest and requires little machinery. It involves drying the whole cherry and hulling (Mutua, 2000). Wet coffee processing requires the use of specific equipment installation and removal of substantial quantities of water. Soon after the harvest of the red cherry, mechanical de-huller removes the outer layer followed by the operation known as degumming, during which the mesocarp (the mucilage adhering to the endocarp) is removed. The degumming operation involves immersion of the de-hulled fruits in water for 24 hours (fermentation period). Water involved in fermentation is rich in organic matter, possess high pollutant capacity and need to be treated (Rolz et al., 1988).

The residue from dry processing is burnt while those from wet processing are dumped into rivers, both being disposed into arable land and surface water. The residue from the wet coffee processing firms particularly coffee processing effluent and discharge from the factory can cause considerable pollution to water courses (Henok et al., 2011), which are mainly the source of water not only for coffee processing but also for domestic and agricultural requirements. Use of coffee residue in agriculture is restricted and thus imposes environment problem due to the presence of polyphenols, which are considered as anti-nutritional and phytotoxic substances, such as caffeine, tannin, and organic acids (Bressani, 1979). On the other hand, these wastes contain high concentrations of biodegradable organic and minerals of plant origin, which can better be utilized by composting with other organic materials (additives) (Henok et al., 2011).

In Ethiopia soil erosion and declining of fertility is a serious problem to agricultural productivity and economic growth . Average soil removal all over the country was estimated to be about two billion tons per year (Getnet, 2008). Hence, to sustain the balance of soil fertility and reduce soil erosion, and to ensure agricultural productivity adoption of composting technology and application of environmentally amenable compost is quite essential. Growing concerns relating to land degradation, threat to eco-systems from either or inappropriate use of inorganic fertilizers causes atmospheric pollution, soil health, soil biodiversity, and sanitation have rekindled the global interest in organic recycling practices like composting (Getnet, 2008).

Composting is one of the technologies of integrated waste management strategies, used for the recycling of organic materials in to a useful product. It can be defined as the biological decomposition of waste organic matter into a humus-like, stable product under controlled, aerobic conditions (Epstein E., 1997). The term “controlled” indicates that the process is managed and optimized to decompose potentially putrescible organic matter into a stable product that may be used for soil improvements, and to disinfect organic wastes from pathogens and weed seeds (Epstein E., 1997). The application of compost to agricultural land is a practice which is gaining importance particularly due to its beneficial properties in improving soil fertility and plant growth, and contributing in reducing the potential of erosion and desertification. Compost is applied to soils to maintain or increase the organic matter content of the soil, resulting in improved moisture and temperature characteristics and an increased biological activity . The major reasons for applying compost are to provide plants with a supply of nutrients in a stable organic form; to make soil more porous, allowing water, air and plant roots to penetrate more readily; and to improve the water retention capability of soil (Epstein 1997).

During composting organic matter from the raw products is microbiologically degraded, resulting in a final product containing more or less stabilized carbon, nitrogen and other nutrients in the organic fraction (Getnet, 2008). The composting process is currently viewed primarily as a waste management method to stabilize organic waste, such as manure, yard trimmings, municipal bio-solids, and organic urban wastes. Composting process can be carried out using different methods like windrow, in-vessel, static pile, aerated pile and vermicomposting (Tchobanoglous et al, 1977).

Using compost for soil amendment can be economically feasible and environmentally sound under Ethiopian conditions where soil degradation is severe and low external input agriculture is common practice due to socio economic situations of the smallholder farmers. The production of inorganic fertilizer demands much energy and generates considerable greenhouse gas emissions and chemical mixed liquid wastes. It is estimated that fertilizer production consumes approximately 1.2% of the world’s energy and is responsible for 1.2% of the total greenhouse gas emissions (Wood and Cowie,2004).

Dale woreda is located about 330 Km south of Addis Ababa on the Ethio-Kenya road. The woreda is sub divided in to 76 PAs and has a total area of 1,411 Km^2. In dale altitude ranges from 1170 around Lake Abaya in the west to about 3200 in the east. The district is found in Sidama zone, Southern Nations, Nationalities and Peoples Regional State (SNNPR). In the District, most farmers (96 %) are growing coffee as the main source of income. Maize, enset, teff, sorghum and haricot bean are also cultivated mainly as alternative food source and market sale. The Sidama Zone Agriculture and Rural Development Bureau, in 2009 reported that about 13,421 tons of coffee was produced in Sidama zone in the year 2008. This represents about 12.6% of SNNPRs output and 4.4% of Ethiopia's total output. Coffee is an important cash crop in Dale district covering 15.35 square kilometers planted with crops. In 2005 E.C. a total of 59111.6 quintals of washed and 112499.56 quintals of unwashed coffee were produced and traded in Dale district. The average coffee product both washed and unwashed (jenfel) traded from 2006/07-2012/13 by the primary coffee producer farmer cooperatives and individual traders in the district. According the data 1,824,209 and 1,414,437.7 quintals of washed and unwashed coffee were traded by cooperatives respectively and 2,685,469.14 and 669,897.7 quintals of washed and unwashed coffee were traded by individual coffee traders respectively (WARD, 2013).

Major and medium growing districts contain an estimated 800,000 coffee farmers with approximately 520,000ha under coffee cultivation, of which 35.9 percent in SNNPR. Smallholder producers are responsible for about 95 percent of production, while state-owned plantations account for 4.4 percent and private investor plantations 0.6 per cent. In SNNPR total area of 186,000 hectares of land is covered with coffee trees (ECX, 2009). This huge potential of coffee production of the woreda in turn results in the discharge of coffee processing wastes from processing firms.

The main aim of this study is composting of this wastes with other organic amendments and to evaluate the physicochemical quality of compost in terms of its major plant nutrients (N-P-K), C:N ratio, power of hydrogen, salt level, moisture content and organic matter content made from coffee processing wastes with other additives using windrow composting system due to its simplicity for practical applicability and control of process odours and nuisance free from environmental perspectives.

1.2 Statement of the problem

The number of coffee processing firms in the country has increased in recent years due to the higher market price for processed coffee, which in turn has resulted in the generation of huge amounts of processing wastes and is mainly dumped in to water bodies and unsanitary landfills. This poses threat to the environment because of unsafe disposal of coffee pulp, husk and effluent leading to pollution of water and land around the processing firms.

Dale district is one of the districts in SNNPR which has the potential of producing huge amount of coffee processing wastes every year (around 1,342,146 Kg of processing wastes), and the problem of solid waste management in the district is not anything different. The inability of the municipality to pursue the use of high technologies to handle the solid waste generated, coupled with poor enforcement or non-existence of waste management by laws have resulted in the dependence of primitive disposal methods such as landfilling (not-engineered) and discharge in to forests and rivers in which the mucilage affects aquatic way of life. In the woreda there is no any treatment technology for this amount of generated waste from the firms.

Due to large volume of waste that goes to the landfill and rivers Uncontrolled biodegradation is taking place at the dumping site and it causes leachate which highly affects both ground and surface water resources and emission of greenhouse gases. Moreover they cause an offensive odour and attract flies which are disease causing microorganisms.

This triggers the need to find a sink for this growing amount of waste. So it is prudent to look for alternative treatment options beyond the land filling to handle solid waste generated from these firms. The present study seeks to examine the possibility of using composting to manage the solid waste and produce valuable organic fertilizer which is the corner stone of organic farming.

1.3. Objectives

1.3.1 General Objective

The general objective of this study is composting of coffee processing wastes with the intention to alleviate environmental impacts while to produce soil conditioner using windrow composting techniques.

1.3.2 Specific Objective

The specific objective include

- To characterize the physic-chemical composition of the wastes.
- To determine the weight ratio composition of the wastes.
- To determine the composting process at different stage of composting.
- Characterization of the compost including determination of N-P-K content of the final product.
- Optimization of the composting process by controlling parameters that affect the quality of compost.
- To see the effect of compost on plants.

2. Literature Review

2.1 Coffee Processing

Coffee berries are harvested from late August to December. The berries are harvested up on reaching maturity, which is indicated by an intense dark red colour of the fruit (Braham and Bressani, 1979). After picking of coffee cherries (Fig. 1), the fruit has to undergo several processing steps in order to remove the outer parts of the fruit, i.e. Skin (exocarp), pulp (mesocarp), the mucilage layer and the endocarpal parchment (Von Enden and Calvert, 2002). There are essentially two ways of processing coffee beans from the freshly picked red cherries of the coffee plant: wet and dry processing. Each process produces a different quality of "green coffee" and residues with very different characteristics (Yishak et al,.2009).

2.1.1 Dry Processing Method

In the case of the dry method, the air–dried coffee berry is subjected to mechanical friction, whereby the coffee bean is separated from the other fractions of the coffee berry. The most simple and least polluting way of processing is the dry method. In this method, the cherries are picked and left in the sun until the whole fruit reaches a moisture content of around 11% (Mutua, 2000) and is mostly applied for Robusta coffee (Adams and Dougan, 1987).

A mass of 100 kg of red cherries picked at 65% moisture content will result in approximately 40 kg of sun-dried coffee cherries delivered to the processing plant. Of this mass, about 17 kg will become sun-dried coffee beans while the remaining 23 kg will end up as residue at the processing plant (Yishak et al,.2009).

2.1.2 Wet Processing Method

In the case of wet method, the berry are transported and filled in to the either a dry feed cemented tank or wet fed siphon pipe. The pulper separates the bean from the pulp through mechanical squeezing. The pulp and the bean are carried to different compartment with a sieve system supported by a continuous flow of water. The pulp, which is carried away with running water, accumulates in some catches along the course of the water. The coffee beans that are still covered with the mucilage and parchment are fermented for about 2-3 days in order to break down the mucilage which is eventually washed away with water. After the removal of the mucilage, the beans are dried before they are hulled to remove the parchment, the third by- product of the total process. The proportion of the fractions of the coffee berry is about 45% pulp, 10% mucilage, 5% parchment and 40% beans on a fresh weight basis (Gohl, 1981). The way of processing determines the quality of the end product (Mutua, 2000).

The average residue production per tonne of wet red cherry is about 600 kg or, based on green coffee bean production, the residue potential would be 1.4 times the mass of green beans produced (Yishak et al,.2009).

2.2 Residue Availability for compost production

Most of the coffee production areas and processing plants in Ethiopia are found in the southern and eastern parts of the country, notably in the Southern Nations, Nationalities and People's Region (SNNPR) and in Oromia, which each host more than 500 coffee processing plants.

With increasing participation of the private sector both in production and export, the production of coffee and coffee arrivals at coffee processing stations has increased over recent years. The total volume of coffee supply to the official market is estimated to be about 160,000 tonnes per year. However, it is estimated that a considerable amount of coffee is also traded illegally and total coffee production could be as high as 250,000 tonnes per year. Considering the lower production figure, the corresponding annual coffee residue production would be at least 200,000 tonnes.

Currently, the wet pulp is discharged into local streams and rivers where it tends to clog, forming a putrescent mass and producing a highly acidic effluent which pollutes the water, destroying aquatic life and generating an offensive odour. Table 2.1 shows the regional distribution of coffee residues in Ethiopia (Yishak, S et al., 2009).

Table 2.1 Regional Distribution of Coffee Residues

Process	Location	Green Coffee (tonnes/year)	Coffee Residue (tonnes/year)	Number of processing plants
Dry process	SNNPR	35,060	49,496	113
	Oromia	94,145	132,911	273
	Gambela	1,033	1,458	2
	Others	112	158	-
Wet process	SNNPR	16,533	20,006	309
	Oromia	6,959	8,421	189
	Gambela	1,519	1,838	6
	Others	8	10	-
Grand Total		155,369	214,299	892

Source: Yisehak,S 2009

This indicates that Ethiopia is reach in biomass which can be used as a bio-fertilizer through processing of the waste by transforming in to usable form.

2.3 Basic composting principles

Composting is the manipulation or control of the natural decomposition of organic matter. It requires optimizing the conditions for the mixed population of microorganisms (mainly bacteria, fungi and actinomycetes) responsible for the decomposition. These microbes, normally found on the surface of leaves, grass clippings and other organic materials, thrive in a warm, moist, aerobic (oxygen rich) environment (Archer et al., 2009).

During decomposition, the microorganisms multiply and liberate carbon dioxide (CO_2), water, other organic products and energy. Some of the energy is used in metabolism and the remainder is given off as heat (Figure 2.1). Eventually, the readily-available food supply is exhausted, microbial growth and heat generation decrease, and a humus-like material remains. This material is called compost (Archer et al., 2009).

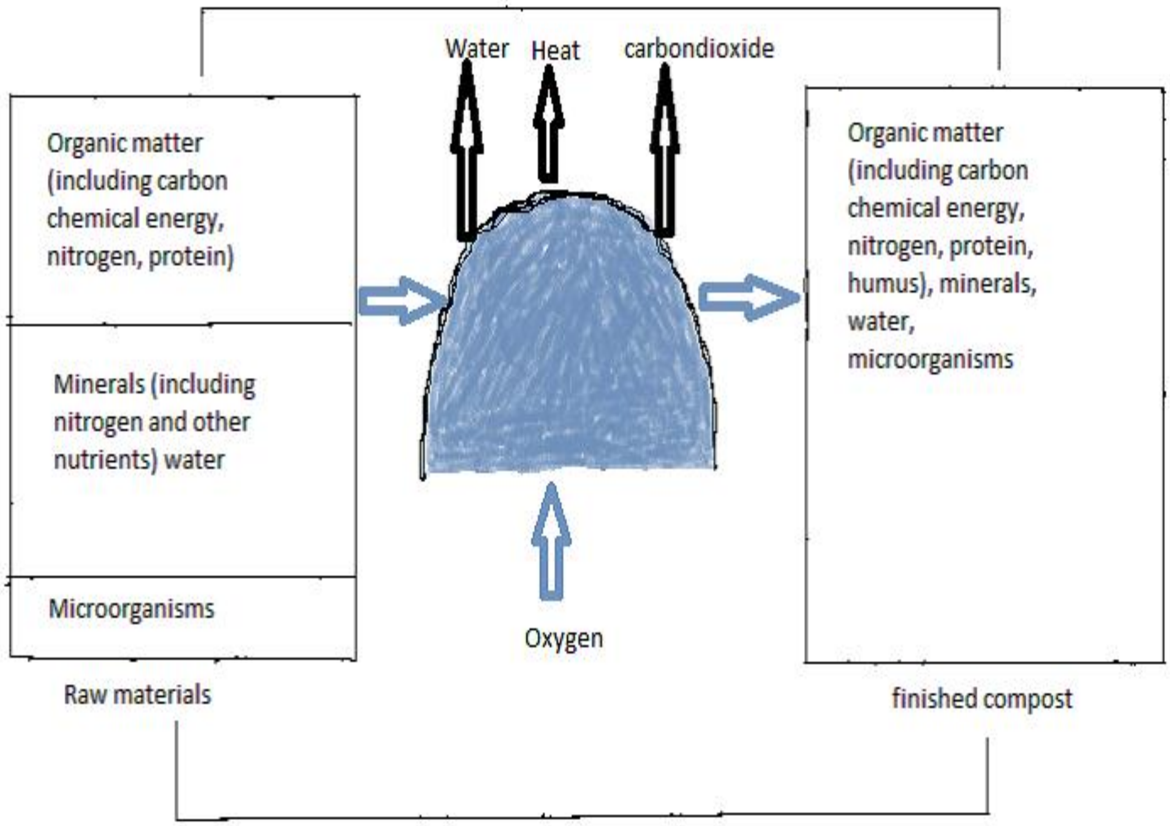

Figure2.1 Composting Process (Reprinted with permission from On-Farm Composting Handbook, NRAES, 1992.)

2.4 The role of microorganisms

Composting is a succession of microbial activities where by the environment created by one group of microorganisms invites the activity of successor groups. Different types of microorganisms are therefore active at different times in the composting pile. Bacteria have the most significant effect on the decomposition process, and are the first to take hold in the composting pile processing readily decomposable nutrients (primarily proteins, carbohydrate and sugars) faster than any other type of microorganism (US.EPA, 1994).

Fungi, which compete with bacteria for food, play an important role later in the process as the pile dries, since fungi can tolerate low moisture environments better than bacteria. Some types of fungi also have lower nitrogen requirements than bacteria and are therefore able to decompose cellulose materials, which bacteria cannot.

Microorganisms also play a role in composting process. Rotifers, nematodes, mites, springtails, sowbugs, beetles and earthworms reduce the size of composting feedstock by foraging, moving in the compost pile or chewing the composting materials. These actions physically breakdown the materials, creating greater surface area and sites for microbial action to occur (US.EPA, 1994).

The bacteria and fungi important in decomposing the feedstock material can be classified as mesophilic and thermophilic. Mesophilic microorganisms or mesophiles (those that grow best at temperatures between 25 and 45^{0}C (77 to 113^{0}F) are dominant throughout the composting mass in the initial phases of the process when temperatures are relatively low. These organisms use available oxygen to transform carbon from the composting feedstock to obtain energy, and, in so doing, produce carbon dioxide (CO_2) and water. Heat also is generated as the microorganisms metabolize the composting feedstock. As long as the compost pile is of sufficient size to insulate internal layers from ambient temperatures and no artificial aeration or turning occurs most of the heat generated by the microorganisms will be trapped inside the pile. In the insulated center layers, temperatures of the composting mass will eventually rises above the tolerance levels of the mesophilic organisms. When the temperatures reach toward 45^{0}C (113^{0}F), mesophiles die or become dormant, waiting for conditions to reverse.

At this time, thermophilic microorganisms or thermophiles (those that prefers temperatures between 45 and 70^{0}C (113 and 158^{0}F) become active, consuming the materials readily available to them, multiplying rapidly, and replacing the mesophiles in most sections of the composting pile. Thermophiles generate even greater quantities of heat than mesophiles, and the temperatures reached during this time are hot enough to kill most pathogens and weed seeds. Many composting facilities maintain a temperature of 55^{0}C (131^{0}F) in the interior of the compost pile for 72 hours to ensure pathogen destruction and to render weeds in viable.

The thermophiles continue decomposing the feedstock materials as long as nutrient and energy sources are plentiful. As these sources become depleted, however, thermophiles die and the temperature of the pile drops. Mesophiles then dominate the decomposition process once again until all readily available energy sources are utilized (US.EPA 1994).

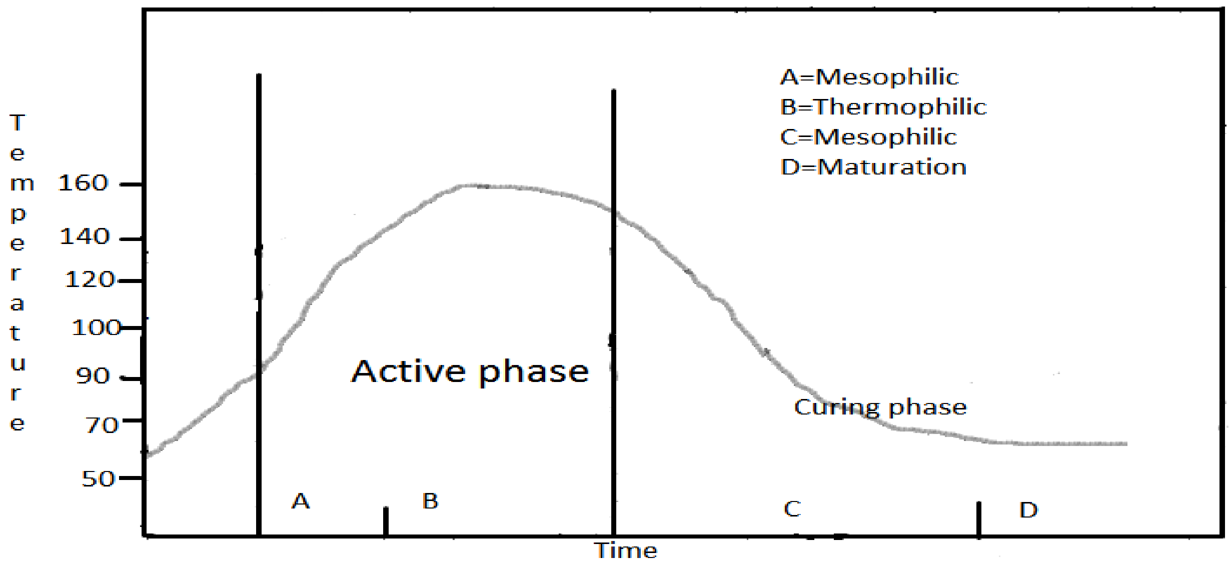

Fig 2.2 Temperature changes in an average compost pile

2.5 Composting methods

Composting can be carried out in a number of different ways, including static piles, passive aerated windrows, aerated static pile, in-vessel, pit, vermicomposting and windrows systems (Christian et al., 1997). Each method is summarized below for comparison.

2.5.1 Static Piles

This is the oldest and most common form of composting manure, yet it is also the least effective. The static pile, as the name suggests, is simply a pile of raw materials, except none of the conditions affecting the composting process are actively controlled. This method works best when bedding, such as straw or sawdust and is used as a bulking ingredient, thus increasing the carbon to nitrogen (C:N) ratio of the manure and decreasing the moisture content. It is recommended that piles not exceed six feet high (1.86 m) and twelve feet wide (3.7 m), which allows air to move through the pile (Rynk, 1992). This method of composting is slow, increases the chance of odors, and usually yields an inferior product.

2.5.2 Aerated Static Pile

In this method, air is forced through the compost pile by a blower. These piles are five to eight feet high (1.6 to 2.5 m) and seventy to ninety feet long (21.7 to 27.9 m). With this technique the pile is not turned and is again formed over a bed of wood chips or chopped straw which contains the perforated aeration pipe. The pipe is connected to a blower that either pushes or pulls air through the pile. The pile need to be covered with fresh composted manure to maintain moisture, reduce heat loss, and to minimize flies and odors, while also filtering out some ammonia (Rynk, 1992).

2.5.3 Windrow Composting

This is a relatively simple process that involves placing a mixture of manure and bulking materials into windrows or piles that are turned regularly. Windrow composting consists of placing the mixture of raw materials in long narrow piles called windrows that are agitated or turned on a regular basis (Rynk, 1992). The turning operation mixes the composting materials and enhances passive aeration. Typically, the wind-rows are from 0.9 m high for dense materials such as manures to 3.60 m high for light, voluminous materials such as leaves (FAO, 2003).

Windrows aerate primarily by natural or passive air movement (convection and gaseous diffusion). The rate of air exchange depends on the porosity of the windrow. Therefore, the size of a windrow that can be aerated effectively is determined by its porosity. A windrow of leaves can be much larger than wet windrow containing manure. Where the windrow is too large, anaerobic zones occur near its center. These release odours when the windrow is turned. On the other hand, small windrows lose heat quickly and may not achieve temperatures high enough to evaporate moisture and kill pathogens and weed seeds (Martin, 1991; FAO, 2003). For small- to moderate-scale operations, turning can be accomplished with a front-end loader or a bucket loader on a tractor or manually using forks.

The frequency of turning depends on the rate of decomposition, the moisture content and porosity of the materials, and the desired composting time. Because the decomposition rate is greatest at the start of the process, the frequency of turning decreases as the windrow ages. Turning releases trapped gases, water vapor, and excessive heat that may exist in the compost mixture (Rynk, 1992). With the windrow method, the active composting stage generally lasts three to nine weeks depending upon the nature of the materials and the frequency of turning.

2.5.4 In-Vessel system

These include bin composting, rectangular agitated bins, and silos. In-vessel composting system was first developed by Becari and modified by Verdier and Bordas, and latter several such systems have been developed (Gotaas, 1956). The main advantage of this system is process rapidity, low land requirement, complete process control and consistency of end-product. The main feature of in-vessel composting systems is that the compost materials are mixed and the mass advanced and aerated automatically and mechanically. In-vessel methods confine the compost mixture to buildings, containers or vessels, and tend to rely on numerous forced aeration and mechanical turning methods which accelerates the composting process (Rynk, 1992). In-vessel composting is both very sophisticated and expensive, and relatively uncommon despite its good results. They are costly to install and operate, and need intensive and skillful management.

2.5.5 Vermicomposting

The term vermicomposting means the use of earthworms for composting organic residues. Earthworms can consume practically all kinds of organic matter and they can eat their own body weight per day, e.g. 1 kg of worms can consume 1 kg of residues every day (Mathur et al., 1989). The excreta (castings) of the worms are rich in nitrate, available forms of P, K, Ca and Mg. Common worm species for this type of composting are Eisenia foetida and Lumbricus rubles. These are sometimes called "red wigglers" or manure worms. These worms are added to the feedstock materials to assist in the decomposition of the organic matter and transform it into worm castings.

2.5.6 The pit method

Composting can be carried out in a circular or rectangular pit. Crop residue, animal manure, aquatic weeds or green manure crops are used and often silt pumped from river beds is mixed with the crop residues. The pits are filled layer by layer, usually, the first layer is of a green manure crop or water hyacinth, the second layer is a straw mixture and the third layer is of animal dung (FAO, 2003). These layers are alternated until the pit is full, when a top layer of mud is added; a water layer of about 4 cm depth is maintained on the surface to create anaerobic conditions which help to reduce losses of nitrogen. Three turnings are required, the first after a month of piling, the second after another month and thirdly after two weeks of turning.

2.6 Choosing Composting Method

The choice of composting technology depends on the location of the compost site and the amount of specialized equipment available to produce compost. The location of composting site is important from environmental impact and potential nuisance perspectives (US.EPA, 1994). Composting sites located in rural-urban and urban areas often are forced to use high technology options to minimize nuisance complaints. The decisions about technology options and management intensity can be viewed as a continuum. Low technology options usually go hand-in-hand with minimal management. Examples include static, passively aerated piles where you would use dry and large particle size feedstock to give the compost pile sufficient porosity. These options make the most sense for individuals in rural areas making compost largely for their own use.

Intermediate technology - moderate management intensity includes turned windrow composting using non-specialized equipment. The most common example is building and turning piles using a manure spreader. High technology options usually include specialized composting equipment: tractor-pulled or self-propelled windrow turners, forced aeration systems with perforated pipes and blowers and enclosed (or in-vessel) systems. These require serious financial and labor commitments. Use of these technologies are justified when the composter intends to make a saleable product and when the compost site is located either on the rural-urban boundary or within an urban setting.

Generally, composting using pit and static piles is slow and potentially more problematic while in-vessel systems need more management and design requirements are frequently too expensive for typical on-farm composting facilities. The most practical systems for on-farm composting are usually the turned windrows, aerated pile or aerated bin composting systems. Due to its simplicity in management and non-requirement of specialized equipment I prefer turned windrow system for this research work.

2.7 Composting of Coffee Residue

In coffee producing areas, large quantities of coffee wastes are problems. The fermenting piles give off unpleasant smells; breed flies and pollute waterways. Coffee waste is a good fertilizer as it is rich in organic matter, nitrogen and potassium. Some growers spread the heavy wet pulp on their coffee plantations but there can be problems with transport and spreading and this can lead to smells and plant growth problems. It is much better to compost the material first so that it can be used more effectively.

This dense material needs good aeration so a number of above-ground, elevated heaps should be constructed. These elevated heaps need to be roofed or covered to stop too much water from entering the compost heap. The elevated floor can be made of bamboo poles mounted on bricks or stones.

Before composting, the pulp needs to be drained and loaded into the heap to a height of about one meter. Vegetable waste can be mixed in if available as well as some soil or compost. This is to obtain the right micro-organisms that decompose the waste (madeleine et al,. 2005).

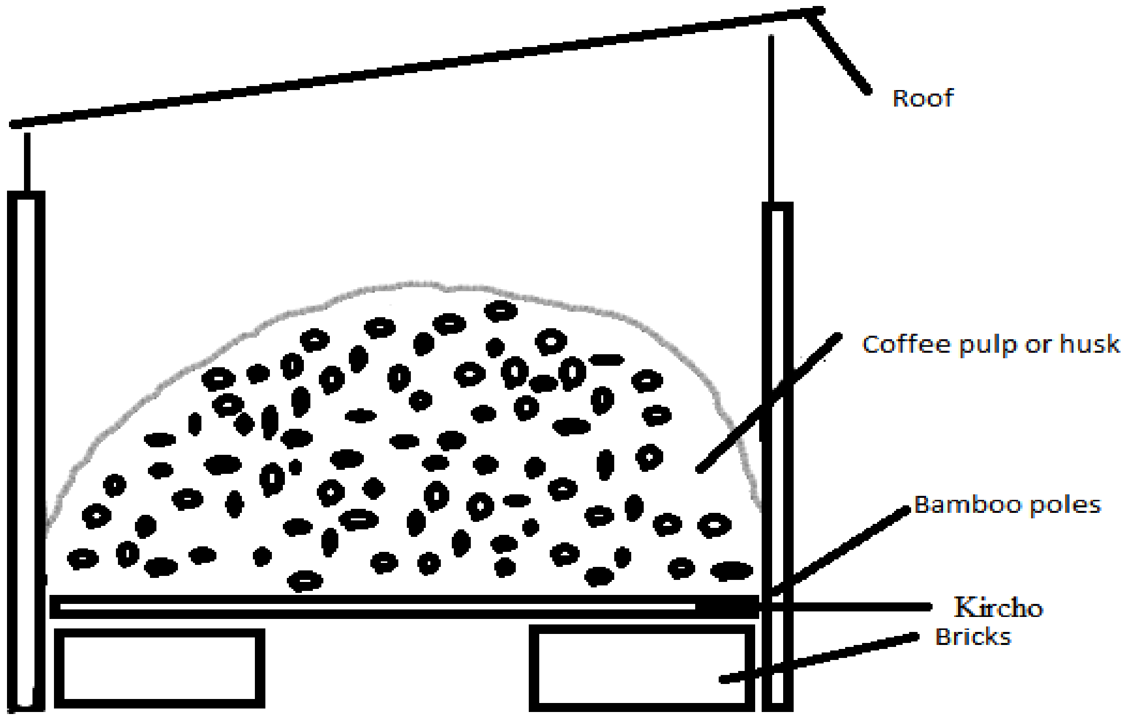

Fig.2.3 Elevated compost heap (Source: HDRA)

2.8 Factors affecting the composting process

The compost pile must be monitored and the appropriate adjustments must be made throughout the composting period. This is necessary to sustain a high rate of aerobic microbial activity for complete decomposition with a minimum of odors as well as maximum destruction of pathogens, larvae, and weed seeds. Microorganisms are essential to composting, so environmental conditions that maximize microbial activity will maximize the rate of composting. Microbial activity is influenced by oxygen level, particle size of the feedstock material, nutrient levels and balance (indicated by carbon-to-nitrogen ratio), moisture content, temperature and acidity and alkalinity (PH). These basic considerations apply no matter which technology is used. Any changes in these factors are interdependent; a change in one parameter can often result in changes in others (US.EPA 1994).

2.8.1 Particle size

The particle size of the feedstock affects the composting process. The size of feedstock materials entering the composting process can vary significantly. In general, the smaller the shreds of composting feedstock, the higher the composting rate. Smaller feedstock materials have greater surface areas in comparison to their volumes. This means that more of the particle surface is exposed to direct microbial action and decomposition in the initial stages of composting. Smaller particles within the composting pile also result in a more homogeneous mixture and improve insulation (Gray et al., 197l b). Increased insulation capacity helps maintain optimum temperatures in the composting pile. At the same time, however, the particles should not be so small as to compact too much, thus excluding oxygen from the void spaces. Thus it is important to shred the feedstock materials before the beginning of composting to proper size to have a good porosity which allow ventilation and enhance microbial activity.

2.8.2 Temperature

Temperature is a critical factor in determining the rate of decomposition that takes place in a composting pile. composting temperatures largely depend on how the heat generated by the microorganisms is offset by the heat lost through controlled aeration, surface cooling, and moisture losses (Richard, 1992a). The most effective composting temperatures are between 45 and 59°C (113 and 138°F) (Richard, 1992a). If temperatures are less than 20^{o} C (68°F), the microbes do not proliferate and decomposition slows. If temperatures are greater than 59°C (138°F), some microorganisms are inhibited or killed, and the reduced diversity of organisms results in lower rates of decomposition (Finstein et al., 1986; Strom, 1985). Microorganisms tend to decompose materials most efficiently at the higher ends of their tolerated temperature ranges. The rate of microbial decomposition therefore increases as temperatures rise until an absolute upper limit is reached. As a result, the most effective compost managing plan is to maintain temperatures at the highest level possible without inhibiting the rate of microbial decomposition (Richard, 1992a; Rynk et al., 1992).

2.8.3 Oxygen

Composting can occur under aerobic or anaerobic conditions, but aerobic composting is much faster (10 to 20 times faster) than anaerobic composting (EPA, 1994). Anaerobic composting also tends to generate more odorous because gases such as hydrogen sulfide and amines are produced. Methane also is produced in the absence of oxygen. Microorganisms important to the composting process require oxygen to break down the organic compounds in the composting feedstock. Without sufficient oxygen, these microorganisms will diminish, and anaerobic microorganisms will take their place. To support aerobic microbial activity, void spaces must be present in the composting material. These voids need to be filled with air. Oxygen can be provided by mixing or turning the pile, or by using forced aeration systems. The amount of oxygen that needs to be supplied during composting depends on the stages of the process and the type, particle size and moisture content of the feedstock (Lorrine, 2003).

2.8.4 Nutrient levels and Balance (C:N ratio)

For composting to proceed efficiently, microorganisms require specific nutrients in an available form, adequate concentration, and proper ratio. The essential macronutrients needed by microorganisms in relatively large amounts include carbon (C), nitrogen (N), phosphorus (P), and potassium (K). Microorganisms require C as an energy source. They also need C and N to synthesize proteins, build cells, and reproduce. P and K are also essential for cell reproduction and metabolism. In a composting system, either C or N is usually the limiting factor for efficient decomposition (Richard, 1992a). Composting organisms also need micronutrients, or trace elements, in minute amounts to foster the proper assimilation of all nutrients. The primary micronutrients needed include boron, calcium, chloride, cobalt, copper, iron, magnesium, manganese, molybdenum, selenium, sodium, and zinc (Boyd, 1984). While these nutrients are essential to life, micronutrients present in greater than minute amounts can be toxic to composting microorganisms. Even if these nutrients are present in sufficient amounts, their chemical form might make them unavailable to some or all microorganisms. The ability to use the available organic compounds present depends on the microorganism's "enzymatic machinery" (Boyd, 1984). Some microorganisms cannot use certain forms of nutrients because they are unable to process them. Large molecules, especially those with different types of bonds, cannot be easily broken down by most microorganisms, and this slows the decomposition process significantly. As a result, some types of feedstock break down more slowly than others, regardless of composting conditions (Gray et al., 1971a). For example, lignin (found in wood) or chitin (present in shellfish exoskeletons) is very large, complex molecules and is not readily available to microorganisms as food. These materials therefore decompose slowly.

The C:N ratio is a common indicator of the availability of compounds for microbial use. The measure is related to the proportion of carbon and nitrogen in the microorganisms themselves. High C:N ratios (i.e., high C and low N levels) inhibit the growth of microorganisms that degrade compost feedstock. Low C:N ratios (i.e., low C and high N levels) initially accelerate microbial growth and decomposition. With this acceleration, however, available oxygen is rapidly depleted and anaerobic, foul-smelling conditions result if the pile is not aerated properly. The excess N is released as ammonia gas. Extreme amounts of N in a composting mass can form enough ammonia to be toxic to the microbial population, further inhibiting the composting process (Gray et al., 1971b; Haug, 1980). Excess N can also be lost in leachate, in either nitrate, ammonia, or organic forms (Richard, 1992b).

2.8.5 Moisture

The moisture content of a composting pile is interconnected with many other composting parameters, including moisture content of the feedstock, microbial activity within the pile, oxygen levels, and temperature. Microorganisms require moisture to assimilate nutrients, metabolize new cells, and reproduce. They also produce water as part of the decomposition process. If water is accumulated faster than it is eliminated via either aeration or evaporation (driven by high temperatures), then oxygen flow is impeded and anaerobic conditions result (Gray et al., 1971 b). This usually occurs at a moisture level of about 65 percent (Rynk et al., 1992). Water is the key ingredient that transports substances within the composting mass and makes the nutrients physically and chemically accessible to the microbes. If the moisture level drops below about 40 to 45 percent, the nutrients are no longer in an aqueous medium and easily available to the microorganisms. Their microbial activity decreases and the composting process slow. Below 20 percent moisture, very little microbial activity occurs (Haug, 1980). So, it is important to control the moisture content of the pile by adding water on the pile when it decreases and turning the pile when it increases, because microorganisms will thrive in an aqueous environment which will lead to a faster degradation.

2.8.6 Acidity/Alkalinity (pH)

The pH of a substance is a measure of its acidity or alkalinity (a function of the hydrogen ion concentration), described by a number ranging from 1 to 14. A pH of 7 indicates a neutral substance, whereas a substance with pH level below 7 is considered to be acidic, and a substance with a pH higher than 7 is alkaline. Bacteria prefer a pH between 6 and 7.5. Fungi thrive in a wider range of pH levels than bacteria, in general preferring a pH between 5.5 and 8 (Boyd, 1984). If the pH drops below 6, microorganisms, especially bacteria, die off and decomposition slows (Wiley, 1956). If the pH reaches 9, nitrogen is converted to ammonia and becomes unavailable to organisms (Rynk et al., 1992). This too slows the decomposition process.

Like temperature, pH levels tend to follow a successional pattern through the composting process. Most decomposition takes place between pH 5.5 and 9 (Rynk et al., 1992; Gray et al., 197 lb). During the start of the composting process, organic acids typically are formed and the composting materials usually become acidic with a pH of about 5. At this point, the acid-tolerating fungi play a significant role in decomposition. Microorganisms soon break down the acids, however, and the pH levels gradually rise to a more neutral range, or even as high as 8.5. The role of bacteria in composting increases in predominance again as pH levels rise. If the pH does not rise, this could be an indication that the compost product is not fully matured or cured.

2.9 Quality of Compost

Various parameters, which may have a significant influence on compost quality, are discussed below.

2.9.1 pH

The pH value of compost is important, since applying compost to soil may alter the soil pH and therefore have an effect on the availability of nutrients to plants. As cited in Bord na Mona (2003) recommends a range of pH from 6.9-8.3. Efforts will need to be made to lower the pH of compost if it exceeds this range. If it is so, adding additional organic matter or composted material will reduce the pH, in the meantime ammonia volatilization of ammonia and odour problems will be reduced.

2.9.2 Organic Matter

Organic matter is an important ingredient in all soils and has an important role to play in maintaining soil structure, nutrient availability and water holding capacity. It is usually expressed as a percentage of dry weight. There is no absolute value of organic matter, which is ideal for compost. It may range from 30-70% (US Composting Council, 2003). I suggest that this figure is extremely important for the compost quality, in which I proved that compost having values between these range is problem free for plants, which enhance plant growth and development.

2.9.3 Moisture Content

Moisture content is a measure of the amount of moisture present in a compost sample and is expressed as a percentage of fresh weight. Compost with low moisture content (<35%) may be too dry and dusty and irritating when handled. Compost with too high a moisture content (>65%) can become too clumpy and difficult to transport which will limit its chances of being marketed as a quality product (US Composting Council, 2003).

2.9.4 Electrical Conductivity

Conductivity is the measure of a solutions ability to carry electrical charge, that is, a measure of the soluble salt content of compost. The salt content of compost is due to the presence of sodium, chloride, potassium, nitrate, sulphate and ammonia salts (Brinton, 2003). Some soluble salts may be detrimental to plants whereas, other plant nutrients supplied to plants exist in salt form and are essential for plant growth. Though excessive amounts of soluble salts in compost used in growing media or applied to the land may inhibit crop growth and affect crop yield (Barker, 1997). Herity, (2003) report that the recommended range for conductivity in compost is between 2-6 mS/cm.

2.9.5 C:N Ratio

The C:N ratio is not a test within itself, it is rather a test for organically bound carbon and for total nitrogen. The ratio of these two can be used to provide an indication of the rate of decomposition of the feedstock and to determine when ripeness has been reached. Therefore, C:N ratios should be used in conjunction with some other relevant parameter for testing compost maturity (Wood End Research Laboratory, 1998). The EPA acknowledges this and specifies within a waste licence that the C:N ratio of compost must be below 25.

2.9.6 Nutrient Content of Compost

Nitrogen, phosphorous and potassium are the nutrients, which are utilised, in the greatest quantities by plants. Knowledge of the nutrient content of compost is important because the nutrient content of compost can vary widely and also because it allows facility operators to determine an appropriate end use for the compost. In general, nutrients are organically bound within compost and are slowly released over a period of time as a result of microbial activity. This ensures a continuous supply of nutrients to the plant (US Composting Council, 2003). Total nutrient content is usually expressed as a percentage on a dry weight basis.

2.9.6.1 Nitrogen

Nitrogen is an essential nutrient for successful plant production. The concentration and availability of nitrogen in compost is a very important factor to be assessed when considering its agronomic value. Körner and Stegmann (2003) state that certain parameters such as pH, temperature and moisture significantly influence the rate of nitrogen turnover from proteins in bio-waste to inorganic and organic forms. They found that the highest concentration of ammonia could be measured during the thermophilic stage while mature compost contains more nitrogen in the inorganic form as NO_3-N. Hence, by regulating the composting process, compost with a more predictable nitrate content can be produced.

To report compost as having fertilising capabilities and for it to be used in agriculture the TN content must be over 1%, dry weight (Barker, 1997). If compost contains TN of less than 1%, supplemental nitrogen fertiliser will be required if the compost is to be used as a soil improver or in potting media. If the TN in compost is approximately 0.6% or less there is a chance that nitrogen immobilisation will occur. Thus, compost with low TN levels is better used as mulch (Barker, 1997). The typical range of TN in compost is 1.0-3.0%, dry wt. Compost over 3% TN is usually found to be immature and ammoniacal (Barker, 1997).

2.9.6.2 Phosphorous

Phosphorous is also an important nutrient for plant growth. Phosphorus is essential for cell reproduction and metabolism. Total phosphorous (TP) is usually expressed in terms of percentage concentration per dry weight. According to Bord na Mona (2003) the range of TP is usually between 0.4 - 1.1%, dry wt for bio-waste and green waste compost.

2.9.6.3 Potassium

Potassium is a very abundant nutrient in plants. Potassium in its available form in compost exists as K_2O. The amount of potassium in compost depends on the feedstock but also on the composting process (Barker, 1997). Compost usually does not contain a great concentration of potassium because due to its high water solubility it can be easily leached from the feedstock during the composting process. Bord na Mona (2003) state that as cited in Herity, (2003), the typical range of total potassium (TK) in bio-waste and green waste compost is between 0.6-1.7%, dry weight.

2.9.7 Maturity and Stability

Compost stability/maturity is increasingly recognised as an important characteristic. In specific situations, immature, poorly stabilised composts may be problematic. Continued active decomposition when these composts are added to soil or growth media may have negative impacts on plant growth due to reduced oxygen in the soil-root zone, reduced available nitrogen, or the presence of phytotoxic compounds. Consequently, tests have been developed to evaluate the maturity of compost materials.

Compost maturity and stability are often used interchangeably. However, they each refer to specific properties of these materials. Stability refers to a specific stage or decomposition or state of organic matter during composting, which is related to the type of organic compounds remaining and the resultant biological activity in the material. The stability of given compost is important in determining the potential impact of the material on nitrogen availability in soil or growth media and maintaining consistent volume and porosity in container growth media. Most uses of compost require a stable to very stable product that will prevent nutrient tie up and maintain or enhance oxygen availability in soil or growth media.

Maturity is the degree or level of completeness of composting. Maturity is not described by a single property and therefore maturity is best assessed by measuring two or more parameters of compost. Maturity is in part, affected by the relative stability of the material but also describes the impact of other compost chemical properties on plant development. Some immature compost may contain high amounts of free ammonia, certain organic acids or other water soluble compounds which can limit seed germination and root development. All uses of compost require a mature product free of these potentially phytotoxic components (LIFE05 TCY/MA/000141, 2008). According to Zucconi *et al*. (1981) the GI, which combines the measure of relative seed germination and relative root elongation of radish seed (*Lepidium sativum L*) is an integrated biological indicator, which is regarded as the most sensitive parameter used to evaluate the toxicity and degree of maturity of compost. Herity (2003) recommended the germination of cress seeds in compost must be >90% of the germination rate of the control sample.

Table2.2 Plant Phytotoxicity tests

	Units Rating		
Test methods	Very mature	Mature	Immature
Seed germination % of control	>90	80-90	<80

Source: California environmental protection Agency (2002) and Brinton (2000)

2.10 Environmental benefits of Composting

The most considerable environmental benefit of composting is that the amount of waste going to landfill is reduced, since landfills cause serious environmental impacts. Water forms leachate when percolating through the waste and becomes contaminated by substances originating in the waste. This leachate contains oxygen depleting substances, toxic organic substances and metals, and can pollute ground and surface water. Lining and covering the landfill can in a short perspective prevent this, but in the long run some leakage is inevitable (Strömberg,1995). Another environmental impact is gas emissions. When water enters the landfill, biological activity starts and landfill gas is formed, including hydrogen sulphide and methane, which is an aggressive greenhouse gas (The Swedish Environmental Protection Agency, 1993).

Composting biologically degradable waste not only reduces the amount of waste put on landfill, but can also reduce the environmental impact of the remaining waste at the landfill, since putting less organic matter in the landfill will reduce methane production (The Swedish Environmental Protection Agency, 1993). There are also suggestions that less organic material in the landfill will reduce the negative environmental impact of leachate (Laine-Ylijoki et al,. 2005). A fire on landfills is another factor with large environmental impact. With less organic waste going to landfill, the risk of fire can be reduced.

Compost has the potential of being organic fertilizer and can thus be environmentally beneficial by substituting artificial fertilizers (Montemurro et al,. 2005). On the agricultural front, a lot of concerns have been raised about the effect of chemical fertilizers on human health and the environment coupled with its high price, pollution of water bodies, and its residual effect on crops and on non-target microorganisms in the soil (Samuel.K 2011). To what degree the compost will enhance the nutrient status of the soil depends on both the waste that the compost is made from and the treatment technology (Gutser et al,.2005). Even if the compost is low in nutrients it can be valuable since application of compost, or any other form of humic material, effectively enhances soil structure, improves the water holding capacity and reduces the sensitivity to erosion (Manser & Keeling ,1996). Several tests also show that application of compost represses plant diseases in the field (Ros et al,. 2005). Composting thus reduces the risks of environmental degradation, but can also have other positive side effects, including economizing with limited natural resources. Composting is therefore an interesting option for municipalities developing their waste management by minimising and recycling waste that today ends up on landfill (Lotten and Kristina, 2007).

2.11 Composting practice in Ethiopia: Trend, challenges and opportunities

Ethiopia is one of the least developed countries in the world and its economy is based mainly on agriculture (Bekalo and Bangay, 2001). The country currently faces a number of environmental challenges resulting directly or indirectly from human activities due to agricultural practices, rapid population growth and the consequent increase in the exploitation of natural resources (Devi et al., 2007). The challenges range from land degradation to environmental pollution. So, environmentally sound farming system is the vision for the society to cope up the problems of chemical based farming system (UNEDP, 1995).

Pit Composting of the farm waste and its immediate vicinity, together with domestic animal dropping is being introduced as a new technology in Tigray, Northern Ethiopia by ISD and EPA, which aimed at stimulating local communities to intensify production and the results were remarkable. In the local community, while comparing the impacts of different inputs, ‗‘Composting increases yield two to three times, comparing favorably with no Fertilizers input, and in the case of some crops , use of compost out-performs chemical fertilizers (ISIS, 2002). This result is comparable with the ILRI study in the highland of Tigray, in which the use of compost increases crop productivity by 16% (Berhanu et al., 2001).

What the farmers now realize is that the effect of chemical fertilizers disappears often even before one season is out, while the effect of compost is cumulative over several consecutive years. Their experience in all four communities at the farm and its immediate vicinity, together with domestic animal dropping give enough compost for intensifying food production without incurring any debt" (ISIS, 2002).

On top of that, their finding (ISD) indicates that using compost has made difference especially during drought period as the organic matter in the compost improve the water holding capacity of the soil. In the Kindo Kosha, south of the country, women collect household refuse, cow dung, and chopped enset leaves for making compost, while men collect leaf litter and grass. Both men and women are responsible for taking the compost to the fields (Bierwirth et al., 2001).

But there are challenges from the economic perspective; the economic failure is the inability to obtain an income from the sale of compost product or even to give the product away at zero cost. The perceived value of the end product depends up on many factors including; its quality in comparison with competing products, proximity to end users and of course the cost. The perceived value of the waste -derived compost is low.

2.12 Comparison of Environmental and Economic benefits of compost and chemical fertilizer

2.12.1 Environmental performance and economic benefit of compost

The emission of landfill gases (LGs) produced by the anaerobic and aerobic decomposition of organic matter is a major source of Greenhouse gases (GHG) which are responsible for global warming and ozone depletion. Composting is one of the simplest ways to prevent emissions of methane because the organic fraction of the waste stream is diverted from landfill. While composting does release carbon dioxide, it is currently considered to be a neutral process since the removal of carbon dioxide from the atmosphere by photosynthesis to produce organic matter is also not considered (Hoornweg et al.,2000).

Composting rarely generates profits on its own. However, when viewed as a component of an integrated solid waste management program, composting can provide economic benefits on a much larger scale. The costs of composting includes raw materials, production, marketing, and hidden environmental costs; whereas the benefits involve the market value of the compost, savings from avoided waste disposal costs, as well as various positive environmental impacts . When considering the large quantities of organic matter generated in developing countries, governments can save money by reducing the amount of waste requiring collection, transport, and disposal. The extent of these savings are dependent on how the waste management system incorporates composting initiatives, including the elimination of temporary dumping sites, rerouting of collection vehicles, and the redirection of labor (Economist, 1998).

2.12.2 Environmental performance and Economic benefits of chemical fertilizers

Emissions during production of urea: considerable amount of CO_2 is emitted during the production of urea and much of the CO_2 emission is associated with ammonia synthesis, modern urea factories emit 3.1 kg CO_2-eq kg-1N (Wood and Cowie, 2004).

Emissions during transportation: the emission due to transportation does not directly related to urea synthesis but other factors such as truck or ship used for transportation and amount of fuel consumed per km during transportation of the product, European average 0.1 kg CO_2-eq kg-1N (www.yara.com, 2010).

Emissions during application: due to application of urea fertilizer nitrogen is emitted as N_2O-N which is deemed as highly "effective" greenhouse gas with a global warming potential of 310 times stronger than CO_2 (IPCC, 1996). The default emissions factor for direct N_2O emission (N_2O-N) is 1% of the applied nitrogen, plus another 0.325% due to indirect emission, occurring elsewhere from nitrogen that has been leached or emitted, thus 0.01325 kg of applied nitrogen is emitted as N_2O-N (Edi et al., 2003). This is equivalent to 6.45 kg CO_2-eq kg-1N, with the conversion factor of N_2O-N to N_2O, 44/28 (IPCC, 2006).

The production of fertilisers demands much energy and generates considerable greenhouse gas (GHG) emissions. Kongshaug (1998) estimates that fertiliser production consumes approximately 1.2% of the world's energy and is responsible for approximately 1.2% of the total GHG emissions. All the above factors indicates that there is an advantage in using compost as fertilizer than using chemical fertilizer both in terms of economic and environment aspects, which is very useful strategy for the current development program of the country.

3. Methodology

3.1 Description of the study area

Dale district is one of the 19 districts in Sidama Zone and covers a total area of 30,212 ha, located at about 320 km south of Addis Ababa along the main highway to Moyale, about 5km to the left after traveling 40km from the region capital Hawassa. The district shares boarder with Wonsho district in the east, Loka-Abaya district in the west, Aleta Wondo and Chuko districts in the south, and Shebedino district in the north. In addition, the district is located in 6^0 44” latitude to the north and 38^0 28’’ longitude to the east. The district is subdivided into 36 Kebeles and all those produces coffee (WoFED, 2013).

3.2 Methods

3.2.1 Collection of Composting Material

Coffee husk and coffee pulp was collected from Yirgalem wet and dry coffee processing firms directly from their dumping sites. Cow dung and Khat waste (Garaba) was collected from dairy farms and Khat selling houses in Awassa respectively. Finally the common bulking agent top soil was taken from Hawassa agricultural Research Center. In this study, cow dung and khat wastes were used as co-substrates in the composting of coffee residues. As coffee husks have a high C:N ratio, amendment with cow dung and khat wastes which are rich in easily biodegradable N compounds was conducted in order to reduce the C:N ratio and to increase the rate of degradation.

3.3 Experimental Design and Layout

3.3.1 Experimental Design

Six different treatments each having three replicates in Randomized complete block design with the total of 18 piles (heaps) were prepared with different composition of coffee residue, cow dung, and khat waste (Garaba). The RCBD is the standard design for experiments. The field is divided in to units to account for any variation in the field. Treatments are then assigned at random to the subjects in the blocks once in each block. In this design:

- Treatments are assigned at random within blocks of adjacent subjects, each treatment once per block
- The number of blocks is the number of replications
- Any treatment can be adjacent to any other treatment, but not to the same treatment within the block.

Treatment 1: (T1) coffee processing wastes (coffee husk and pulp)

Treatment 2: (T2) coffee processing wastes plus cow dung

Treatment 3: (T3) coffee processing wastes plus Khat waste (Garaba)

Treatment 4: (T4) coffee processing wastes plus cow dung plus Khat wastes (Garaba)

Treatment 5: (T5) coffee pulp plus cow dung

Treatment 6: (T6) coffee husk plus cow dung

The composts base area was 1m width, 1m length and 1m height ($1m^3$ in volume), above 20 cm height of bricks bed. The piles were constructed over a bamboo made kiricho on a brick with the composting material in layers. Each layer had a thickness of 100cm. The experimental set up is depicted in figure 3.1. The composting process carried on under aerobic condition. The compost piles temperature and moisture content were treated and monitored by turning the piles and spraying water and the mean temperature of the compost piles was recorded using thermometer. The heap was shuffled after one week in order to enhance the composting process by blending and breaking up the composting materials (Harold et al., 1994). The piles were turned on less windy, relatively calm weather, damp days to reduce the dissipation of process odors (Edwards, 2003; Bidlingmaier, 1996 as cited in Desalegn et al., 2012). The top soil was added to each treatment at the top of the pile which will introduce microorganisms to the piles.

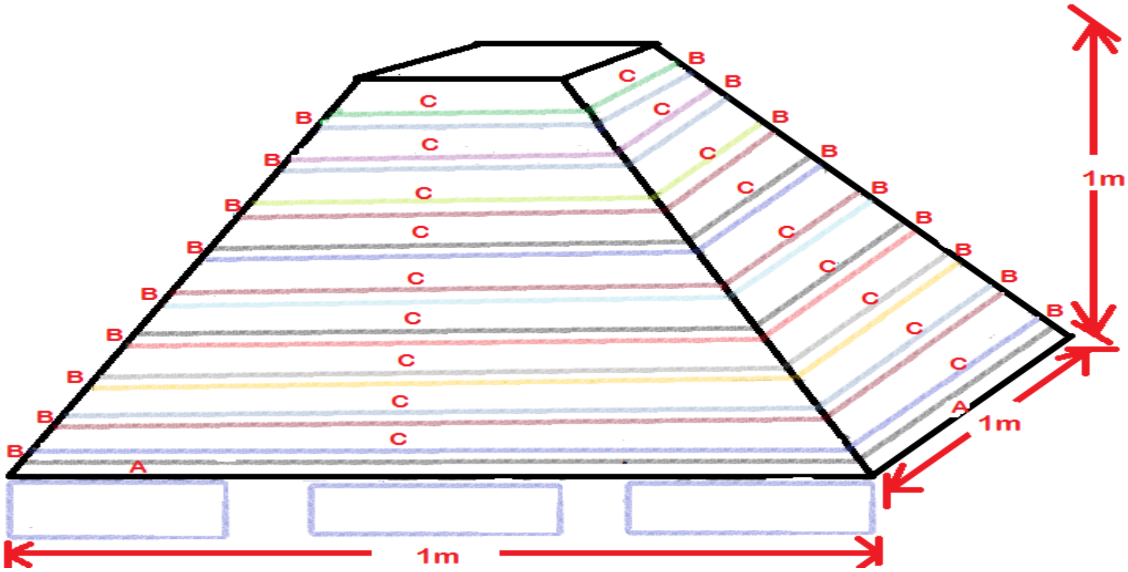

Fig 3.1 Layout of composting

Layer A: This layer was prepared from locally available material which made from dry bamboo stem called-kircho. This is difficult to decompose and allows ventilation which is important for the survival of microorganisms.

Layer B: This layer consists of coffee by-products (coffee husk and pulp).

Layer C: Varies with the treatment i.e cow dung / and khat waste, in order to reduce the C:N ratio of the coffee husk and pulp for rapid decomposition

These layers were repeated (except layer A) until the heap reaches 1m long.

Upper layer: Covered with grass or leaves to prevent water loss.

Table 3.1: Proportion of coffee wastes and each organic residue (top soil, cow dung, Khat waste (Garaba)) in each treatment on dry weight basis.

S.no	Pile Type	Treatments					
		T1	T2	T3	T4	T5	T6
	Coffee pulp	350 Kg	315 Kg	286 Kg	224 Kg	780 Kg	------
	Coffee husk	80 Kg	66 Kg	57 Kg	45 Kg	------	325 Kg
	Cow dung	-----	------	68 Kg	60Kg	125 Kg	92 Kg
	Khat waste	-----	39 Kg	------	31 Kg	…….	…….
	Top soil	23 Kg	19 Kg	14 Kg	11 Kg	49 Kg	36 Kg

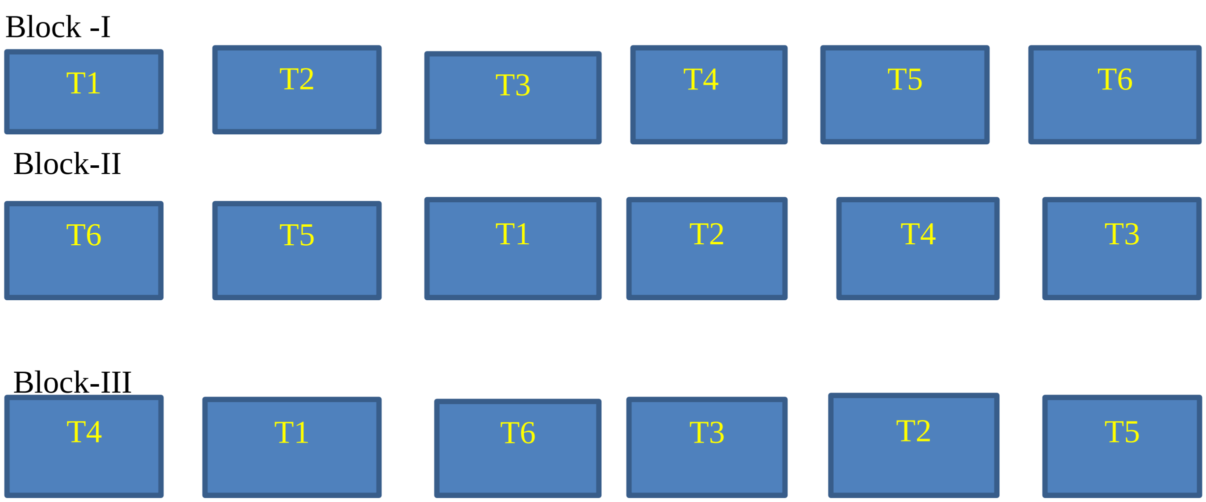

Fig 3.2 Randomized complete block design (RCBD) arrangement

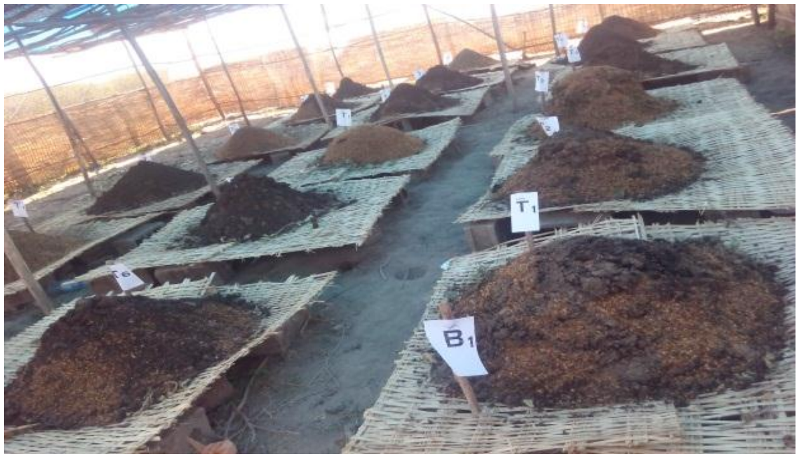

Fig 3.3 Application of RCBD

3.4 Sampling and Sample Collection from the compost pile

Representative samples were taken for three times (at the beginning, middle and final) stage of the composting process, from all compost piles for physicochemical parameter analysis using random sampling methods. 500 g samples were taken from all piles using polyethylene bag and transported by vehicle to wonji sugar corporation research and development organization. The samples were analysed at analytical chemistry and soil laboratory. The samples were taken from each pile from all sides of the pile (i.e. from the bottom, top, left, right side and interior of the pile (heap) by hand using gloves and by turning the pile to take the sample from the bottom of the pile and thoroughly mixed together to get a homogeneous and representative sample of the entire pile at 0, 45 and 80 days of composting. The samples were served for analysis of raw feedstock, processing compost and matured compost, respectively for determination of specific parameters. The drop in temperature in a compost piles to a level of ambient temperature was an indication of compost maturity at 80 days of composting.

3.5 Methods and Procedures of Physicochemical Analysis

The following physicochemical properties power of hydrogen (pH), Electrical Conductivity (EC), Total potassium (TK), Total phosphorus (TP), percentage of moisture content (MC), dry matter (DM), organic matter (OM), total carbon (TC), total nitrogen (TN) and carbon to nitrogen (C:N) ratio were analyzed and calculated for the raw feedstock, processing composts after 45 days and matured compost after 80 days for all composting piles, and the results were reported in mean.

3.5.1 Procedure for measuring temperature

Temperature was measured using digital thermometer daily for the first 30 days on the site. The frequency of measuring the temperature of the pile reduced then after within a range of 5 to 8 days at the final stage while the composting process progressed and the data were recoded. During measurement the thermometer probe was inserted 30cm depth inside the windrow at three points and the average of three readings was recorded. The ambient temperature was taken from the research center meteorology department for the composting period of time.

3.5.2 Procedures for Determination of pH and EC

PH is a good indicator of the balance of available nutrients in the compost, whereas Electrical conductivity almost viewed as the quantity of available nutrients in the soil. The pH of compost samples were determined using standard procedures. A sub-sample (10 g) of air-dried ground compost (<2mm) was transferred into a flask and 25 ml of distilled water for 1:2.5 compost/water suspension. Transfer the samples in to an automatic stirrer, stirred for 30 minutes and the pH measured on the upper part of the suspension using an electronic pH meter. The flasks were capped and shaken mechanically for 15 min and allowed to stand for 30 min. The pH of the suspension was measured using an electronic pH meter. The electrical conductivity was determined following a standard procedure in compost and deionized water ratio of 1:2.5 (w/v) using conductivity meter (Sahlemedhin & Taye 2000).

3.5.3 Determination of Moisture Content and Dry Matter

Dry matter is the dry weight of the compost after the water has been removed, which indirectly related to percentage of organic carbon and organic matter. Five gram of the representative fresh sample (FS) was weighed for the determination of moisture content and dry matter in a clean, dry, pre-weighed and recorded moisture free tin and loaded in an oven at 105^0C up to a constant weight (24 hours). Oven dried samples was cooled in desiccators for 30 minutes and reweighed (Sahlemedhin & Taye 2000). The percentage of dry matter and moisture content revealed that they are in inverse relation to each other. The recommended range of moisture content was maintained using squeezing test and experimentally in the laboratory.

The moisture content in % by weight and dry matter content was obtained as follows:

$$\%MC=\frac{Mpf-Mpd}{Mpf-Mp}*100 \qquad (3.1)$$

$$\%DM=\frac{Mpd-Mp}{Mpf-Mp}*100 \qquad (3.2)$$

Where: MC: moisture content in (%MC)

DM: dry matter in (%DM)

Mp: mass of empty plate in (g)

Mpf: mass of plate + mass of fresh sample in (g)

Mpd: mass of plate + mass of dry sample (g)

3.5.4 Determination of OM and OC

Weigh 2g air-dry compost and transfer to a 500ml Erlenmeyer flask. Add 10ml 1 N $K_2Cr_2O_7$ solution with pipette to both samples and blank. Carefully add 20ml concentration H_2SO_4 with measuring cylinder in the fume cupboard and swirled the flask and allowed standing asbestos or corking pad for 30 minutes. Then add 200ml distilled water and allowed it to cool. Add 10ml conc. orthophosphoric acid just before titration, and add 0.5 ml of barium diphenylamine sulphonate indicator. Titrate both samples and blanks with 0.5 N ferrous sulfate solution until the color changed to purple or blue, then added ferrous sulfate solution drop by drop until the color flashes to green then continue to a light green end point (Sahlemedhin& Taye 2000).

Percentage of carbon is expressed as:

$$\%C=N*\frac{V1-V2}{S}*0.39*mcf \qquad (3.3)$$

Where: N= normality of ferrous solution (from blank titration)

V1= ml ferrous sulfate solution used for blank

V2= ml ferrous sulfate solution used for sample

S= weight of air-dry sample

$0.39 = 3*10^{-3} *100\%*1.3$ (3 equivalent weight of carbon)

mcf= moisture correction factor

% Organic Matter= 1.724*% carbon (3.4)

3.5.5 Determination of total Kjeldahl nitrogen

The total nitrogen was determined following the Macro Kjeldahl method Total Kjeldahl Nitrogen (TKN). The Kjeldahl method for nitrogen determination involves three processes: digestion, distillation and titration.

Accurately weighed 1 g compost samples and transferred into digestion tubes. Added 2 g of catalyst mixture and few carborundum boiling stones mixed well and rinsed with little water just enough to moisten the mixtures. Added 7ml of conc. H_2SO_4 and mixed by swirled. Placed the digestion tubes stand with the samples beside the block digester and fitted the exhausted manifold on top of it. Place the tubes with racks and exhaust manifold on the digestion block, preheated in the fume hood. Digest for 3hours or until the digestion is white on block digesters preheated to 300^0C allow cooling and cautiously adding 50ml of distilled water, and then cooling again. Transfer the acid digest quantitatively to the macro-Kjeldahl flasks and rinsed using distilled water. Measure 20ml boric acid solution from dispenser in to receiver Erlenmeyer flasks corresponding to the number of samples. Add to it 2 drops of indicator solution and place under the condenser. Pour 75ml of 40 percent NaOH carefully down the necks of the distillation flasks containing the digests and mix gently. Fit the prepared 250ml Kjeldahl distillation flasks containing the digest to the corresponding holder, close it as soon as possible and start the distillation by heating the flasks containing the digests. When the distillation is complete, i.e. when about 80ml of distillate has been collected, removed the receiver flasks. Continue with the next samples. Add a stirrer bar and titrated the receiver flasks solution from green to a pink end point with 0.1 N H_2SO_4. Record the reading of the burette. Always standardize the acid to obtain the exact normality of the titrant (sahlemedhin & Taye 2000).

Then the percentage (%) of total nitrogen present in the sample was calculated as follows:

$$TKN\ (\%) = \frac{(a-b)}{s} * N * 0.014 * mcf \qquad (3.4)$$

Where a= ml of H_2SO_4 required for titration of sample

b= ml of H_2SO_4 required for titration of blank

S= air-dry sample weight in grams

N= Normality of H_2SO_4 (0.1 N)

0.014= meq weight of nitrogen in gram

Mcf = moisture correction factor

3.5.6 Determination of available Phosphorus

Weighed 2g air-dried compost <2mm mesh in flask with stoppers. Include one standard sample and two blanks with each series. Add 20ml of extracted solution Bray II, Shake exactly 1 minute by hand and filter directly after mixing through a whatman No. 42 filter paper. Pipette 2ml of standard series, samples and blanks. Add 8ml boric acid 0.5 % and mix. Add 2ml of mixed reagent and mix. Measure the absorbance with a 10mm diameter cuvette at 882nm after 30 minutes but within 12 hours, phosphate in the extract is determined by spectrophotometer. The absorbance of the 4ppm P standard is about 1.0 (Sahlemeghin & Taye 2000).

$$P\ (ppm\ or\ mg/l) = (a-b)*\frac{20}{s}*mcf = (a-b)*10*mcf \qquad (3.5)$$

Where a= ppm P or mg/l P in sample extract

b= ppm P or mg/l P in blank

10= extraction ratio (20/2)

S= sample weight in g (2)

20= ml of extracting solution and conversion factor P_2O_5= 2.29*P

3.5.7 Determination of exchangeable potassium

Weighed 10g of compost passed through 2mm mesh sieve in to 100 ml shaking bottle. Add 50ml of extracting solution and Shake for 30 minutes at minimum of 180 oscillations per minute. Filter and collect the filtrate in a 100ml Erlenmeyer flask. Dilute extracts 5 times using the extracted solution.

Measurement of K by Flame photometer

100 mg/l K diluted standard series: pipette 100ml of the potassium stock solution 1000ppm K, into 1 liter volumetric flask and dilute to volume with distilled water. Standard series working solution of 0-2-4-6-8-10 mg/l K: pipette in to volumetric flasks, respectively 0-5-10-15-20-25 ml of the diluted 100 mg/l standard solution. Under this procedure, the sample extracted with morgan's solution and K in the extract is measured by flame photometer (Sahlemedhin & Taye 2000).

3.6 Phytotoxicity Test/Seed Germination and Growth

Biological properties of compost can be measured in many ways, and each one addresses a different characteristic that makes compost either safe or unsafe for plants. Seed germination and plant growth bioassay are the most common techniques used to evaluate compost phytotoxicity. It is generally considered that phytotoxicity is eliminated when GI reaches 80-85% (Rasapoor et al.,2009). In this study, the toxicity of the compost was evaluated using the germination bioassay for 6 types of compost samples with different composition after 80 composting days. The characteristics of the compost samples were compared with the control (soil). After the composting process, the phytotoxicity of the composts (T1 to T6) was evaluated using the seed germination bioassay. In these tests I used maize (BH540). The germination method was briefly described as follows: in 10 liter plastic pot to test the phytotoxicity of the compost on maize variety (BH540) in field. The pots were set up in the shade under randomized completely block design (RCBD) in the composting site in triplicate. A total of 21 pots were used, 18 for compost samples and 3 for the control. Crop sowing was three seeds per pot to have available spaces for the plant to grow. At the end of 15th day's root length and germination index of maize was checked.

Maize plant was selected as a test for germination index due to its availability at the research center during the research period. The soil was taken from hawasaa agricultural research center to simplify the transportation cost incurred to bring if from other places.

The percentage of seed germination, root length and germination index (GI) was calculated using the formula (Zucconi et al., 1981):

$$\text{RSG (\%)} = \frac{\text{nVSS}}{\text{nVSC}} * 100 \qquad (3.6)$$

$$\text{RRL (\%)} = \frac{\text{RLS}}{\text{RLC}} * 100 \qquad (3.7)$$

$$\text{GI (\%)} = \frac{\%\text{RSG} * \%\text{RRL}}{100} \qquad (3.8)$$

Where: RSG express relative seed germination

nVSS express number of viable seeds in the sample

nVSC express number of viable seeds in the control

RLS express the root length in the sample

RLC express the root length in the control

RRL express relative root length and

GI express germination index.

3.6.1 Data collection for Maize seedling growth parameters

From the maize seedling the following data was recorded:

Shoot length (cm): was measured in centimeter (cm) with the help of ruler from soil surface to the top of plants. Average plant height of all three replications was calculated.

Root length (cm): Each plant roots was dug out, washed with tap water and length of each longest root was recorded in centimeter (cm) from point of emergency to the tip by using ruler and the average was taken.

Whole seedling fresh weight (g): The weights of whole plant seedling were measured by using sensitive balance and the average was taken.

Total dry matter (Total dry biomass) (g): After drying the whole plant parts (shoots plus roots) in oven drier for about 24 hours at 103 ^{o}C, the average weight of dried whole plant parts (shoots plus roots) were measured by using sensitive balance and averages were taken.

Leaf number: The newly growing leaves were counted and the average was taken.

Leaf area: The leaf area was determined according to the formula of Mokhtarpour, et al,. (2010).While calculating the leaf area the maximum leaf width was taken from the selected stem.

Leaf area of maize: $LA = L \times W \times A$

Where: LA expresses leaf area,

L expresses leaf length,

W express maximum leaf width

A = constant = 0.75

4. Results and Discussions

Composting of coffee processing wastes with cow dung and khat waste was conducted for a total of 80 days, from February 02, 2016-April 21, 2016. Characterization of raw material was the first task to be conducted for adjustment of parameters that have a big impact on the composting process. Moreover; characterization of processing compost and matured compost for various parameters was conducted to have the knowledge about the ongoing process and to compare the results obtained with other research work on that area and with that of the standards of different countries.

4.1 Physico-chemical characterization of feedstock and compost

Analytical results of key Physico-chemical properties of raw feedstock, processing compost after 45 days and matured compost after 80 days of composting are tabulated below in table 4.1.

The table contains all the measured parameters mean value for raw material processing compost after 45 days of composting and matured compost measurement value after 80 days of composting, which was crucial for adjustment of some influential parameters that will affect the composting process and matured compost which indicate the results proximity with that of the standard.

Table 4.1Mean Physico-chemical values of the raw feed stocks, processing and matured compost on days 45 and 80

	Parameters									
	MC %	DM%	pH	EC (dS/m)	OM%	OC%	TN%	TP (%)	TK (%)	C:N ratio
	Raw feedstock									
CH	11.86	88.14	5.6	1.96	87.9	50.98	1.25	-	-	40.8:1
CP	82.11	17.89	8.7	4.2	70.5	40.89	2.38	-	-	17.2:1

Table 4.1 Continued

CD	64	36	8.1	4.2	40.3	27.37	1.69	-	-	16.2:1
Khat	60	40	8.1	3.6	45.9	26.63	2.27	-	-	11.7:1
TS	7.9	92.1	7.9	0.14	12.5	7.25	0.25	-	-	29.1
	Processing compost after 45 days									
T1	68.2	31.8	8	2.4	51.5	29.87	1.09	0.09	1.3	27.4
T2	65.5	34.5	8.2	1.83	45.7	26.56	1.23	0.17	0.78	21.59
T3	69.6	30.4	7.96	2.67	48.3	28	1.45	0.1	0.81	19.3
T4	64.2	35.8	7.93	2.07	47.9	27.8	1.36	0.14	0.69	20.44
T5	67.6	32.4	8.1	1.81	45.34	26.3	1.21	0.12	0.63	21.7
T6	68.3	31.7	7.89	2.29	46.55	27	1.22	0.13	0.74	22
	Matured compost after 80 days									
T1	49.6	50.4	7.85	2.66	42.7	26.68	1.28	0.25	0.25	20.8
T2	39	61	8.05	4.3	39.76	23.49	1.76	0.87	1.26	13.34
T3	40.5	59.5	8.2	3.19	39.5	22.32	1.97	1.02	0.74	11.32
T4	38.4	61.6	8.1	4.4	39	22.3	2.06	0.9	1.48	11
T5	40	60	7.9	3.96	40.9	24.36	1.45	0.53	0.91	16.8
T6	39	61	8.0	4.15	41.6	25.3	1.71	0.49	0.85	14

CH=coffee husk, CP=coffee pulp, CD=cow dung, TS=top soil, EC=electrical conductivity, pH=power of hydrogen, OC=organic carbon, OM=organic matter, MC= moisture content, DM=dry matter, TN=total nitrogen.T1=CP+CH+TS, T2=CP+CH+TS+CD, T3=CP+CH+TS+Khat, T4=CH+CP+TS+Khat+CD, T5=CP+TS+CD, T6=CH+TS+CD.

4.1.1 Temperature

The temperature trend of the compost piles were indicated in figure 4.1. The temperature of the compost began to rise soon after the establishment of composting conditions within 24-72 hours of composting period except T1 which remains for almost 5 days at mesophilic phase. In similar way Misra and Roy, (2003) reported within four to five days, the temperature has raised to 60 – 70^{O}C. For all treatments, the temperature increased relatively rapidly and the three typical phases of composting were observed during the process. i) a short initial mesophilic phase during approximately 2-5 days for all treatments ii) a thermophilic phase lasting 20-25 days on average and iii) a mesophilic and maturation phase shortly thereafter the temperature decreased rather gradually and the compost temperature equaled that of the ambient. No changes of temperature were observed after turning during this phase, indicating a stabilization of the compost.

A maximum of 59°C was achieved in T4, showing maximum organic matter reduction as compared to those of other treatments whereas T1 was the one observed having a short thermophilic phase. The pattern of these temperature changes in all piles i.e. first an increase to a high temperature, persistence of a high temperature, and then a decrease to a low temperature, is a typical temperature profile of the composting process which is similar to the ideal curve of temperature variation of composting (Tchobanoglous et al., 1977) as it indicated in figure 4.1. The temperature levels in the compost piles tended to increase and reach 50-59°C due to the energy released from the biochemical reactions of the microorganisms in the compost piles, while the temperature levels in the compost piles tended to decrease after the thermophilic phase due to a loss of the substrate and a decrease in microbial activity (Bertoldi et al., 1982). In this study all the piles attain the ambient temperature range at the end which indicates compost stabilization. The recorded compost pile temperature and ambient temperature is tabulated in table 4.2 here under.

Table 4.2 Recorded ambient and mean temperature of the piles (^{O}C)

Date	Amb. temp (^{O}C)	Treatments temperature (^{O}C)					
		T1	T2	T3	T4	T5	T6
4-2-16	19.75	18.5	20	20.5	20	19	20
5	20.5	28.8	39	27	49	35	38.5
6	20	34.4	46	41	49.5	43	46.5
7	21.25	39.5	48	47	52	47.5	48.5
8	23.25	43	50	49.5	51	45	49
9	23.5	40	52	51	54	49	51
10	23	44	55	53.5	49	50.5	48
11	24.25	46	56	50	52	53	52
12	22	45.5	52	54	54	52	50.5
13	21.25	49	50	54.5	59	50	52
14	21.25	49	45	51	55	50.5	48.5
15	21	50	43	46	52.5	47.5	44
16	22.25	50	42	41	47	46	42.5
17	22	46	48	44.5	46.5	42	41
18	21.75	44	48	47	49.5	44	45
19	20.5	44.5	49	48.5	46	41	43.5
20	19.5	48	48.5	49	45	45	42
21	20	48.5	45	50.5	47	49	46.5
22	20	49.5	46	50	52	45	46
23	23.75	49	48	51	49	43.5	50
24	23.75	48.5	49.5	48	50.5	50	51
25	21	46	46.5	49.5	48	47.5	49
26	20.25	48	48	46.5	49	47	47
27	22.25	45.5	47.5	49	47.5	45	46
28	21.5	44.5	46	48	47	46	45.5
29	22.25	40	47	45.5	48	44	45
1-3-16	22.5	41	45.5	46.5	45	44.5	44

4	23	38.5	46	47	42	43	46
7	24.25	35	48	44	38	43	40
10	21.25	29.5	45	45	33	40	36
13	25.5	27	41	43	30	38	37
16	24	25	39.5	41	28	35	34
19	23	24.5	35	38.5	26.5	31	32
22	25.25	25	30.5	34.5	26	27	30.5
25	22.25	23	28	28.5	25	24.5	27
28	24.25	22	24	24.5	22	23	26.5
31	24	22	25	23	21	23	24
1-4-16	22.5	21	23	21	20	22	24
6	21.75	20	21	20.5	20.5	21	22
11	21	19	21	21	21	22	21
16	21.5	19	20	21	19	20	20
21	20.25	18	20	20	19	18	19

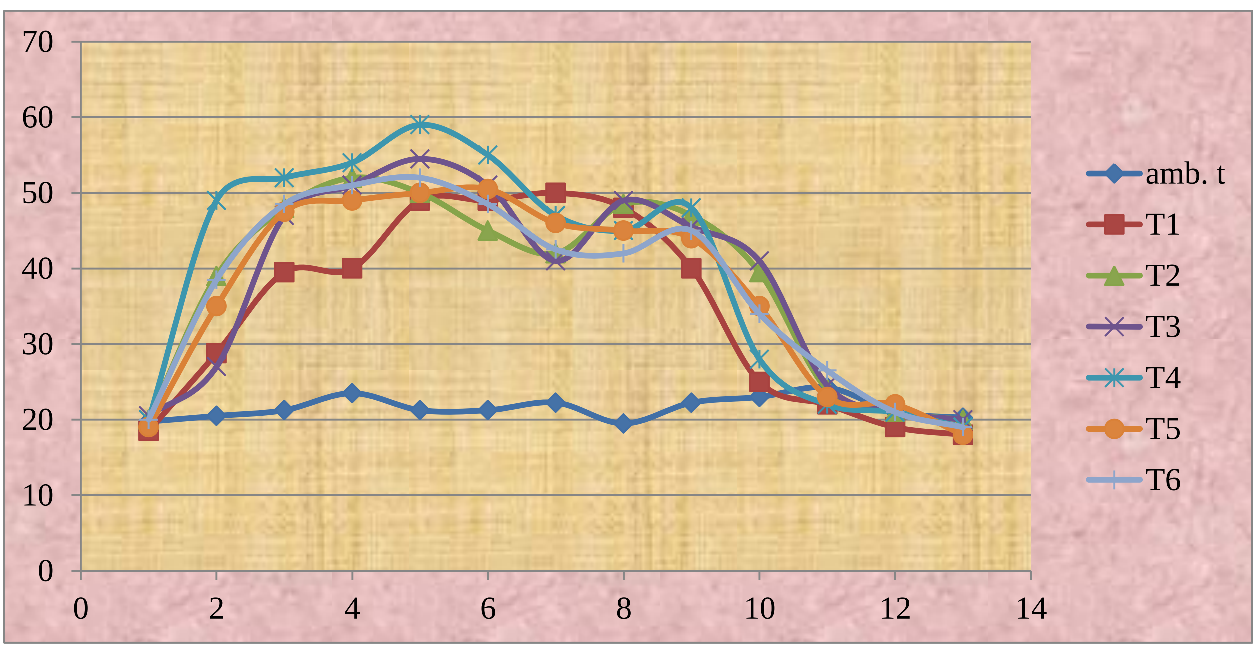

Fig 4.1 Typical temperature variations in a compost pile

4.1.2 Moisture content

The mean percentage moisture contents of treatment windrows were graphically shown by Fig.4.2 here under. An optimum level of moisture content was previously reported to have a strong effect on the oxygen consumption rate of aerobic heterotrophic microorganisms and was efficient between 45 -60%. All of the compost piles were adjusted to have a moisture content of 45-60 percent to create a conducive environment for microorganisms to proliferate and degrade materials, because survival of these microorganisms in composting system is primarily dependent on the moisture content. This optimum range of moisture level was maintained using squeezing test at onsite and experimentally in the laboratory. When an ambient temperature was reached, the addition of water was stopped, although the composting process continued.

At the initial stage of composting, the moisture content of all piles was approximately 55-60% and then dropped gradually throughout the composting time except T1, which had a short thermophilic phase, which resulted in reduced evaporation of moisture in to the environment as compared to those of the other treatments as shown in Figure 4.2. In the co-composted piles, highest moisture levels were seen in the active phase with high moisture losses occurring afterwards. The reduction in moisture in Piles 2, 3, 4, 5, and 6 might be due to microbial heat generation causing enhanced desiccation. Moisture loss during the composting process can be considered as an indicator of the decomposition rate because the heat generation that accompanies decomposition drives evaporation. The moisture content of all piles slowly decreased to a final content of approximately 38.4-49.6% at the end which is on the range recommended by California integrated waste management board compost quality standards for finished compost similarly the result is in conformity with the recommendations of properties of good compost for agriculture in UK. Overall there was no significant change in moisture content of the pile regardless of waste type as water was sprinkled in to the pile regularly to maintain the optimum level of moisture in which microorganisms proliferate.

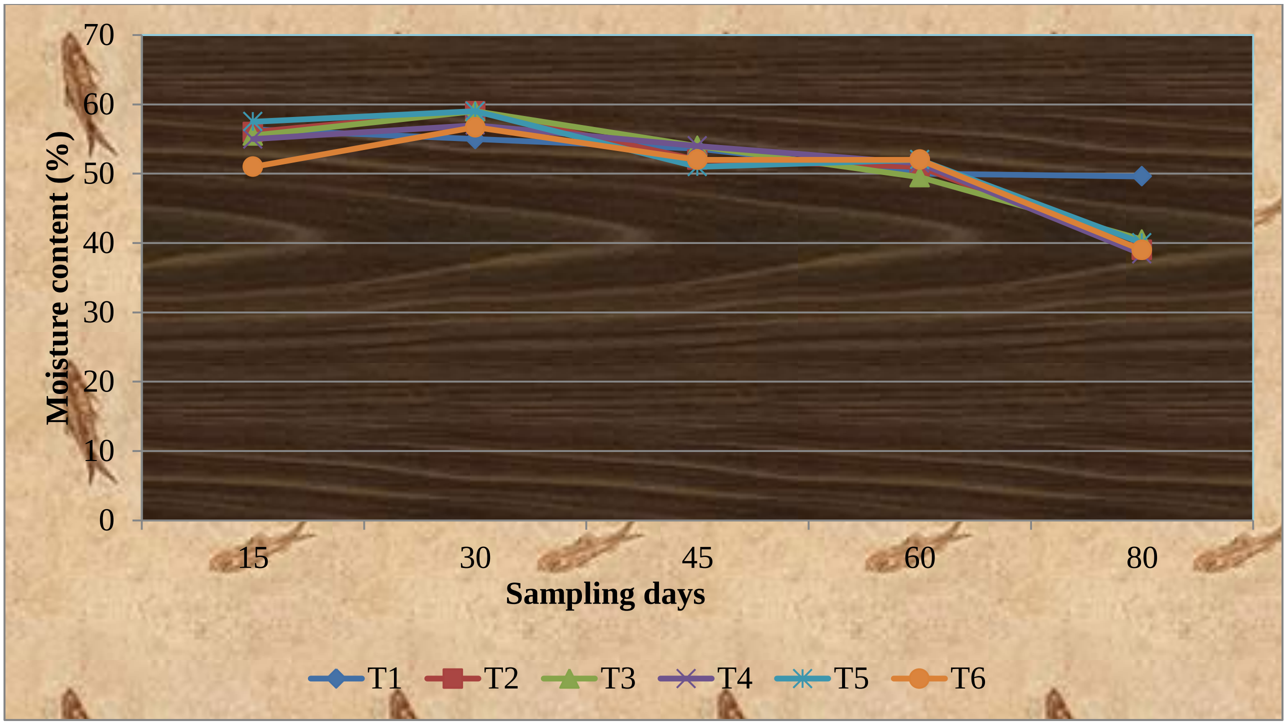

Fig 4.2 Mean moisture content of piles during composting

4.1.3 pH Change

The pH value indicates the acidity or alkalinity of the organic materials, and affects microorganism growth. A pH ranging between 6.0 and 7.5 is preferred by bacterial decomposers while a pH ranging from 5.5 to 8.0 is a good working environment for fungal decomposers (Rynk, 1992). The PH varied with time during the composting process. A decrease in pH was observed at the early stage of composting, although it increases at later stage. The decrease in pH is attributed to the formation of organic acids (typically due to the anaerobic conditions that are established in the waste materials before the beginning of the composting process. As these acids are degraded the pH begins to rise due to the production of ammonia during ammonification and mineralization of organic nitrogen as a result of microbial activities (Samuel.K, 2011). Fungal species can tolerate a low pH environment and they can consume the organic acids formed in the pile during the initial stage of composting thereafter the pH increases as these acids are degraded.

The pH of all treatments was found to be within 7.85-8.25. This result is in agreement with the compost quality standards for compost used in agriculture in Switzerland (pH < 8.2) and Great

Britain (7.5-8.5) (OVAM, 1999). In addition, it is in the recommended range for the quality compost used by the countries such as Dutch, Belgium & Italy that is 6.5-8.5. Hence the matured compost of this study is very promising, since no chemicals are required to balance the pH before applying to soils. Its trend is indicated here under in figure 4.3

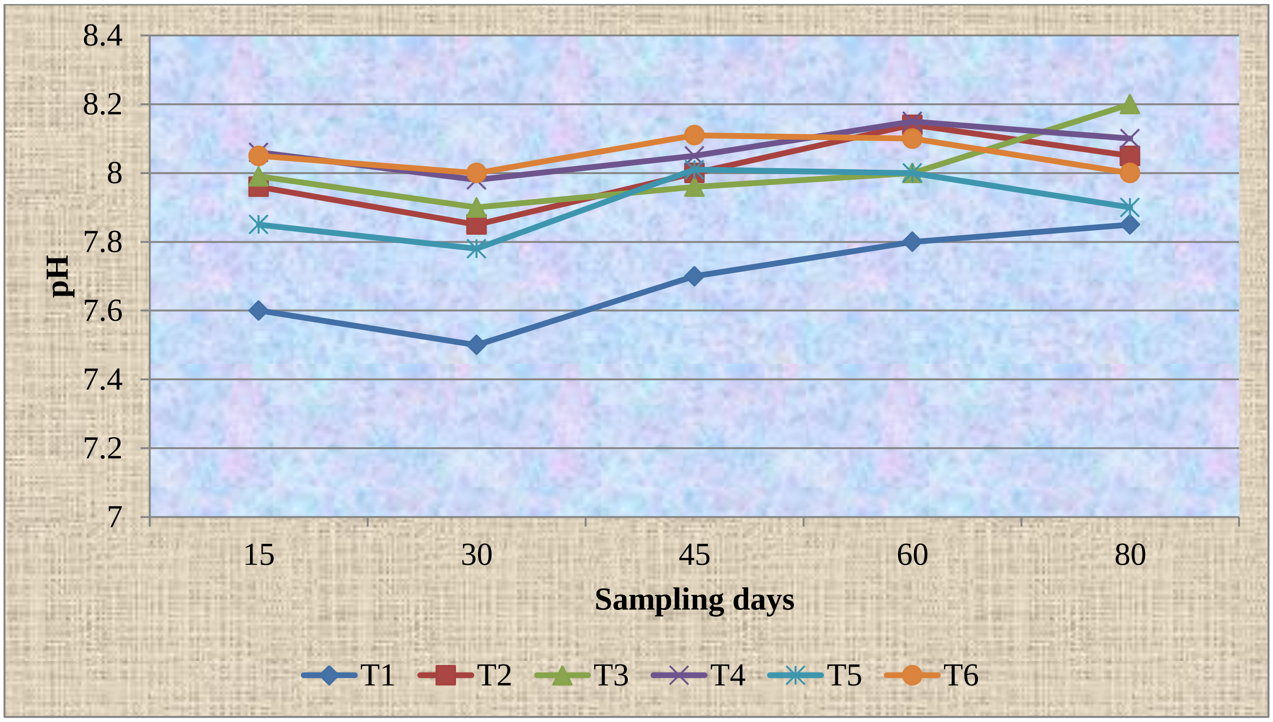

Fig 4.3 Variation of pH as a function of time in composting

4.1.4 Electrical conductivity

Generally, increase in EC was observed in the present study slightly from initial composting period to the final composting stage. The increase in EC could be due to the release of mineral salts such as phosphates and ammonium ions through the decomposition of organic substances and water loss, thus increasing the concentration of relative soluble salts (Huang et al., 2004). Study by Anandavalli et al., (1998) on recycling of banana Pseudo stem as compost also show similar EC increment as the composting process proceeds. The mean EC values of all the treatments of matured composts were found to be between 2.66-4.4 dS/m, in which the highest value of EC was recorded at T4. The difference may be originated from the quantity of feedstock matrices and content of ions responsible for the electrical conductivity of compost samples. This result is in agreement with the quality compost used by the countries such as Dutch, Belgium and Italy that is < 5 dS/m (OVAM, 1999). Similarly, this result is in the recommended range by Mona (2003 as cited by Herity, 2003) within 2-6 dS/m. The mean EC analysis results of piles changing trends during composting are shown in Figure 4.5 below.

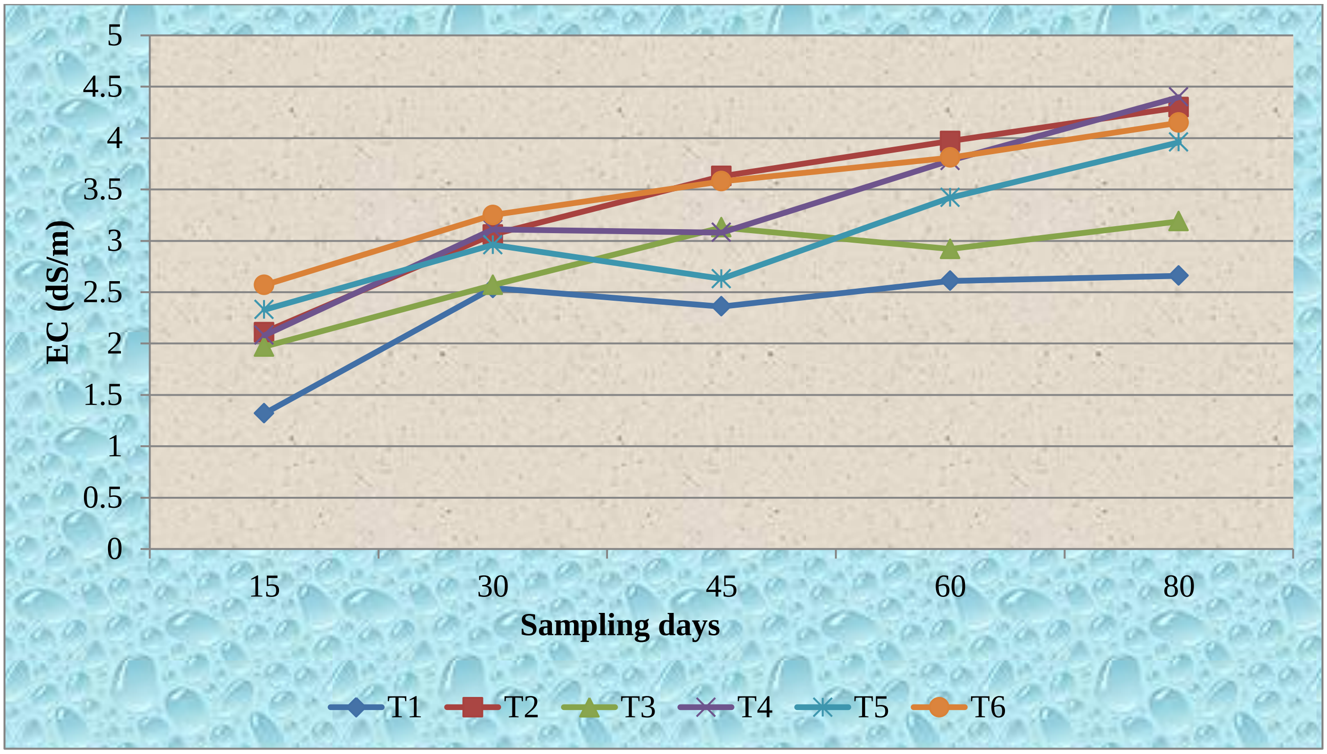

Fig 4.4 EC change trend during composting

4.1.5 Total organic carbon

Generally the total organic carbon in all test treatments showed a declining trend as the decomposition progressed. Composting time had a significant effect on the total organic carbon (TOC) content in all composts, but this effect varied depending on the starting raw material. Initially the total organic carbon content of the piles was 41.2%, 38.05%, 37.12%, 38.46%, 39.12% & 38.6% and reduced to 26.68%, 23.49%, 22.32%, 22.9%, 24.36% & 24% respectively. The highest TOC reductions were found in T4 reflecting a notable mineralisation of organic matter over time. In this study, T1 (coffee husk and pulp compost) had the lowest TOC reduction probably because of the higher concentration of recalcitrant compounds. This pile contained no additional organic matter that could fuel the kinetic process; hence, its decomposition occurred more slowly. At the beginning of biodegradation process TOC reduction of the compost displayed a similar trend in all treatments, which decreased rapidly while the temperature of the piles was at peak. It was followed by a gradual decrease showing an overall loss of total organic carbon in the composting process. The organic carbon content of the compost piles are indicated in figure 4.5 here under.

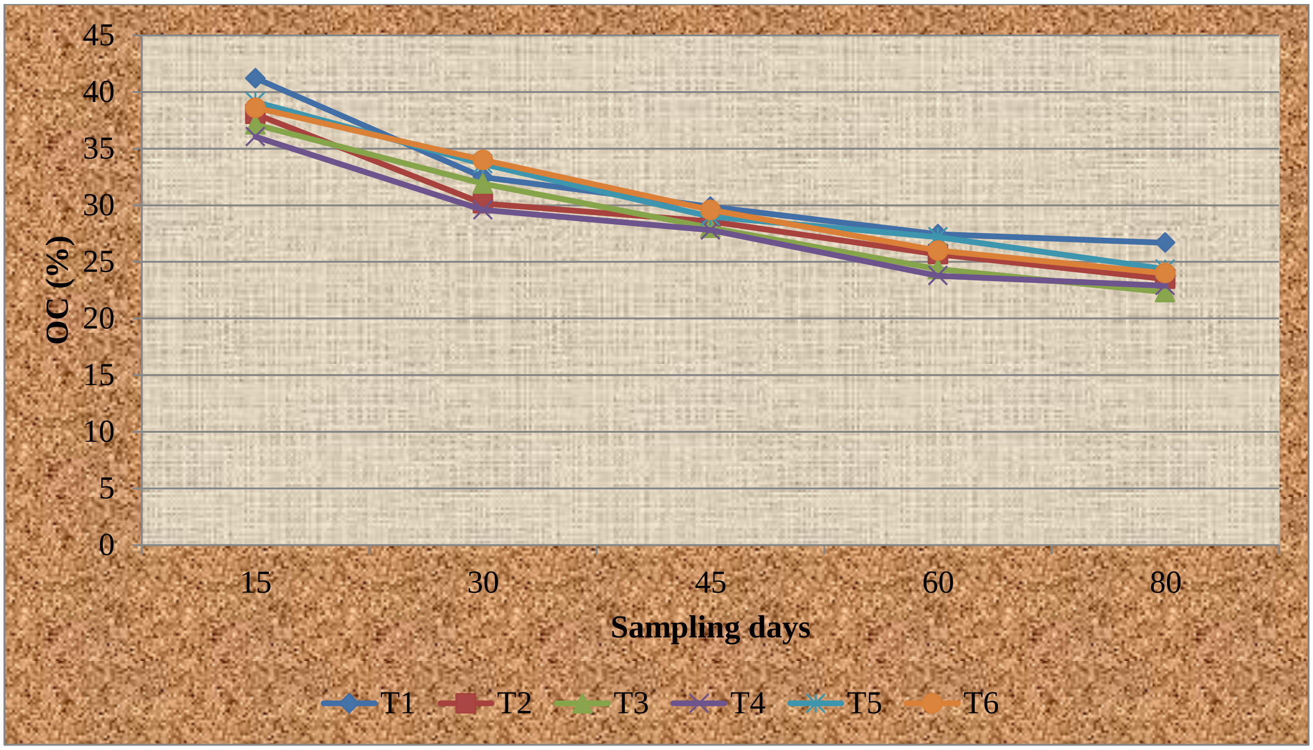

Fig. 4.5 Organic carbon content trend in piles

4.1.6 Organic matter content

Generally, the organic matter content decreases significantly from the initial composting period to the final composting stages for all the treatments as shown in figure 4.3. The reason for the reduction in total organic matter in compost sample is mineralization of initial organic matter to CO_2 during the composting process, by microorganisms leading to a faster decrease in total organic matter at the beginning of the process because of the degradation of the most easily biodegradable organic matter fractions (Mekuria, 2011).

The initial organic content was 63.4%, 65.6%, 64.39%, 66.3%, 68.5% and 69% and reduced to 46%, 40.5%, 39.5%, 39%, 42% and 43.6% in trial 1, 2, 3, 4, 5 and 6 respectively, at the end. However, The rapid organic matter fallout was observed during the first 30 days of composting which was the thermophilic temperatures attained, and there after the change was very slow. The lower organic matter content was recorded in T4. This might be due to the presence of additional bulking agents that used to increase porosity, decrease phytotoxic material and maintain optimum level of C:N, which pave the way for the right C:N ratio and create suitable conditions for microbial activity. However, the result obtained in all treatments is in agreement with the quality compost criteria, which is used by the countries such as Dutch, Belgium and Italy that is >20%. Similarly the mean content of organic matter in all types of composts analysed were all greater than the lowest critical threshold level of 30% as specified by the EPA. The changes in organic matter content of all treatments through time are indicated in Fig.4.6 below.

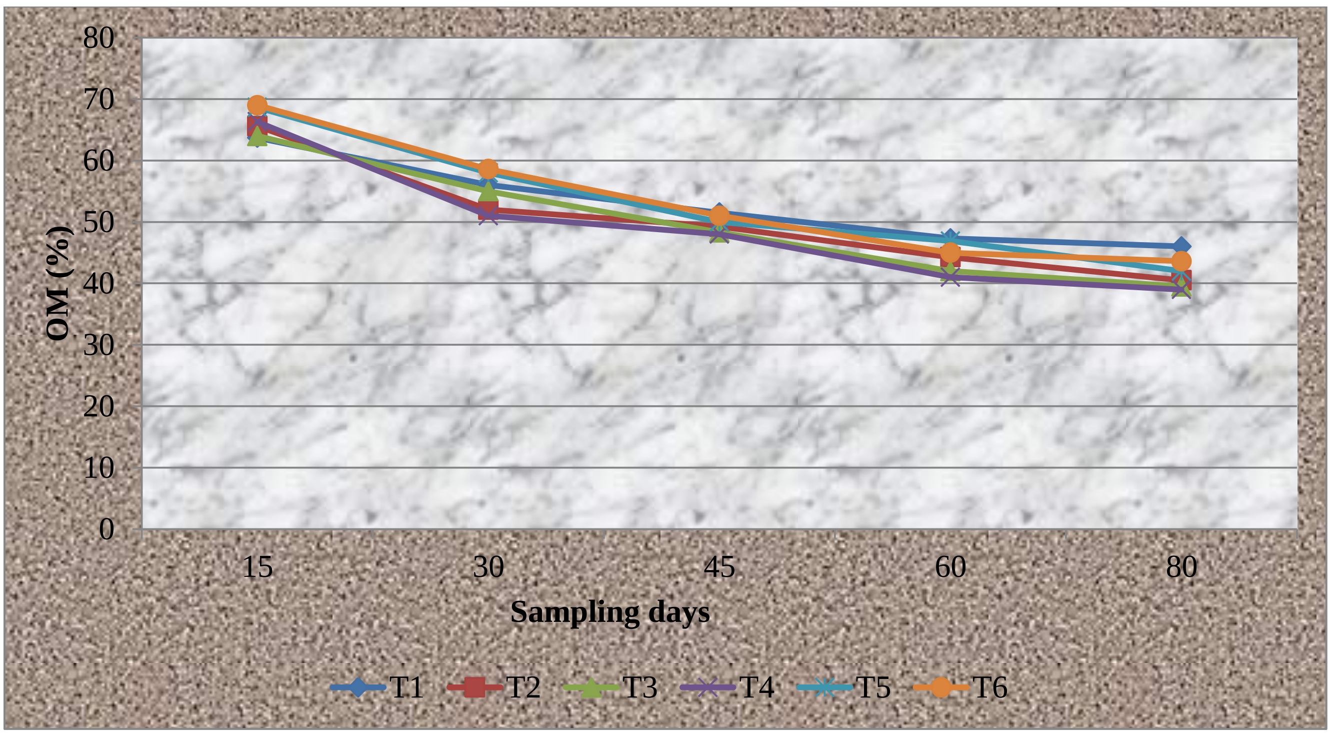

Fig4.6 Mean organic matter content trend in piles

4.1.7 Change in C/N ratio

The C/N ratio (i.e., the TOC to TKN) indicates the availability of nitrogen for the biological decomposition of a compost mixture, and the decrease in this ratio with composting time has been widely accepted as an index of compost stability and maturity. The C/N ratio decreased significantly over time, especially in the co-composted piles, as C was lost in the form of CO_2 through microbial respiration and N was recycled (Ryckeboer et al., 2003). A higher C/N ratio at the end of the composting process for the coffee husk and pulp compost (Pile 1) was found, indicating a slow kinetic process in this compost. The addition of cow dung and khat wastes to coffee husk and pulp, however, significantly contributed to the decomposition of the ligno-cellulosic compounds of the husk and pulp.

The final value for C:N is 20.8, 13.34, 11.32, 11, 16.8, 14 in trial 1, 2, 3, 4, 5 and 6 respectively. The largest shift in C:N ratio was recorded inT4 which might be due to the extra organic amendments that is mixed with coffee husk and pulp. Except T1 the C/N ratio of the studied compost samples are in agreement with the compost quality standards used by the countries such as Dutch, Belgium and Italy that is less than 18. Similarly all studied compost samples are in the range of the recommendations of Ontario Compost quality standards that is less than 22. Again, the result is within the range of the Ethiopian Federal EPA guidelines that recommended the C/N ratio of good quality compost to have a final C: N ratio of 29:1 or less (FEPA, 2004). The difference in C:N ratio may be originated from the difference in geographical location, which results in a different climatic condition countries may set their own standards which may be proved by measuring the necessary macronutrients at different level of C:N ratio. The C:N ratio trend during composting period is indicated here under in figure 4.8.

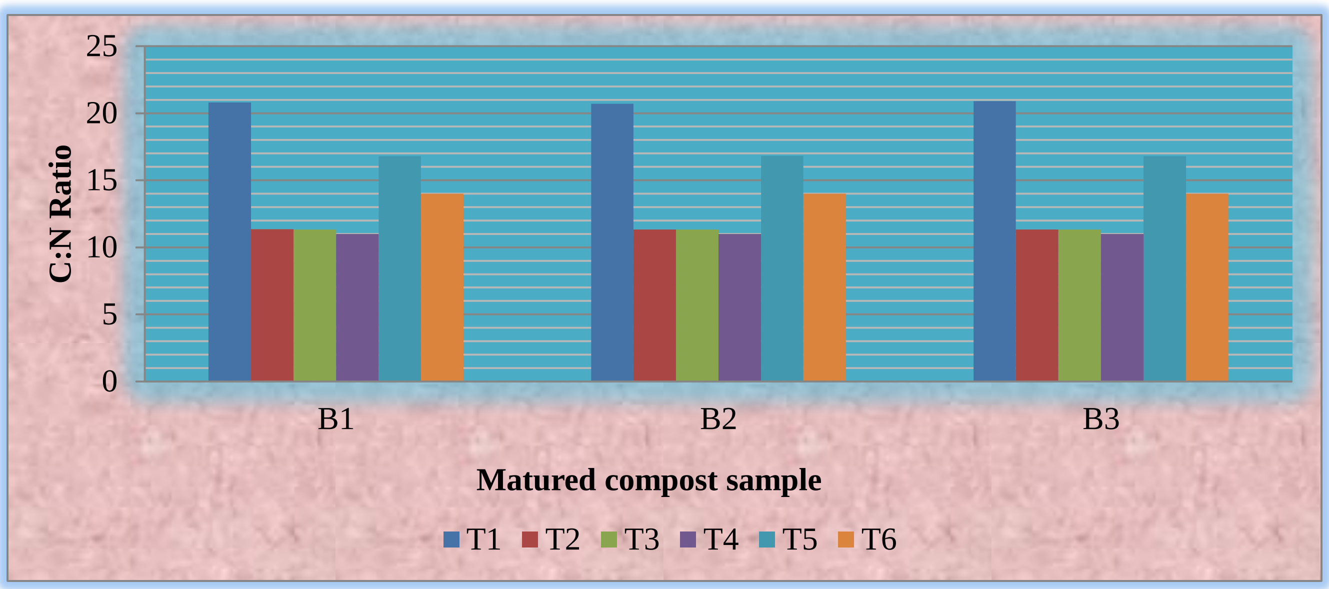

Fig.4.7 C:N values in matured compost

4.2 Nutrient content of compost

Soil fertility and productivity is affected by nutrient elements. Nitrogen, phosphorous and potassium are the nutrients, which are utilised, in the greatest quantities by plants. In general, nutrients are organically bound within compost and are slowly released over a period of time as a result of microbial activity. This ensures a continuous supply of nutrients to the plant (US Composting Council, 2003).

4.2.1 Total Kjeldahl Nitrogen (TKN, %)

Total nitrogen (TN) percentage showed an increasing trend with composting duration, which is due to the concentration effect caused by carbon loss associated with mineralisation of the organic matter. The apparent increase in total nitrogen from initial to matured compost is not only due the reduction in weight because of decomposition. Similar justification was given by parveen (2010) as cited by Mekuria, 2008, for increment of total nitrogen during composting process. The increase in TN may be due to the net loss of dry mass as CO_2 evolution and moisture loss by generation of heat by microbial action on organic matter.

The higher nitrogen for this study is recorded in T4 followed by T3 probably due to the concentration effects caused as a result of degradation of organic compounds which decreased the dry matter content due to the additional bulking agents. The recorded total nitrogen content of the trials was 1.28%, 1.76%, 1.97%, 2.06%, 1.45% and 1.71% for trial 1, 2, 3, 4, 5 and 6 respectively. This result is in agreement with the quality compost criteria, which is used by the counties such as Dutch, Belgium and Italy that is >0.7%. Similarly, the result is in conformity with recommendations for total N in compost by Barker (1997 as cited in Herity ,2003) that is 1-3% dry weight and Ontario ministry of the environment (2004) that recommended the typical minimum concentration (% dry weight) of Total N as 0.6. Similarly, the result is in agreement with compost quality standards for compost used in agriculture in Switzerland (> 1 %) and India (> 0.8 %). Therefore, since the compost samples have Total N over 1%, they have fertilizing capability and can be used in agriculture and hence no supplemental N is needed. The mean percentages of TN content of the matured compost are shown in fig 4.9.

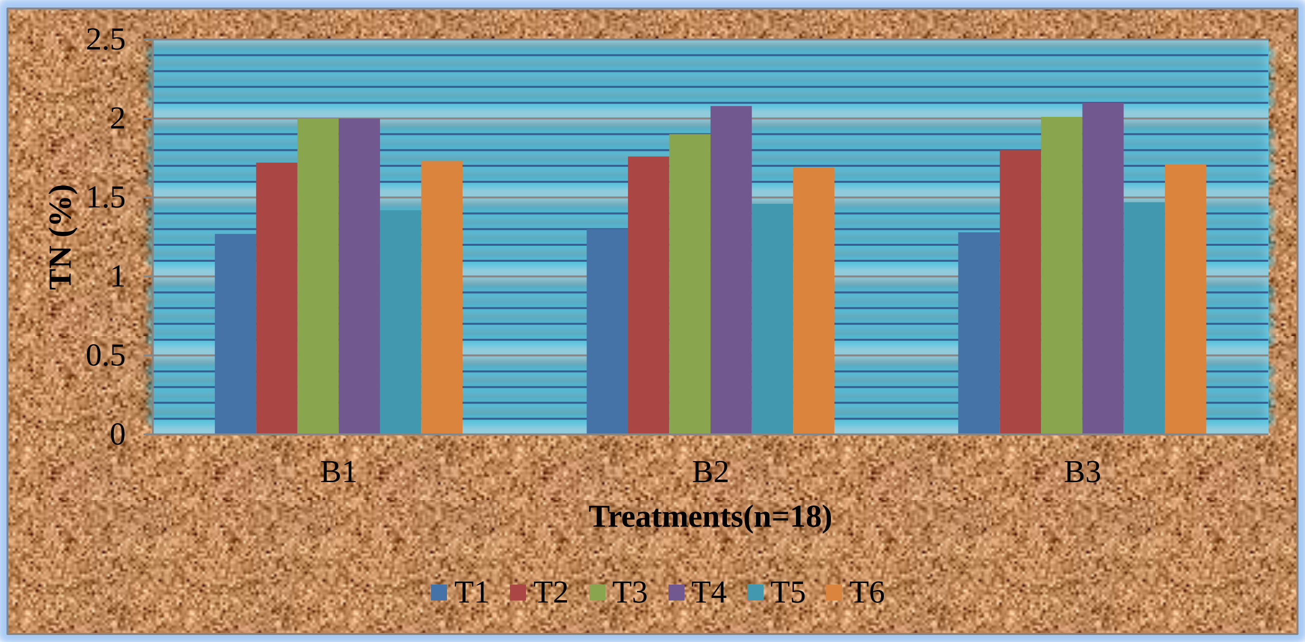

Fig 4.8 Graphical representation of TKN in matured compost

4.2.2 Total phosphorus

Available phosphorus also showed a gradual concentration increment from raw feedstock to processing compost and again in matured compost. The increase of TP concentration during the composting process was attributed to the solubilization of inorganic phosphate by different species of Trichoderma, Aspergillus and Penicillium (as Cited in Mekuria, 2011).

The Total P % content of the matured composts for all the treatments were found to be in between 0.25 – 1.02 %. The highest phosphorus content is recorded in T4, from the overall physicochemical observation of composting process unavailable form of nutrients found in raw feedstock might be converted into available form of nutrients through composting process and recovered in matured composts. The result obtained in this study is in conformity with the recommendations of Ontario ministry of the environment (2004) that recommended the typical minimum concentration (percentage dry weight) of total P as 0.25. In addition, the result obtained was in agreement with the recommendations of Mona (2003 as cited in Herity, 2003) who recommended that the range of Total P to be 0.4-1.1%. The value of total phosphorus for the matured compost is given in figure 4.9 below.

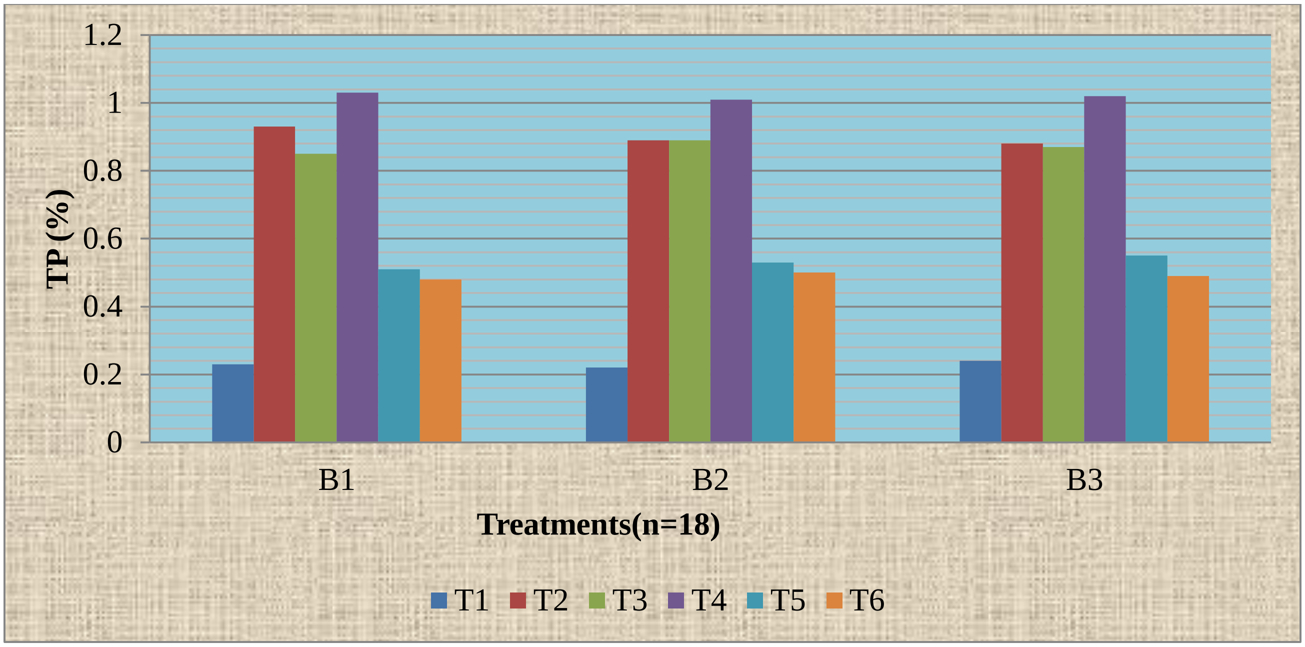

Figure 4.9 Graphical representation of total phosphorus content of matured compost

4.2.3 Total potassium

Potassium in finished compost is much more available for plant uptake than nitrogen and phosphorus since potassium is not incorporated into organic matter. The concentration of potassium showed an increasing trend from initial to final compost through time except T1. The increase of TK concentration during composting process might correspond to the parent materials, enrichment of nutrients and potassium releasing fungus species. Aspergillus fumigants have been reported to be a potassium releasing fungus (as cited in mekuria, 2011). Study by Anandavalli et al., (1998) on recycling of banana Pseudo stem as compost also showed Total K increment as the composting process proceeds. The decrease in total potassium content at T1 might correspond to potassium high water solubility coupled with the high moisture content in the pile results in leaching of the potassium. The value of potassium for the studied compost ranges from 0.25-1.48 in percent, in which T4 is recorded as the highest possibly due to parent material variation from the others that accelerate decomposition. The results obtained in this study is in conformity with the quality compost criteria, which is used by the counties such as Dutch, Belgium and Italy that is >0.75%, except T1 which is out of the recommended range of most countries. The value of K in the final compost is indicated in figure 4.10 below.

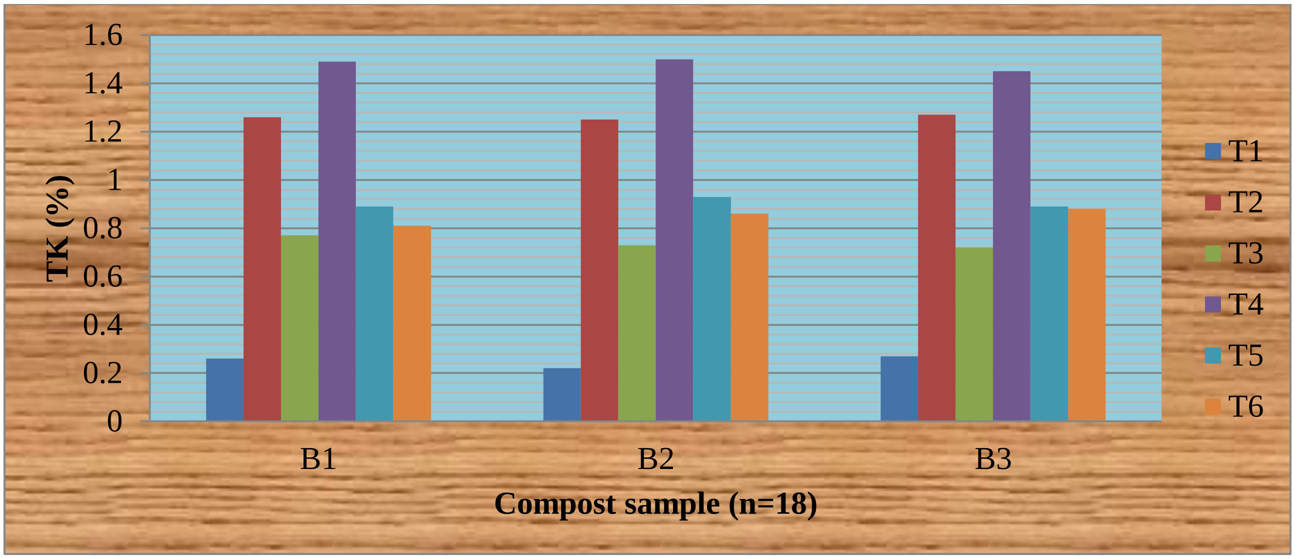

Fig. 4.10 Graphical representation of TK content of matured compost

4.3 Maturity/phytotoxicity test

Immature compost may contain phytotoxins that will often kill seed embryos. Seeds grown in immature compost won't sprout or may die immediately after sprouting. Seed germination and plant growth bioassay are the most common techniques used to evaluate compost phytotoxicity (Kapanen and Itavaara 2001) (quality).

A widely used maturity index is the germination index (GI); it is based on relatively simple to perform seed phytotoxicity tests, which are germination bioassays that quantify seed growth upon the application of compost to the seeds. The GI was first introduced by Zucconi et al.(1981). According to Zucconi et al. (1981), GIs allow to evaluate both low levels of toxicity, that affect root growth, as well as high levels of toxicity, which affect seed germination. Based on that, it would be reasonable to state that GIs lower than 100% indicate a potential phytotoxicity, whilst values greater than 100% indicate a beneficial effect on seed growth, and therefore indicate a mature compost (Dimitrios et al., 2009).

4.3.1 Pot experiment

The pot experiment was carried out for a total of 15 days using maize (BH540) on all treatments and a control (a soil amended with nitrogen fertilizer) to check the maturity of the prepared compost relative to the control. The pot trial was established on April 22, 2016 as a complete randomized block design with three replicates. All growth characteristics of seedlings were determined at the end of 15 days period. Compost was applied to 10L pots which are perforated. Crop sowing was at a rate of 3 seeds per pot. The seed began to germinate at the fifth day of plantation. The following results were obtained during this phytotoxicity test.

4.3.1.1 Plant height

Response of compost on plant height after 15 days of plantation is shown in Figure 4.11. Data clearly indicated that application of compost significantly affected the plant height. Minimum plant height (29 cm) 15 days after plantation was observed in control. All treatments containing compost caused an increase in plant height ranging from 31 to 49 cm 15 days after plantation. The maximum plant height (49 cm) 15 days after plantation was observed on (T4) and the increase was significantly more than that of control. Comparative analysis of compost indicates that effect of compost amended with organic matter showed better results on plant height than control and even than compost produced from coffee residue only.

The reason is that compost had more narrow C:N ratio than that of control and supplied nutrients more quickly. That's why the mean plant height that was observed more in compost application than control due to supplying of more readily available nutrients. In addition to this soil applied organic matter not only served as a reservoir of all the required plant nutrients, but it also gave better structure to the soil, provided energy for the microbial activity which is essential for recycling of nutrients, affected the nutrient availability like N, P and K .

4.3.1.2 Root length

Effect of compost on root length is graphically shown in Figure 4.12. The data clearly depicted that application of compost significantly affected the root length. Minimum root length (8 cm) was observed in control and T1. All other treatments containing coffee residue and other organic amendments caused an increase in root length ranging from 10-12 cm. The maximum root length (12 cm) was observed in T4 where coffee residue was amended with both cow dung and khat waste which is significantly more than that of the control and T1. This was followed by T2 (10 cm) where compost was made from coffee residue with cow dung.

Comparative effect indicated that the effect of compost made from coffee residue together with other organic amendments showed better results on root length per plant than control and even than compost from coffee residue only. The reason is that compost perform better in long terms in soil and affected the root length while staying more consistently in soil and supplied essential nutrients. That's why mean root length was observed more in compost application than control.

Table 4.3: Comparative studies on plant bioassay (plant height)

Treatments	Root length (cm)	Shoot length (cm)	Total length (cm)	No. of leaves
Control	8	21	29	3
T1	8	23	31	3
T2	10	30	41	3
T3	9.7	29	38.7	3
T4	12	37	49	3
T5	9	26	35	3
T6	9.5	27	36.5	3

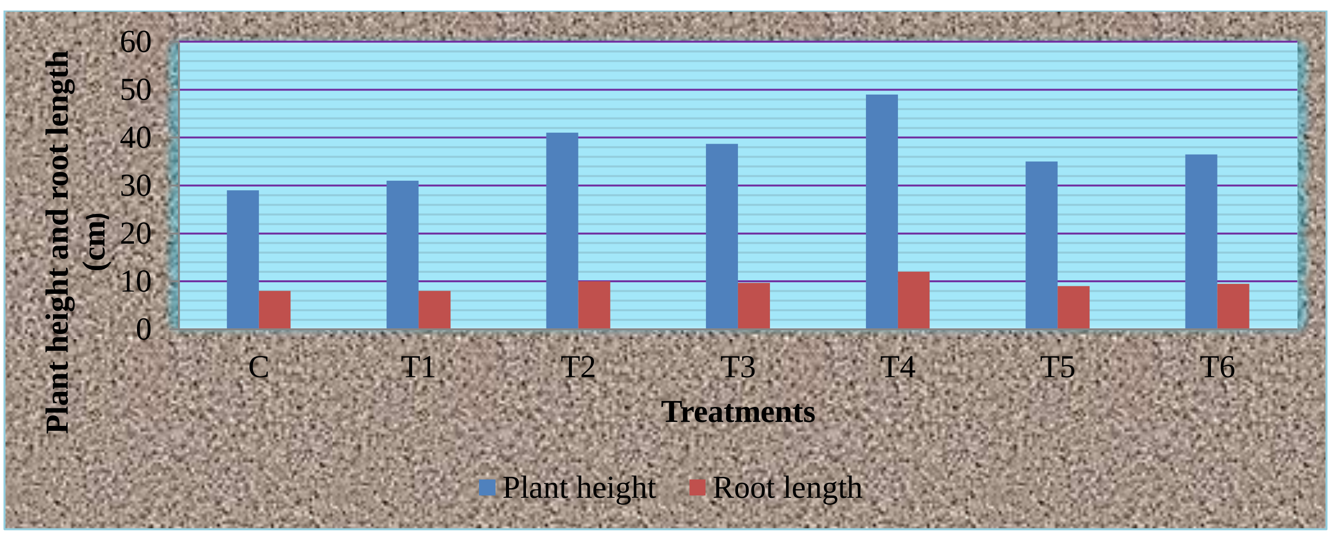

Fig 4.11 Effect of compost on plant height and root length

4.3.1.3 Seed germination

Full germination of all planted maize was observed at the seventh day. The germination was 100% in all test samples and control. Table 4.4 shows that the compost is matured; no more decomposition is going on that release toxic substances that would have the potential to inhibit seed germination and intact root elongation. As indicated in the table below, relative root length is greater than 100 % and above, which indicated that the relative root length of the studied compost samples was much greater than that of the control.

Table 4.4 Comparative studies on plant bioassay (seed germination) and relative root length using each treatment

Treatments	Seed germination (%)	Relative root length (%)
T1	100	100
T2	100	125
T3	100	121
T4	100	150
T5	100	112.5
T6	100	118.75

4.3.1.4 Phytotoxicity test/ Germination index

The entire studied sample produces full germination of the seed that were planted on to the pot. There were no differences between treatments for relative seed germination. The germination index values recorded were more in T4 compared to other compost samples. The data in table 4.5 depicts germination index is greater than 100% for all treatments; due to the availability of plant nutrients in the compost root length is much greater in compost sample than the control. Application of compost will enhance the nutrient status of the soil (Gutser et al,.2005). Even if the compost is low in nutrients it can be valuable since application of compost, or any other form of humic material, effectively enhances soil structure, improves the water holding capacity and reduces the sensitivity to erosion (Manser & Keeling, 1996). Several tests also show that application of compost represses plant diseases in the field (Ros et al,. 2005).

Table 4.5: Plant phytotoxicity test/Germination index using each treatment

Treatments	Plant	RSG (%)	RRL (%)	Phytotoxicity test (%)
T1	maize	100	100	100
T2		100	125	125
T3		100	121	121
T4		100	150	150
T5		100	112.5	112.5
T6		100	118.75	118.75

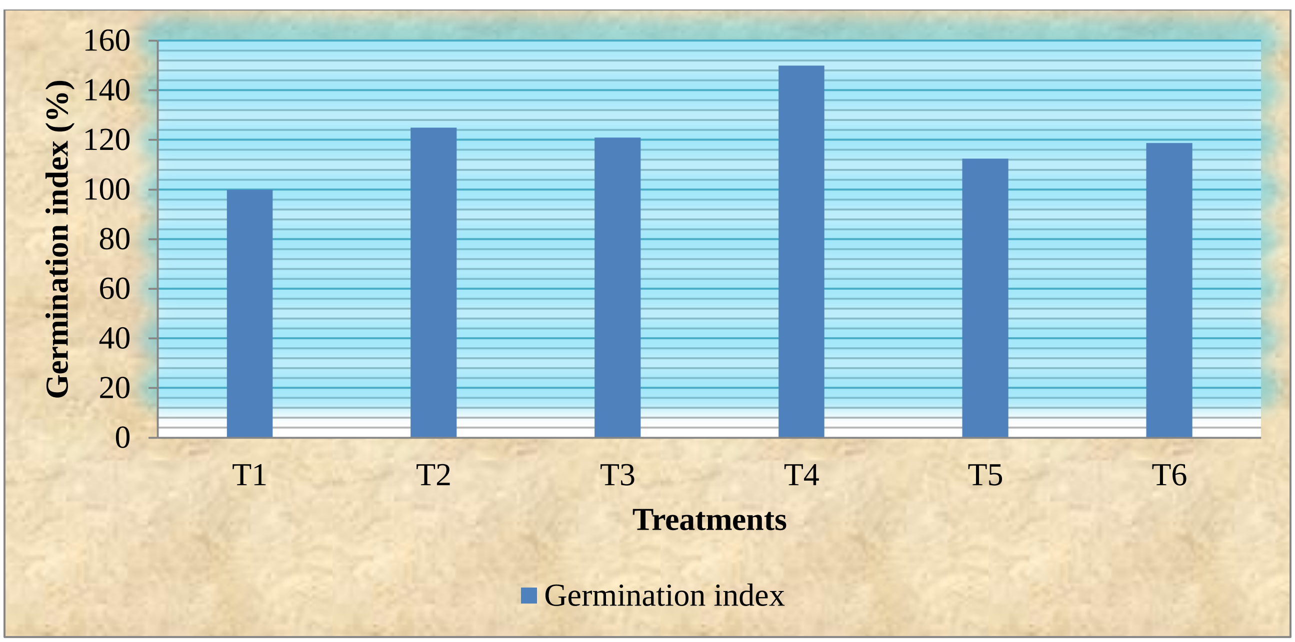

Fig 4.12 Effect of compost on plant germination

4.3.1.5 Leaf Area

As the data depicted below T4 has the largest leaf area than the other treatments, which is significantly different from that of the control, when this happen the plant leaf is more exposed to sunlight which enables it to synthesize more protein through chlorophyll. The effect of compost application on leaf area is indicated here under fig 4.15.

Table 4.6 Comparative studies on plant bioassay (leaf area) using each treatment and control

Treatments	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)
Control	12	2	18
T1	15	2.3	25.87
T2	20.5	3.3	50.7
T3	19.7	2.5	36.9
T4	26	3	58.5
T5	17	2.5	31.87
T6	18	2.7	36.45

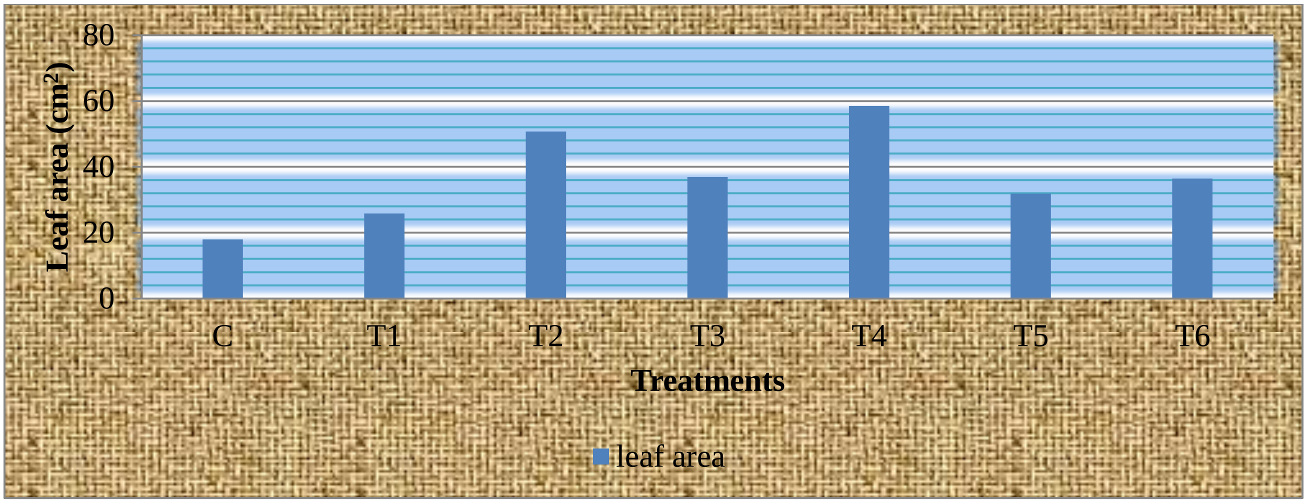

Fig 4.13 Effect of compost on leaf area of a plant

4.3.1.6 Plant fresh weight

Effect of compost on plant fresh weight is graphically shown in Figure 4.15. The data clearly depicted that the application of compost affected the plant fresh weight. Minimum plant fresh weight (6 g) was observed in control. All treatments containing compost caused an increase in plant fresh weight ranging from 7-12 gm. The maximum root fresh weight (12 g) was achieved at T4 which is significantly different from that of the control, which is produced from the application of coffee residue with that of cow dung and khat waste.

Comparative analysis of compost and control indicated that the application of compost showed significantly positive results on plant fresh weight than control. Compost releases nutrients which are useful for the normal growth of plants in the meantime it increases the whole plant bi-omass.

4.3.1.7 Plant dry weight

Effect of compost on plant dry weight graphically is shown by Figure 4.16. The data clearly depicted that application of compost affected the plant dry weight. Minimum plant dry weight 0.9 g was observed in control. All treatments containing compost caused an increase in plant dry weight ranging from 1.23-2.32 gm. Maximum plant dry weight (2.32 g) was observed in T4. The same is true for plant dry mass as that of plant fresh mass. It is due to the readily available nutrients for the plant that increases plant biomass in the compost than the control.

Table 4.7 Comparative studies on plant bioassay (plant fresh and dry weight) using compost

Treatments	Total weight (g)	
	FW(g)	DW(g)
Control	6	0.9
T1	7	1.23
T2	10	1.87
T3	10	1.83

T4	12	2.32
T5	8	1.41
T6	9	1.49

FW: fresh weight in (g), DW: Dry weight in (g)

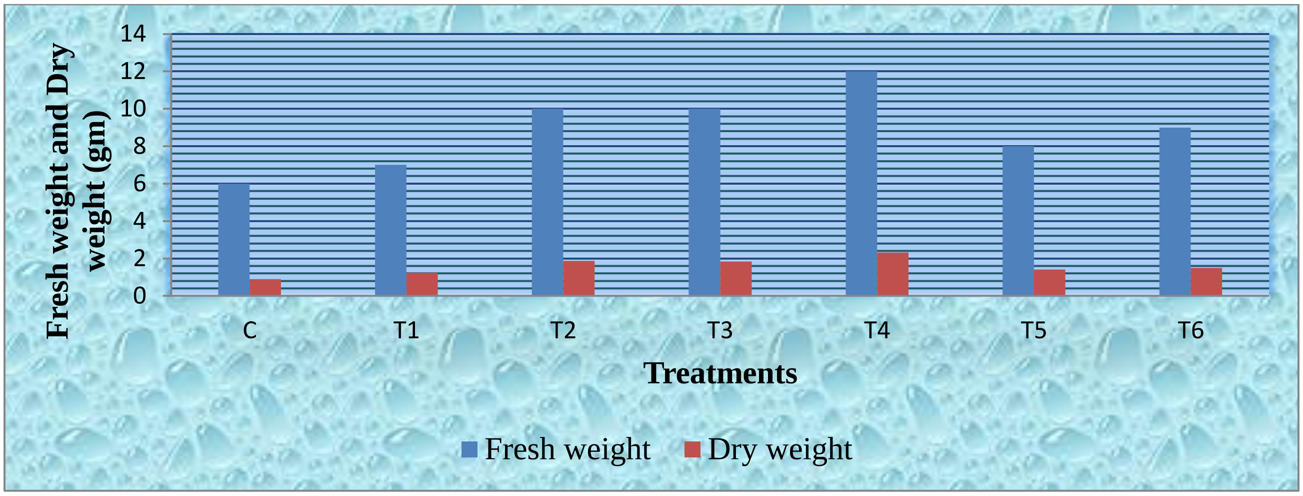

Fig 4.14 Effect of compost on plant fresh and dry weight

4.4 Summary of Maturity Findings

On looking at the parameters assessed for maturity determination, all compost samples were found to be fully mature. Results reveals that all compost samples have the germination index over 100% which mean that all composts are mature, don't have any potential of phytotoxicity. Despite the fact that, the germination index values recorded were more in T4 compared to other treatments. The values of the germination index for compost sample, 100%, 125%, 121%, 150%, 112.5% and 118.5 for T1, T2, T3, T4, T5 and T6 respectively. Results obtained showed differences between control where the GI was lower and the compost where the GI was highest.

The results obtained from the study reveals that height of plant root (12cm), shoot (37cm) and total height of the plant (49 cm), number of leaves (3), leaf area (58.5cm^2), fresh plant weight (12gm), dry weight (2.32gm) and germination index 150% were in T4 compost sample. The study confirm that compost samples composed of coffee residue with khat waste and cow dung greatly influenced plant growth which depicted T4 is the best of all treatments.

4.5 Comparison between selected parameters of the studied matured compost and compost quality standards

The mean values of each parameter for the matured composts and standards of compost quality parameters for quality compost taken from European countries (http://www.compost.org/pdf/Certifica.PDF) and Composting Council of Canada, 2002) are presented in Table 4.8 below.

Table 4.8 comparison between selected parameters of matured compost and compost quality standards

Parameters	Treatments						Quality standards taken from EU and composting council of Canada
	T1	T2	T3	T4	T5	T6	
pH	7.85	8.05	8.2	8.1	7.9	8	6.5-8.5
EC(dS/m)	2.66	4.3	3.19	4.4	3.96	4.15	<5.5dS/m
MC (%)	49.6	39	40.5	38.4	40	39	>= 40
OM (%)	42.7	39.76	39.5	39	40.9	41.6	>20
OC (%)	26.68	23.49	22.32	22.3	24.36	25.3	NA
TKN (%)	1.28	1.76	1.97	2.06	1.45	1.71	>= 0.7
TP (%)	0.25	0.87	1.02	0.9	0.53	0.49	>= 0.5
K (%)	0.25	1.26	0.74	1.48	0.91	0.85	>= 0.75
C:N ratio	20.8	13.34	11.32	11	16.8	14	<25

5. Conclusions and Recommendations

5.1 Conclusions

- Coffee processing wastes contain high fraction of organic wastes which can be transformed to valuable agricultural fertilizer through windrow composting which is technically simple, economically viable and easily adaptable to construct anywhere at farmers level within a short period of time.
- The Physico-chemical characteristics are within the limits recommended standards of most countries for matured compost. Parameters like OC, OM and C/N ratio decreases throughout the composting process while other parameters like pH, EC and plant macronutrients TN, TP and TK increases as composting process progressed till maturity.
- Comparing the compost samples, the Physico-chemical characteristics, germination and plant bioassay were more for T4. The overall study shows that, the compost produced by coffee residue with other organic amendment has high nutrient values which can be used effectively as bio compost.

5.2 Recommendations

- Composting of coffee processing waste for 80 days is important for maturity and to have the necessary plant macronutrients.
- More research is needed on leachate control mechanism during composting process which I didn't consider in this thesis work due to time constraints.
- Not only leachate control, but also there is a need to optimize the process affecting factors on small scale level.

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