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**Monitoring Microbial Numbers, Temperatures, Physical and
Chemical Properties during Composting Under Shambat Conditions
(Sudan)**

مراقبة الأعداد الميكروبية ودرجات الحرارة والخصائص الفيزيائية والكيميائية
للكومة الصناعية تحت ظروف شمبات (السودان)

By

Noon Mustafa Kamal Ali Khaliel

B.Sc. Honors (Soil and Water Sciences)

College of Agricultural Studies (CAS)

Sudan University of Science and Technology (SUST)

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Supervisor

Prof. Mohamed Ahmed Elhag Hadad

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الآية

سَمِ اللّٰهَ بِالرَّحْمٰنِ الرَّحِیْمِ

وَاضْرِبْ لَهُمْ مَثَلِ الْحَيَاةِ الدُّنْيَا كَمَا عَلَّمْنَا مِنْ السَّمَاءِ
تَلَطَّ بِهَا نَبَاتُ الْأَرْضِ فَأَصْبَحَ هَشِيمًا تَذْرُوهُ الرِّيحُ وَكَانَ
اللَّهُ عَلَىٰ كُلِّ شَيْءٍ مُّقْتَدِرًا (صدق الله العظيم.

سورة الكهف الآية (٤٥)

DEDICATION

To
Mother,
Father,
Sister,
Brothers
And friends

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*Thanks, appreciation and gratitude First to **Allah, glorified and exalted** and to my supervisor **Prof. Mohamed Ahmed Elhag Hadad** for his supervision and help and his efforts to complete this study.*

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ABSTRACT

The study was conducted during the year 2015-2016 to study the variation in microbial diversity (bacteria, fungi and actinomycetes), numbers and their effect on chemical properties (pH, nitrogen, phosphorus, potassium, organic carbon and the ratio of carbon / nitrogen) of compost during maturation under shambat (Sudan) conditions.

The study included the preparation of compost and laboratory analysis for the samples, which were taken weekly from compost and measured for physical, chemical and biological properties. The obtained results were as follows: The temperature range was between (29 - 39 °C), pH (7.4 - 8.17), nitrogen (0.4 - 5.0%), phosphorus (0.8 - 5.1 ppm), potassium (46.6 – 84.1%), organic carbon (1.1 to 7.2%), and the carbon / nitrogen ratio (0.4 - 2.0%). Fluctuations in all measured properties were reported during the period of compost maturation.

As regarding the biological properties, fungi was dominant during the first month while weak growth was noticed in the rest of the months. Bacterial growth, on the other hand, was very high during all the time taken for compost maturation (four months), and actinomycetes growth was ranging from average to weak. Microbial growth was certainly influenced by the rise and decrease in temperature inside the compost pile.

These fluctuations in microbial numbers were reflected in the chemical properties of the compost obtained. For example, the rise in temperature was associated with increase in fungal growth, while bacteria and actinomycetes growth was depressed with high pH (7.4 - 8.2). It was noticed also that high growth of bacteria during the period of maturity of the compost was followed by an increase in potassium percentage with a decrease in phosphorus percentage.

ملخص البحث

أجريت هذه الدراسة خلال العام 2015-2016م لدراسة التغيرات في التنوع الميكروبي (بكتيريا وفطريات وأكتينومايسيتات) وأعدادها والخواص الكيميائية (درجة الحرارة والرقم الهيدروجيني والنيتروجين والفسفور والبوتاسيوم والكربون العضوى ونسبة الكربون/النيتروجين) للكومة الصناعية أثناء فترة النضج تحت ظروف منطقة شمبات بالسودان.

إشتملت الدراسة على قسمين وهما تحضير السماد العضوى والجزء المعملى لتحليل العينات الماخوذة اسبوعيا من السماد والتي أجريت عليها التحاليل الكيميائية والبيولوجية.

وقد سجلت النتائج التاليه : تراوح مدى درجة الحرارة (29-39 درجة مئوية) والرقم الهيدروجيني (7.4 – 8.17) و النيتروجين (0.4 – 5.0 %) والفسفور (0.8-5.1 جزء من المليون) والبوتاسيوم (46.6 – 84.1 %) والكربون العضوى (1.1 – 2.7 %) ونسبة الكربون / للنيتروجين (0.4 – 2.0 %) ، حيث لوحظ إزدياد نسب الخصائص تدريجيا مع مرور الشهور.

فيما يختص بالخواص البيولوجية كانت الفطريات أكثر سيادة خلال أسابيع الشهر الأول وضعف نموها فى بقية الشهور. أما البكتيريا فقد أظهرت نموا عاليا خلال جميع الشهور في حين أن الاكتينومايسيتات تدرج نموها من متوسط الى ضعيف وجميعها تأثرت سلبا أو إيجابا بإرتفاع وإنخفاض درجة الحرارة داخل كومة السماد .

وقد إنعكست التذبذبات في أعداد الميكروبات على الخواص الكيميائية للسماد وعلى سبيل المثال، إرتفاع درجة الحرارة تبعه زيادة فى نمو الفطريات مع إنخفاض فى نمو البكتيريا والاكثينومايسيتات ، أما عند مدي الحموضة (7.4 – 8.17) فقد تأثر سلبا نمو كلا من البكتيريا والأكتينومايسيتات. تمت أيضا ملاحظة زيادة في نمو البكتيريا خلال فترة نضج السماد تبعه زيادة في نسبة البوتاسيوم وإنخفاض في نسبة الفسفور.

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Chapter one

Introduction

Africa's declining food production phenomenon is no longer news. The continent's per capita food production growth rates have consistently diminished over the past four decades. Statistics for the developing regions in the early 1990 highlight the contrast between per capita food production indices in China and Sub-Saharan Africa (FAO, 1998).

Soil fertility degradation is one of the most important limitations to food security in Sub-Saharan Africa (Sanchez, 2002 and Waddington *et al.*, 2004). Sub-Saharan Africa is reported to have lost in excess of 22 kg of nitrogen (N), 2.5 kg of phosphorus (P) and 15 kg of potassium (K), per hectare of cultivated land each year in the last three decades through soil mining (Sanchez, 2002). The soil organic matter (SOM) deficiency is an important cause of soil degradation in these areas, reflected in poor soil physical status, loss of favorable biology and occurrence of several nutrient deficiencies (Stoorvogel *et. al*, 1993).

The challenge is to find ways of replenishing and sustaining soil fertility, soil organic matter and food crop productivity within the existing low-income resources and land and labor constraints of the smallholder farmers.

Sudan, being part of Africa, is facing similar challenges regarding soils deficient in organic matter, which needs to be replenished. The climate of Republic of the Sudan is generally hot arid in the north. The soils are deficient in organic matter, which is reflected the low content of nitrogen (N), available phosphorus (P) and sometimes potassium (K). Nevertheless, the relatively high cation exchange capacity (CEC) and percentage base saturation values of these soils indicate their greater ability to retain added nutrients and a reduced tendency to lose them through leaching (FAO, 2006). And Sudanese soils content soil organic matter between (0.05-0.2%).

Composting could be one of the means to replenish soils organic matter. It is the deliberate biological decomposition of organic matter under controlled, aerobic conditions into humus-like stable product (Epstein, 1997). The compost product is an organic matter source and adds humus to soil. It acts to improve soil conditions and plant growth, and reduce the potential for erosion, runoff, and non-source pollution. The composting process is primarily concerned with the creation of a suitable environment in which aerobic microorganisms that are responsible for breakdown of organic matter can be optimally active.

The objectives of this study is therefore are to develop techniques to optimize the composting systems and quality of compost produced by resource poor farmers of Sudan for increased crop production. These could be achieved through:

- Investigating for the microorganism participating in the compost production.
- Montoring of the nutrient release characteristics of the produced compost.
- Plant and animal waste management at the Faculty of Agricultural Studies.
- Increase soil fertility by adding compost to the collage lands.

Chapter two

Literature review

2.1. Background:

Fertilizers are important to the health and vigor of plants. The type of fertilizer selected by the farm owner however is a matter of choice.

Fertilizer is any substance that is added to the soil or sprayed on plant foliage to supply one or more plant nutrients (Mahler, 1990).

Organic fertilizer is a fertilizer consisting of harvested organic materials or wastes. Common organic fertilizers include bird guano, poultry and animal manures of all types, and municipal sewage sludges. Just because a fertilizer is composed of organic compounds, however, does not ensure it qualifies as “organic” under state or national standards for organic agricultural production (Mahler, 1990).

Composting is an aerobic process by which organic materials are degraded through the activities of successive groups of microorganisms; it is an environmentally sound way to reduce organic wastes and produce organic fertilizer or soil conditioner (Gajdos, 1992). Alternatively composting was defined as an aerobic microbial process in which organic materials, such as animal manures, yard trimmings, food waste and crop residues are decomposed to create stable, humus-like product that can be used as a soil amendment (Keener *et al.*, 2011).

2.2. Composting methods:

Some basic composting methods which have been developed include those that use bins, passive windrows, turned windrows, aerated static piles and in-vessel channels.

2.2.1. Bin composting

Is the production of compost in a bin, the compost is produced by natural aeration, and through turning. The compost mix is turned using a tractor frontend loader. Bin composting represents a low technology, medium labor approach producing a medium quality product. Bin composting methods are commonly used for yard waste, smaller amounts of manure and for poultry. Turning compost can reduce decomposition time to two months or less. High temperatures, from 32 °C to 60 °C (90 to 140 °F), are produced when piles are turned every five to ten days.

2.2.2. Turned windrow composting

Is the production of compost in windrows using mechanical aeration, the compost mix is aerated by a windrow turner, which can be powered by a farm tractor (PTO), self powered or self propelled. Turned windrow composting represents a low technology and medium labor approach and produces uniform compost.

2.2.3. Passive windrow composting

Is the production of compost in piles or windrows, compost is produced by natural aeration, over long periods of time. Passive windrow composting represents a low technology and labor approach. Attention to details such as the porosity of the initial mix, uniform product mixing and particle size greatly improves the speed of the process and product quality.

2.2.4. Aerated static pile composting

Is the production of compost in piles or windrows with mechanical aeration, the windrow or pile is located above air ducts, and aeration is achieved by blowing or drawing air through the composting material. Aeration systems can be relatively simple, using electrical motors, fans and ducting or sophisticated, incorporating various sensors and alarms. Aerated static pile composting offers a medium technology and low labor approach, sometimes resulting in a non uniform product. In some systems, mechanical aeration may occur near the end of the active compost period.

2.2.5. In-vessel composting

Is the production of compost in drums, silos or channels using a high rate controlled aeration system, designed to provide optimal conditions. Aeration of the material is accomplished by continuous agitation using aerating machines which operate in concrete bays and/or fans providing air flow from ducts built into concrete floors. In-vessel composting represents a high technology and low labor approach, producing a uniform product (MAFF, 1996).

2.3. The role of soil microorganisms in compost produced:

Compost is produced through the activity of aerobic (oxygen requiring) microorganisms. These microbes require oxygen, moisture, and food in order to grow and multiply. When these factors are maintained at optimal levels, the natural decomposition process is greatly accelerated. The microbes generate heat, water vapor, and carbon dioxide as they transform raw materials into a stable soil conditioner. Active composting is typically characterized by a high temperature phase that sanitizes the product and allows a high rate of decomposition, followed by a lower temperature phase that allows the product to stabilize while still decomposing at a lower rate. Compost can be produced from many feedstocks (the raw organic materials, such as leaves, manures or food scraps) (USCC, 2008).

2.4. Benefits of compost and its effects on soils and plants:

USCC (2008) summarized such benefits as follows:

- Improves the soil structure, porosity and density, thus creating a better plant root environment.
- Increases infiltration and permeability of heavy soils, thus reducing erosion and runoff.

- Improves water holding capacity, thus reducing water loss and leaching in sandy soils.
- Supplies a variety of macro and micronutrients.
- May control or suppress certain soil borne plant pathogens.
- Supplies significant quantities of organic matter.
- Improves cation exchange capacity (CEC) of soils and growing media, thus improving their ability to hold nutrients for plant use.
- Supplies beneficial microorganisms to soils and growing media.
- Improves and stabilizes soil pH.
- Can bind and degrade specific pollutants.

2.5. Additional benefits of compost:

Additional benefits of compost were also reported by the same author as follows: (USCC, 2008).

- Binds contaminants.** Compost has the ability to bind heavy metals and other contaminants, reducing both their leach ability and absorption by plants.
- Degrades compounds.** The microbes found in compost are also able to degrade some toxic organic compounds, including petroleum (hydrocarbons). This is one of the reasons why compost is being used in bioremediation of petroleum contaminated soils.
- Wetland restoration.** Compost has also been used for the restoration of native wetlands. Rich in organic matter and microbial population, compost and soil/compost blends can closely simulate the characteristics of wetland soils.
- Erosion control.
- Weed control.

2.6. Composting disadvantages:

Nelson (2002) summarized such disadvantages as:

- Loss of ammonia compost.** Contains less than half the nitrogen of manure but if manure is not incorporated into the soil it loses nitrogen to the atmosphere and may retain less nitrogen than the compost.
- Time involved composting.** Requires a time commitment to properly manage the windrows to produce quality compost.
- Cost of equipment.** Specialized windrow turners may be required, but they can come at with a high price tag.
- Land required the composting site and storage for finished product can use a considerable area of land.
- Marketing required.** Money and time may be spent advertising, packaging, and For Sale managing the business.

2.7. Use of compost:

Because compost is made up of humus, it can be used for improving soil as stated by Edwards and Araya (2011) as follows:

1-It provides plant nutrients that are released throughout the growing season.

- The plant nutrients are released when organic matter decomposes and is changed into humus.
- The plant nutrients dissolve in the water in the soil and are taken in by the roots of the crops.

2-It improves soil structure so that plant roots can easily reach down into the soil.

- In sandy soil, the humus makes the sand particles stick together. This reduces the size of the spaces (pores) so that water stays longer in the soil.
- In clay soils, the humus surrounds the clay particles making more spaces (pores) in the soil so the root systems of plants can reach the water and nutrients that they need, and air can also move through the soil.
- Therefore, because heavy clay soils become lighter and sandy soils become heavier, soil that has had compost added to it is easier to work, i.e. to plough and dig.

3-It improves the moisture-holding capacity of soil.

- The humus is a dark brown or black soft spongy or jelly-like substance that holds water and plant nutrients. One kilogram of humus can hold up to six liters of water.
- In dry times, soil with good humus in it can hold water longer than soil with little humus.
- When it rains, water easily gets into the soil instead of running off over the surface.
- Water gets into the subsoil and down to the water table, runoff and thus flooding is reduced, and springs do not dry up in the dry season.

4-It helps to control weeds, pests and diseases.

- When weeds are used to make compost, the high temperature of the compost - Making process kills many, but not all, of the weed seeds. Even the noxious weed, Parthenium, has most of its seeds killed when it is made into compost.
- Fertile soil produces strong plants able to resist pests and diseases.
- When crop residues are used to make compost, many pests and diseases cannot survive to infect the next season's crops.

5-It helps the soil resist erosion by wind and water. This is because:

- Water can enter the soil better and this can stop showers building up into a flood. This also reduces splash and sheet erosion.
- Soil held together with humus cannot be blown away so easily by wind.

6-Compost helps farmers improve the productivity of their land and their income.

It is made without having to pay cash or borrow money, i.e. farmers do not have to take credit and get into debt like they do for taking chemical fertilizer. But, to make and use compost properly farmers, either individually or working in groups, have to work hard.

2.8. Microorganisms participating in the composting process:

The composting process, mediated by microbial activity, is affected by physical and chemical environment inside the compost heap which include temperature, aeration, moisture content, C/N ratio and pH (Boulter *et al.*, 2000). The composition of the microbial communities during composting is determined by many factors (temperature, pH, water content, C/N, etc). In addition, under aerobic conditions temperature is the major selective factor for populations and determines the rate of metabolic activities (Sundberg, 2005).

Ministry of Agriculture and Food, British Columbia (1996) noted that the composting process is brought about by several organisms such as bacteria, fungi, actinomycetes and protozoa and may also involve invertebrates such as nematodes, potworms, earthworms, mites and various other organisms. Described succession in the aerobic process, noting that the composition of active micro flora of composting wastes normally shifts from predominant mesophile in the early stages of thermo genesis to thermophiles at the peak of the heating cycle. Several studies have reported the presence of thermophilic bacteria in hot compost (Balasundaran, 2009).

Composting is a thermogenic, solid-state fermentation process, carried out by a succession of microbial populations beginning with mesophilic bacteria, actinomycetes and fungi followed by thermophiles and ending again with mesophiles. Composting process creates stable, soil enriching humus and concentrates the nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg) contents (Eneji *et al.*, 2001 and Balasundaran, 2009).

2.8.1. Bacteria and fungi:

Mesophilic bacteria and fungi are dominant in the initial warming period and during the curing phase and thermophilic bacteria (especially actinomycetes) during the high temperature phase. The quickly changing physicochemical conditions in composting processes are likely to select for a succession of different microbial communities and it can be expected that temperature and the available substrates, including electron donors and acceptors, are the main factors (Ashraf *et al.*, 2007).

The United States Department of Agriculture (2000) stated that the bacteria are small, simple organisms present primarily during the early stages of the composting period. They are responsible for much of the initial decomposition and include a wide range of organisms that can survive in many different environmental conditions. Although they are small relative to fungi and actinomycetes, they are present in significantly greater numbers. Bacteria are fast decomposers. They stabilize most readily available nutrients, such as simple sugars, as well as digest the products of fungal decomposition. Some bacteria can degrade cellulose.

Both bacteria and fungi are present and active in a typical composting process. Earlier studies have revealed that major bacterial groups in the beginning of the composting process are mesophilic organic acid producing bacteria such as *Lactobacillus spp.* and *Acetobacter spp.*, later at the thermophilic stage, gram-positive bacteria such as *Bacillus spp.* and *Actinobacteria spp.*, become dominant. However, it has been observed that the most efficient composting process is achieved by mixed communities of bacteria and fungi (Partanen *et al.*, 2010).

Thermophiles are found in materials or situations that have been naturally or artificially heated such as compost piles or sun heated soils. The number of mesophilic microorganisms increase in the first few days of composting but decrease drastically when the temperature rises to 50 -70 °C. Thermophilic microorganisms require a maximum temperature for growth at or above 50 °C and a minimum temperature for growth at or above 20 °C. A greater predominance of thermophiles may be found in materials or situations that have been naturally or artificially heated such as compost piles or sun heated soils (Balasundaran, 2009).

Aerobic bacteria are the most important initiators of decomposition and temperature increase within the compost pile. Psychrophilic bacteria work in the lowest temperature range and have an optimum temperature lower than 5 °C (40 °F). Mesophilic bacteria do best at temperatures between 10 °C and 45 °C (110 °F). Thermophilic bacteria are heat loving and thrive above 50 °C (120°F). Each category includes many strains of bacteria. The high surface/volume ratio of bacteria allows a rapid transfer of soluble substrates into the cell. Bacteria are nutritionally also the most diverse group of compost organisms, using a broad range of enzymes to chemically degrade a variety of organic materials. Also, the average generation time of bacteria is much shorter than that of fungi which gives them a competitive advantage during those phases of the composting process that are characterized by rapid changes in substrate availability and other process parameters (temperature, moisture, aeration etc.) (Ryckeboer *et al.*, 2003).

Numbers of bacteria (including actinomycetes) are usually much higher than numbers of other microorganisms, e.g. fungi (if total numbers are comparable at all). Consequently, bacteria are responsible for most of the initial decomposition and heat generation in compost, provided that the major growth requirements are met. For bacteria, the optimal moisture content ranges from 50 to 60% and they favor a near neutral pH (Ryckeboer *et al.*, 2003).

Fungi, on the other hand are larger organisms than bacteria. They form networks of individual cells in strands called filaments. Fungi tend to be present in the later stages of composting because of the nature of the material they decompose. Most fungi decay woody substances and other decay resistant material, such as waxes, proteins, hemicelluloses, lignin, and pectin. Fungi are less sensitive to environments with low moisture and pH than bacteria, but because most fungi are obligate aerobes (require oxygen to grow), they have a lower tolerance for low oxygen environments than bacteria. Fungi also cannot survive above a temperature of 140 °F (USDA, 2000).

The ability of fungi to degrade cellulose and lignin is higher than that of actinomycetes and bacteria in general. Temperature is one of the most important factors affecting fungal growth. The majority of fungi is mesophilic (5 °C to 37 °C), with an optimum temperature of 25 - 30 °C. Although most fungi prefer a moderate level of N, low N content is a prerequisite for lignin degradation. Fungi mostly prefer an acidic environment, although they often tolerate a wide range of pH (Tuomela *et al.*, 2000).

2.8.2. Actinomycetes:

The actinomycetes are the third major class of microorganisms that inhabit a compost pile. Actinomycetes are technically bacteria because of their structure and size, but are similar to fungi in that they form filaments and are able to use a variety of substrates. Actinomycetes can degrade organic acids, sugars, starches, hemicelluloses, celluloses, proteins, polypeptides, amino acids and even lignin. They also produce extracellular proteases and can lyse (disintegrate or dissolve) other bacteria. Actinomycetes are more prevalent in the later stages of composting when most of the easily degradable compounds have been degraded, the moisture levels have decreased, and the pH has become less acidic (USDA, 2000).

Actinomycetes develop more slowly than most bacteria and fungi and are rather ineffective competitors when nutrient levels are high (Ashraf *et al.*, 2007). They develop poorly in materials that are too wet or too dry. Most actinomycetes tolerate a higher pH than fungi; their optimum pH is situated between 7-8. Under adverse conditions actinomycetes survive as spores (Ryckeboer *et al.*, 2003).

As moisture decreases, temperature rises above 30 °C and the substrates become more alkaline, actinomycetes, in particular *Streptomyces*, thrive. They cause the characteristic earthy smell of soil and compost by production of geosmine, which are sesquiterpenoid compounds. Actinomycetes compete with other organisms for nutrients and can inhibit microbial growth by production of antibiotics, lytic enzymes or even by parasitism. They play an important role in composting by degrading natural polymers and colonize organic material after bacteria and fungi have consumed easily degradable fractions (Ryckeboer *et al.*, 2003).

The active component mediating the biodegradation and conversion processes during composting is the resident microbial community, among which fungi play a very important role. Therefore, optimization of compost quality is directly linked to the composition and succession of microbial communities in the composting process (Taiwo and Oso, 2004 and Peters *et al.*, 2000).

The composting methods and different substrates are associated with difference in the composition of a microbial community, monitoring of the resident microbial population in compost is essential to determine its quality and field of application (Peters *et al.*, 2000). Thus large and diversified microbial populations were found to be present during the composting process as well as in mature compost. It has been suggested that the appearance of some microorganisms reflects the quality of maturing compost (Ashraf *et al.*, 2007).

2.8.3. Higher organisms:

United States Department of Agriculture (2000) pointed that the higher organisms begin to invade the compost pile once the pile temperatures cool to suitable levels. These organisms include protozoa, rotifers and nematodes. They consume the bacterial and fungal biomass and aid in the degradation of lignin and pectin. These higher organisms contribute to the disease suppressive qualities of the compost.

2.8.4. Pathogenic microorganisms:

Pathogenic microorganisms that may be in compost include bacteria, viruses, fungi and parasites. Although parasites and viruses cannot reproduce apart from their host, Pathogens can be destroyed by heat, competition, destruction of nutrients, antibiosis and time. Antibiosis is the process by which a microorganism releases a substance that, in low concentrations, either interferes with the growth of another microbe or kills it. Most pathogens do not grow at the optimum temperatures for composting. Nutrient requirements of pathogenic microorganisms are specific. If their key nutrients are used by the competing indigenous microbial population, then the pathogens are deprived of nutrients, and they will die (USDA, 2000).

2.9. Keys to good composting:

Rishell (2012) highlighted the steps for good composting:

- 1. Carbon/nitrogen ratio (C/N ratio) by volume** - Combine a mixture of dry leaves old, dead plant material or other sources of carbon with fresh, green plant material or manure for nitrogen. The volume of the brown plant material should equal or be up to three times as much as the green plant material in the pile (C/N ratio of 1:1 to 3:1 by volume).
- 2. Presence of microorganisms** – Compost inoculants, starters or activators, garden soil, and other such materials do not need to be added to the piles because the microorganisms can be found in sufficient numbers on the plant material.
- 3. Moisture level** – The pile should have the moisture of a wrung out sponge. Add water as needed.
- 4. Oxygen level** – A compost pile should be turned periodically to promote decay of its contents. Turning the pile adds oxygen, so the more you turn it, the faster it breaks down.
- 5. Particle size** – The finer the particle size, the more surface there is for microorganisms to work. To speed compost formation, chop or shred leaves and larger materials before adding them.

2.10. Factors affecting the composting process:

Sundberg (2005) stated that composting is a microbial process, and the overall performance of the composting process is therefore the combined effect of the activity of individual microorganisms. It is thus important to understand and control the environmental factors that affect microbial life in composts. The most important parameters for the microorganisms are temperature, oxygen, moisture, pH and substrate composition. Also Partanen *et al.*, (2010) noted the composting is an aerobic process, during which organic waste is biologically degraded by microorganisms to humus-like material. The end product should not contain pathogens or viable seeds, and it should be stable and suitable for use as a soil amendment. Many factors such as oxygen content, moisture, composition of the feed, pH and temperature, affect the composting process and ultimately the end product. Furthermore, these parameters are strongly connected. And Nalivata (2007) mention the composting is dependent on the factors related to the breakdown of organic solids and these include the C/N ratio, pH, temperature, water content and availability of oxygen.

2.10.1. Moisture:

All living organisms need water, so moisture is essential for the function of the composting process. For the microorganisms, there is no upper limit for the water content but excessive moisture reduces the air space in the compost matrix and thus causes oxygen limitation (Sundberg, 2005).

Water is another essential component for the survival of composting microorganisms. The microorganisms require an aqueous environment in which to move and transport nutrients. Water is also necessary to act as the medium for the chemical reactions of life. The ideal moisture content for composting must therefore be a compromise between achieving adequate moisture for the microorganisms to function and adequate oxygen flow to maintain aerobic conditions (USDA, 2000). Water is essential for compost preparation; sufficient moisture helps for quicker decomposition because it is essential for microorganisms to be active. Excess water causes rotting of the materials and creates a bad smell. Without enough moisture, the decomposition process slows down and the materials will not be changed into compost (Edwards and Araya, 2011).

Microorganisms absorb dissolved nutrients and water serves as a medium for distribution within the heterogeneous compost substrate (Spinosa and Vesilind, 2001). Therefore, adequate moisture is essential for microbial activity. A dry compost pile does not decompose efficiently. Likewise, the decomposition of organic matter is seriously inhibited if the moisture content is higher than optimum, as the excess moisture causes an anaerobic condition (Bass, 1999; Nakasaki and Ohtaki, 2002 and Ashraf *et al.*, 2007).

2.10.2. Temperature:

Temperature influences microbial decomposition of waste during composting. As temperature rises in the compost, decomposition speeds up. As temperature drops, composting slows down. Substantial changes occur in microbial populations and species abundance during the various temperature stages (Ashraf *et al.*, 2007).

Nalivata (2007) reported composting processes typically have three main stages as follow:

- 1-Mesophilic growth stage, which is characterized by bacterial growth under temperatures of 25-40 °C.
- 2-Thermophilic stage, where bacteria, fungi and actinomycetes (first level consumers) functioning at temperatures of 50-60 °C, breakdown cellulose, lignin and other resistant materials (this thermophilic stage can go as high as 70 °C).
- 3- Maturation stage, where temperatures stabilize and some fermentation occurs, converting the organic materials to humus (this process commences when the temperature of the composting material reverts to the ambient temperature).

Compost microorganisms are traditionally classified according to their temperature preferences. Microorganisms with optimum temperature for growth at 25-40 °C are called mesophilic and those with optimum temperature above 45 °C are called thermophilic (Madigan *et al.*, 2000). The elevated temperature during composting is not only caused by the microorganisms, but also an important factor determining their activity. Each microbial species can only grow within a certain temperature range, and most microorganisms are killed by too high temperatures. Mesophilic microorganisms are active up to 40-45 °C, while thermophilic organisms have optimum temperatures above that. The temperature for maximum degradation rate in composting is normally near 55 °C, and the degradation rate is much lower at 70 °C (Sundberg, 2005).

Sundberg (2005) noted that during aerobic decomposition of organic substances, the chemical energy in the material is partly released as heat and partly used for the construction of new substances within the organisms consuming the organic material. A large proportion is released as heat, which can be quantified either calorimetrically or through indirect methods. The energy release can be expressed in relation to the consumption of either substrate or oxygen and the latter shows less variation between different substrates. Therefore, the heat produced can either remain in the compost mass, resulting in an increased temperature, or leave it by conduction or radiation either from the surface, or with the air passing through it.

Indirect methods to estimate the heat released during aerobic decomposition use information on substrate composition or oxygen consumption. If the chemical composition of the substance is known, the heat release can be calculated from the proportions of carbohydrates, lipids and proteins. The heat release can also be calculated from the oxygen consumption. The heat of combustion per electron transferred to a methane type bond is relatively constant (Weppen, 2001).

The energy balance, i.e. energy flows and transformations, is crucial to the process development in composting since it (i) determines the temperature and (ii) affects the evaporation. The temperature is an important parameter that determines microbial activity and thus the degradation rate. The evaporation reduces the moisture content, which is important for the degradation rate both directly, as it affects microbial activity, and indirectly, as it affects the structure and therefore the oxygen supply. The two main processes determining the energy balance are the heat generated by decomposition and the heat removed by aeration. In some systems, surface heat losses are also important in the energy balance (Sundberg, 2005).

Aerobic composting involves a process of biological decomposition and stabilization of organic substrates under conditions that allow multiplication and activity of thermophilic microorganisms as a result of biologically produced heat, to produce a final product that is stable, free of pathogens, pests and plant seeds, useful in agriculture and forestry as manure (Balasundaran *et al.*, 1999 and Saravanan *et al.*, 2003). High temperature within waste heap undergoing composting has been considered as consequence of microbial activity, whereby heat is liberated through respiration of microbes and built up within the pile (Tiquia and Tam, 2000).

According to Michel (2009), Temperatures should be taken at various locations and depths. Compost windrows can be turned every 10 days or two weeks. This can minimize labor while creating a good quality product. Organic operation must meet certain temperature and turning frequency requirements.

2.10.3. Aeration:

Based on their use of oxygen, microorganisms can be classified into three groups:

- Obligate aerobes, microorganisms that require oxygen for survival.
- Obligate anaerobes, microorganisms that cannot function in the presence of oxygen.
- Facultative anaerobes, microorganisms that have both aerobic and anaerobic metabolic pathways. Since aerobic metabolism renders more energy for the microorganisms, they grow faster when oxygen is present.

The aeration rate is a key parameter since the gas carries both heat and vapour, and it also supplies oxygen to the process. The multiple functions of aeration make temperature, oxygen consumption and water loss dependent variables, so the possible combinations are limited in a given physical system (Sundberg, 2005).

Compost should have sufficient air, oxygen enters the compost heap. When there is enough oxygen, special bacteria can convert nitrogen into nitrate, the materials are decomposed properly and there is a good smell. If there is not enough air and too much water, the nitrogen is converted into ammonia. The ammonia escapes into the air removing nitrogen from the compost and making it smell bad. If there is excess air and too little water, the materials dry up and do not decompose to become compost (Edwards and Araya, 2011).

Oxygen is necessary for the survival of aerobic microorganisms. If sufficient oxygen is not provided to sustain aerobic microorganisms, anaerobic microorganisms begin to dominate the compost pile, slow the composting process, and produce odors. A minimum oxygen concentration of 5 percent is required to maintain aerobic conditions (USDA, 2000).

Aerobic composting requires large amount of oxygen when the supply of O₂ is not sufficient for the growth of aerobic microorganisms. The rate of decomposition will be slow. Moreover, aeration removes excessive heat, water vapor and other gases trapped in the pile. This may be achieved by controlling the physical quality of the materials (particle size and moisture content), pile size and ventilation by ensuring adequate frequency of turning (Hamad, 2008).

The microorganisms that transform manure into compost require oxygen for their energy deriving chemical reactions. Less than 5 percent of oxygen within the pore space will turn the pile anaerobic (without oxygen), may create a rotten egg smell and will slow the composting process. Aerobic conditions can be replenished by turning the pile. And turning manure is essential to composting manure. Turning compost incorporates oxygen into the system, homogenizes the pile and breaks up clumps. Mixing allows more contact of manure with microbes. Producers have various ways to turn the pile (Augustin and Rahman, 2010).

2.10.4. C/N ratio:

Since composting is a microbial process, compost stability and maturity are the results of microbial activity. Except for extremely mature compost, most compost contains relatively high organic matter content with potentially available organic carbon and nutrients that support microbial populations or activity (Inbar *et al.*, 1993; Butlera *et al.*, 2001 and Wu and Ma, 2002).

Microorganisms require certain nutrients in large amounts. Examples of some of the macronutrients required are carbon (C), nitrogen (N), phosphorus (P), and potassium (K). The relative amounts of carbon and nitrogen present have the greatest effect on the composting process and so are used as the primary indicators of nutrient content. Carbon and nitrogen are also the main nutrient focus because if these nutrients are present in the proper ratio, the other nutrients also tend to be present in the acceptable amounts (USDA, 2000). Compost process efficiency defined as the rate of organic carbon turnover. The carbon dioxide emission or the mass loss of organic matter is two methods that are used to quantify the turnover or decomposition. Decomposition and degradation are two words that are used as synonyms to turnover (Sundberg, 2005).

Manure composts not only improve soil physical and chemical characteristics; they also are a good source of fertilizer for crop production. However, much of the nitrogen is tied up in complex organic compounds (immobilized) and is not immediately ready for plant uptake, whereas commercial fertilizers are predominantly plant available. Cropland soils and compost should be tested for nutrients. Nitrogen, phosphorus and potassium tend to be the most limiting nutrients required by crops (Coyne and Thompson, 2006).

The organic substrates and bulking agents used in composting are mainly derived from plant material. Carbon compounds serve as an energy source for microbial maintenance and growth. The yield coefficient, that is the amount of C incorporated into the cells per unit degraded C, ranges from 10% to 35%, depending on substrate energy content, degrading organism and environmental conditions. Besides a C source, microorganisms require macronutrients such as N, P and K, and trace elements for their growth (Ryckeboer *et al.*, 2003).

Carbon is used both as a source of energy and for growth of microbes. In aerobic decomposition, part of the carbon is released as CO₂ while the rest is combined with nitrogen for microbial growth. As a result, the carbon content of a compost pile is continuously decreasing. And nitrogen is used for the synthesis of cellular material, amino acids, and proteins and is continuously recycled through the cellular material of the microorganisms. Any nitrogen that is incorporated into the cells becomes

available again when the microorganism dies. Because a large part of the carbon is continuously released while the majority of the nitrogen is recycled, the C/N ratio decreases over the composting period. If, however, the system experiences large nitrogen losses, the C/N ratio can increase (USDA, 2000).

Both carbon and nitrogen are needed to make good compost. They are used by the microorganisms to grow and multiply, and to get energy. Some of the carbon is converted to carbon dioxide, and this escapes to the atmosphere. Most of it remains and becomes humus, and the nitrogen becomes nitrates. Methane is not produced if there is a good supply of air to the organisms carrying out the decomposition process. Materials with good nitrogen content help in making good compost, but they should be less than the carbon containing materials. Carbon containing materials should always be more than those containing high nitrogen. A good balance of carbon and nitrogen is needed to make good compost. And when there is enough air and moisture in the compost, nitrogen containing materials are broken down and the nitrogen is changed to nitrates that can be used by plants. And when there is too much water and little air, the nitrogen is changed into ammonia. This is a gas that escapes from the compost, and gives the compost a bad smell, and when its existence, that means the compost needs to be turned over bringing the top to the bottom and the bottom to the top, and mixing in more dry materials and some good soil. This puts more air into the compost, which stops the process of making ammonia so that proper mature compost can be made (Edwards and Araya, 2011).

All organic material contains carbon and nitrogen. Carbon is a major component of the cellulose and lignin that give cell walls their strength. Nitrogen is found in proteins and many other compounds inside plant cells (Augustin and Rahman, 2010). Nitrogen is a critical element for microbial growth. If N is limiting during composting the degradation process will be slow. At excess supply, N may be lost from the system as ammonia gas or through leaching as nitrate. During the process the C/N ratio decreases significantly because part of the C is lost as CO₂ upon microbial respiration while N is recycled (Thambirajah *et al.*, 1995; Larsen and McCartney, 2000 and Tuomela *et al.*, 2000).

Composting material's C/N ratio varies greatly. Differences in manure can be from species, feeding rations, climate, storage facility, etc. The C/N ratio of bulking materials of plant origin varies greatly as well and for the same reasons as manures (Augustin and Rahman, 2010). The C/N ratio is relevant for the ammonia losses from composting processes, with higher losses at lower C/N ratio (Sundberg, 2005). However, the availability of the substrate carbon is also important, as higher carbon availability gives lower nitrogen losses (Barrington *et al.*, 2002).

The breakdown of organic residues by microbes is dependent upon the carbon/nitrogen ratio. Microbes in a cow's rumen, a compost pile, and soil microbes rely on the C/N ratio to break down organic (carbon-based) residues. Consider two separate feed sources, a young tender alfalfa plant and oat or wheat straw. A young alfalfa plant has more crude protein, amino acids, and sugars in the stalk so it is easily digested by microbes whether it is in a cow's rumen, a compost pile, or in the soil. Young alfalfa has a high nitrogen content from protein (amino acids and proteins are high in nitrogen and sulfur), so it has a lower carbon to nitrogen ratio (less carbon, more nitrogen) (Hoorman and Islam, 2010).

The C/N ratio in a composting pile needs to range from (20: 1) (20 parts of carbon for every part of nitrogen) to (40: 1) (40 parts of carbon for every part of nitrogen). Decomposing microorganisms typically have a C/N ratio of (5: 1) to (10: 1). The C/N ratio needs to be higher because approximately 50 percent of the metabolized carbon is released as carbon dioxide. Nitrogen can be lost when too much (C/N ratio below 20: 1) is present, and the pile might smell of volatilizing ammonia. Adding carbon (straw or woodchips) can help alleviate this. Too much carbon (C/N ratio more than 40: 1) in a compost pile can immobilize nitrogen and slows the composting process (Coyne and Thompson, 2006).

A significant amount of nitrogen is lost during the composting process. The amount of nitrogen lost, however, varies widely and is somewhat dependent on the material, method, and management methods. The three possible pathways for nitrogen losses during the composting process are gaseous emissions, leaching, and denitrification. The primary path of nutrient losses during composting is through gaseous emissions. The most important factors in the release of NH_3 from a compost pile are the pH, ammonium $\text{NH}_4 / \text{NH}_3$ equilibrium, mineralization rates of organic nitrogen compounds, C/N ratio, temperature, and pile aeration. A pH greater than 8.0 promotes the conversion of NH_4 to NH_3 . Gaseous NH_3 emissions increase after pile turnings because the action of turning the pile releases any gases that have built up in the pile. In addition, because turning rebuilds porosity and increases pile aeration, it recharges microbial activity so that more NH_3 is produced that is in turn potentially lost (USDA, 2000).

2.10.5. pH value:

The pH value changes during composting, due to changes in the chemical composition. In general, the pH falls below neutral in the beginning due to the formation of organic acids and later rises above neutral because the acids are consumed and because ammonium is produced (Beck *et al.*, 2003).

The pH levels of the raw material of the compost mix do not significantly impact the composting process because different microorganisms thrive at different pH levels. The ideal range for microbial activity is between 6.5 and 8.0. Composting continues at extremes, such as 5 and 9, but the process slows. By the end of the composting process, the pH generally stabilizes between 7.5 and 8.0, regardless of the beginning pH. In most cases the pH does not need to be adjusted because of the natural buffering capacity of the compost pile. The pH does become a concern when material high in nitrogen is to be composted. A basic pH (> 8.5) promotes the conversion of nitrogenous compounds to ammonia. This ammonia formation serves to further increase the alkalinity and not only slow the rate of composting, but also promote the loss of nitrogen through ammonia volatilization. In such cases the pH may need to be adjusted downward below 8. The addition of superphosphate has been shown to conserve nitrogen when used with dairy manure in amounts equal to 2-5 percent of the dry weight of manure (USDA, 2000).

The inhibition of the process when low pH is combined with temperature above the mesophilic optimum is a likely explanation for the lag in the transition from mesophilic and thermophilic temperatures that was observed by Sundberg and Jönsson (2003) and that has been noticed by many others when composting food waste or other acidic wastes (Haug, 1993; Day *et al.*, 1998; Schloss and Walker,

2000; Beck *et al.*, 2001 and Weppen, 2001; Reinhardt, 2002). And noted Reinhardt (2002) when the pH rises, the thermophiles are no longer inhibited, their activity increases and the temperature rise further. This connection between the often observed lag and the low pH.

Adding lime or other alkaline substances to raise the pH is one method to alleviate the inhibition caused by acids in compost and it functions well. However, it is not a perfect solution to acids in compost. First, liming involves extra costs, both for purchase and for the work of adding the lime to the substrate. Second, lime addition can be technically demanding, especially from a work environment perspective. Third, liming increases the ammonia emissions, thus increasing the environmental effects of ammonia release and reducing the nutrient status of the product. As a consequence of the economic, technical and environmental drawbacks of liming, there is reason to search for other ways of overcoming low pH and acid inhibition. One such way is cooling to keep the temperature below 40 °C (Sundberg, 2005). In large scale composting it is difficult to keep the temperature as low as 40 °C, but by increasing the aeration rate it is possible to increase the decomposition rate and thereby shorten the period of low pH (Smars, 2002).

2.10.6. Odors:

Odors produced at the beginning of the composting period are generally caused by the nature of the material used. Material, such as manure or fish processing wastes, often have a strong odor in the initial stages of composting that diminishes as composting proceeds. Odors generated during the composting period result from the production and release of odorous compounds through either biological (microbial respiration) or non biological means (chemical reactions). Odors can be in gaseous form or associated with particulates, such as dust. And the main compounds responsible for odor generation are sulfur compounds, nitrogen compounds, and volatile fatty acids. Sulfur compounds are produced by various processes. They are produced biologically through the decomposition of sulfur containing compounds (cystine, methionine) or through the assimilation of sulfur compounds. Aerobic respiration produces significantly less volatile organics than anaerobic respiration. Volatile sulfur compounds are also produced through the reaction of various compounds that accumulate within the pile. Volatile fatty acids are also responsible for odor generation. They are intermediates in carbohydrate metabolism and accumulate in anaerobic systems (USDA, 2000).

Odors from a composting operation can be a nuisance and a potential irritant. Composting odors are caused by ammonia, amine, sulfur based compounds, fatty acids, aromatics, and hydrocarbons (such as terpenes) from the wood products used as bulking agent's .odors causing compounds during the first 10-14 days of the process (Partanen *et al.*, 2010).

Odor is the most effective and simple indicator of whether the pile conditions are aerobic and, also, to a certain degree, if nutrient losses are occurring through ammonia volatilization. Odors may be detected before composting starts. These odors are generally caused by the raw material itself. This is particularly true for material, such as fish processing waste and manure. However, these odors generally disappear. After the material is incorporated into the compost pile, the odors are masked by the other material in the pile or eliminated because the microbes in the compost mixture use the

odorous compounds as substrates. And strong, putrid odors that sometimes smell of sulfur indicate anaerobic activity, particularly when these odors are accompanied by low temperatures. Anaerobic conditions generally develop in response to high moisture, low porosity environments. If ammonia odors are produced by the compost pile, then it may need to be managed for nitrogen conservation, particularly if nutrient losses are a concern. Such management techniques include reducing the turning frequency and adding carbon rich material to the mix (USDA, 2000).

Ecological factors influence the amount and type of odorous compounds produced and whether they are released. The initial chemical composition of the compost mix, oxygen concentration, oxygen diffusion rates, particle size, moisture content and temperature influences odor production. High temperatures facilitate the release of odors because of increased vapor pressure, increased rate of no biological reactions that produce odor generating compounds and decreased aerobic decomposition (USDA, 2000).

2.11. The size of plant particles:

Whiting (2013) reported the size of plant particles that go into the compost also affects aeration. Large particles allow a lot of air to circulate around the plant chunks, but breakdown is slow because microbes can act only on the outside, not on the inside of the large chunks. Particles chopped into smaller chunks increase the surface area for microbes to operate. Particles chopped too small will compact and restrict air flow. Moderate sized plant pieces of 0.5-1.5 inches are the best size to use and can be produced by hand or machine shredding. Chop woody materials into a smaller size. Leave soft plant parts in larger pieces for effective composting.

2.12. Raw materials used for composting:

Composting is a fertilizing mixture of partially decomposed organic matter from plant and animal origin (Ashraf *et al.*, 2007). A wide variety of waste materials such as sewage sludge, organic refuse and leaves, industrial wastes resulting from brewing, antibiotic fermentation, herbal medicine industry and food processing, tree barks, agricultural residues, abattoir residues and animal manure can be composted (Balasundaran, 2009). Substrate and amendment are two terms that are commonly used in composting. From a technical point of view, substrate normally refers to the wastes that are the primary objective of the operation, and an amendment is any compound is added to improve the process, structurally, biologically or chemically. Most biological material can be composted. Depending on the composition of substrates and amendments, the composting process will be faster or slower, and composting will be easy or more problematic. Four characteristics of the substrate are of primary importance to the process: energy, nutrients, water and structure. Energy, nutrients and water are needed for microbial growth, and structure is essential for the aeration, which supplies oxygen and cools the compost (Sundberg, 2005).

There is a wide range of materials that are good for composting, which include:

- **Alfalfa**, good nitrogen source.
- **Manures**, (horse, sheep, cow, chicken and guinea pigs), good sources of nitrogen and other nutrients.

- **Weeds**, good nutrient source. Best to use when green and no seed heads. Pernicious or perennial weeds should be dried before adding to compost.

Animal manure contains water, nitrogen, phosphorous and potassium, as well as micro nutrients, and is very necessary to prepare good quality compost .and help to produce a high temperature so that the materials decompose into compost easily. Dry materials give structure to the compost making process; they provide space for air to circulate so that the microorganisms can be active and make heat. Green plant materials provide moisture for compost making; they give water and nutrients to the microorganisms so that they multiply and break down the organic materials into humus (Edwards and Araya, 2011).

2.13. Selecting the site:

For Selecting the site has to following factors need to be considered (Edwards and Araya, 2011).

- The site should be accessible for receiving the materials, including water, and for frequent watching/monitoring and follow up.
- The site should be protected from strong sunlight and wind, e.g. in the shade of a tree, or on the west or north side of a building or wall.
- The site should be protected from high rainfall and flooding.
- Preparing the site by clear the site of stones, weeds and grasses, but do not cut down any young trees.
- Pits can be filled two or more times so that a large quantity of compost can be made over the duration of the dry season.
- If pit compost is made during the rainy season or in very wet areas, water can get into the bottom of the pit. This will rot the materials producing a bad smell and poor quality compost. In wet areas it is better to make compost through the piling method.
- It is very important to have frequent follow-up and control of the balance of air and water in the materials being decomposed to make compost.

2.14. The three basic layers for composting materials:

Edwards and Araya (2011) stated that the compost pile is built up by layers of materials, with the following sequence:

- Layer 1: A layer of dry plant materials or mixture of dry plant materials, Water should be scattered by hand or sprinkled with a watering can evenly over this layer making it moist but not soaking wet.
- Layer 2: A layer of moist (green) plant materials, either fresh or wilted, Water should not be sprinkled or scattered over this layer.
- Layer 3: A layer of animal manure collected from fresh or dried cow dung, horse, mule or donkey manure, sheep, goat or chicken droppings.

- The covering layer can be made of wet mud mixed with grass or straw, or from plastic, and can also be protected by putting a ring of stones or making a small fence around it.

2.15. Checking compost heat and moisture:

One week after all the materials has been put in a heap or pit, and it has been covered, remove the inserted stick and immediately place it on the back of your hand and Edwards and Araya (2011) pointed to the following:

- 1-If the stick feels warm or hot and the smell is good, the temperature is normal for the compost and good decomposition has started.
- 2-If the stick feels cool or cold and there is little smell, the temperature is too low for good compositing. This usually means that the materials are too dry, and some water should be added.
- 3-If the stick is warm and wet, and there is a bad smell like ammonia, this indicates that there is too little air and too much water in the compost. The materials will be rotting and not making good compost.

2.16. Solutions for excessive compost moisture content:

Edwards and Araya (2011) highlighted that when the materials are too wet, follow some steps:

- 1-Collect some more dry plant materials and/or some old dry compost. Break up and mix the materials. If old dry compost is not available, use only the dry plant materials.
 - 2-Lift off the top of the heap or take out the top half of the materials from the pit and put them to one side.
 - 3-Mix the new dry materials with the wet compost materials in the bottom.
 - 4-Put back the materials from the side of the heap or pit. If these materials are wet and decaying, put in alternate layers of new dry plant materials with the wet materials.
 - 5-If the top materials are moist and brown showing compost making has started, put them back as they are.
 - 6-Put back the vertical testing stick.
 - 7-Make a new test after a week.
- If the stick is warm or hot and the smell is good, good compost making has started and the heap or top of the pit can be sealed and covered.
 - Testing for heat and moisture should be done every week to 10 days until mature compost is made.

2.17. Qualities and use for good compost:

Edwards and Araya (2011) pointed to although the quality of compost is best evaluated through the growth and productivity of the plants grown on soil treated with it, it is possible to evaluate compost quality through seeing, touching and smelling:

- Good quality compost is rich in plant nutrients and has a crumb-like structure, like broken up bread.
- It is black or dark brown and easily holds moisture, i.e. water stays in it, and it does not dry out fast.
- It has a good smell, like clean newly-ploughed soil, with a smell somewhat like that of lime or lemon.

2.18. Health risks of a composting operation:

A health concern in the operation of composting facilities is the presence of bioaerosols. Are organisms or biological agents that are transported through the air and, under certain specific conditions might cause health problems when inhaled in sufficient quantities. Include bacteria, fungi, actinomycetes, arthropods, endotoxins, microbial enzymes, glucans, and mycotoxins. They must also be present in a dosage sufficient to cause an infection. Most people are not affected by bioaerosols. In many cases bioaerosols only affect individuals who are predisposed to infection. Another health concern of composting facilities is the presence of endotoxins. Endotoxins are metabolic products of gram-negative bacteria that are part of the cell wall and will remain in the bacteria after it has died. Endotoxins are not known to be toxic through airborne transmission, but can cause such symptoms as nausea, headache, and diarrhea (USDA, 2000).

2.19. Compost in Sudan:

Numerous studies were done in Sudan regarding compost preparation. For example, in a study about evaluation of maturing and nutrient content of farm manure composted with chicken manure during the summer seasons. Hamad (2008), found that pH, N, P and K content increased significantly in treated farm yield manure with chicken manure (pH 7.56 – N 2.0 % - P 0.79 % - K 1.3 %). Various genera of bacteria were isolated including, *Bacillus spp*, *Corynebacterium spp*, *Entrbactre spp*, *Micrococcus spp*, *Proteus spp* and *Sreptococcus spp*. It was observed, compost opening time was best after three months when its volume reduced, black in color, crumbly with earthy smell and yields drops of water when tightly squeezed.

Also, another study about which utilized composted baggase, water hyacinth and banana wastes in reclamation of desert soils, the analysis result after 90 days of composting for the prementioned added plants and wastes, Eltaib et al., (2014), reported the following rate of results: N (23.03 / 19.0 / 12.4 g/kg), K (8.9 / 8.3 / 8.5 g/kg), P (84 / 56 / 63 mg/kg), pH (7.3 / 6.9 / 7.4), O.C (30.6 / 32.1 / 42.9 %) and C/N (13.29 / 16.89 / 34.6) respectively. Stable and good quality compost could be prepared from available wastes that can be recycled for desert cultivation. Continuous application of compost from banana and water hyacinth proved to have positive impact on soil quality especially available mineral N, P and K. The project results

showed that grain yield and straw dry matter had consequently increased or showed similar values to the inorganic fertilizer application. Therefore, judicious application of both organic inorganic fertilizers could possibly improve the ecosystem services. Bagasse, a high C/N ratio material should be manipulated carefully before incorporation as this might triggers soil biota and could immobilize nutrients (N and possibly P) applied to the main crop.

Chapter Three

Materials and Methods

3.1. Compost site:

The experiment was conducted at the eastern side of the College of Agricultural Studies - Sudan University of Science and Technology, shambat (Sudan). Where the pile is located south of the new soil laboratory. It was built with brick red and coated with cement; the waste was processed in pile of about 100 cm length, and 100 cm width and a height of 75 cm. The first day for the preparation of compost 7 / January / 2015 to 22 / April / 2015.

3.2. Materials used in the preparation of compost:

All the materials used were collected from the college farm. wet alfalfa was obtained from the local market.

- Fresh alfalfa 14 kg.
- Dry Bermuda Grass 16 kg.
- Cows manure 27 kg.
- Total water 147 liters.

Table (1): Chemical properties of plants used to make composting:

Plants	N%	O.C%	C/N	P ppm	K %
Alfalfa	0.9	1.872	2.08	0.9	47.9
Bermuda Grass (Cynodon-dactylon)	0.3	2.652	8.84	0.12	37.1
Cow manure	1.8	2.769	1.53	0.99	77.9

3.3. Compost materials Preparation:

The wet alfalfa was cut into pieces ranging from (6-11) cm. Materials are put in layers with the dry weed as a basic layer, followed by cow manure and then wet alfalfa till the pile was filled. The Layers of dry weed and cows manure were sprayed with water every now and then to keep them wet. The pile was closed by plastic covers and opened after 7 days for the first sampling.

3.4. Sampling:

The pile was opened every 7 days for sampling. Three samples were taken from different measured depths. Temperatures were measured for all depths that were sampled. The pH was measured to all the samples taken. After sampling the pile was well mixed and an amount of water was added depending on compost dryness.

3.5. Analyses:

3.5.1 Physical and chemical traits measured:

Pile height (cm), Temperature (°C) and pH were measured every 7 days using a measuring meter, thermometer and a pH meter (model 3510), respectively (Ryan *et al.*, 2001).

Samples were air-dried in an open bench at ambient temperature. Total nitrogen was determined using Kjeldhal method, Available phosphorus was determined using Olsen method. Potassium was determined as described by (Ryan *et al.*, 1996). Organic carbon was determined by Walkley and Black (1934).

3.5.2 Isolation of microbial cultures from compost:

During the laboratory work, every tool had been sterilized by using an autoclave which was adjusted at 121 °C and 15 bar for 15 minutes. Decimal serial dilutions 10^{-4} were made and inoculated aseptically in Petri dishes poured with nutrient agar (NA) and incubated in refrigerated incubator (modal 00-E) at 30°C for 7 days. Every sample that was serially diluted was replicated three times. The evaluation of cellular concentration in a compost samples was determined by plate counting of serials dilutions according to equation:

CFU/g = colonies number × dilution of the respective plate. Holt and Krieg (1994).

3.5.3 Statistical analysis:

The influence of chemical parameters (temperature, pH, O.C, N, P, K, compost size) on the microbial concentration was tested statistically using MSTATC program.

Chapter four

Results and Discussion

4.1. The change in microbial succession and chemical properties during composting:

4.1.1. First Month

The data presented in table (2) show fluctuation of the number of fungi, actinomycetes, and bacteria with the depth of the pile and temperature for the first month of composting. In the fourth week, however, high fungal growth was noted with increase in temperature up to 40 °C, with a noticed decrease in growth of bacteria and actinomycetes. Higher bacterial and actinomycetes growth was reported in the second and third week when the temperature was low in the range of (28-36 °C). In addition, very high growth of worms in the third week in Petri dishes.

Bacteria dominated during the 1st two weeks and then declined by the 3rd week when the temperature high, and then fungi dominate. These results are in agreement with the findings of the research conducted by Eneji *et al.*, (2001), Balasundaran, (2009).

Table (2): Effect of time for microbial number during the first month of composting:

Week No.	Temperature °C	Fungi	Actinomycetes	Bacteria
2	33	21	100	254
3	29	0	75	320*
4	39	320	13	2

*320 refer to TMTC (Too much to count i.e. more than 300 CFU/plate).

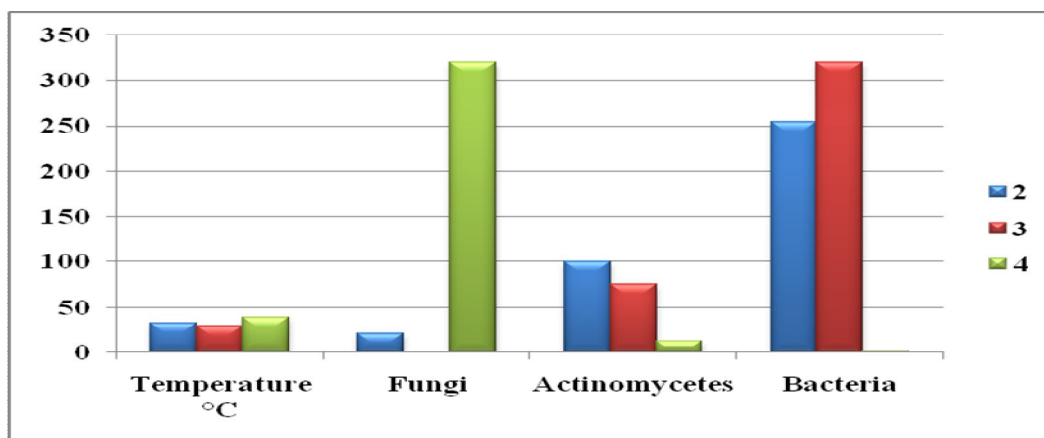


Fig. (1): Effect of time for microbial number during the first month of composting.

The data presented in table (3) show chemical properties of composting samples for the first month with temperature ranging between (29-39 °C). The results showed very low rates of phosphorus and high percentage of potassium through the whole weeks of the month (51.8-70.4%). The pH ranged between (7.7-7.9) and weak ratios of nitrogen (1.33-2.8%) and organic carbon (1.9-2.67%) and C/N (0.68-2.0%). However, both nitrogen and potassium levels showed a trend towards increasing by time and reached the maximum in the fourth week.

Table (3): Chemical properties of the compost during the first month:

Week No.	Temperature °C	pH	N%	O.C%	C/N	P ppm	K %
2	33	7.9	1.40	2.60	1.86	1.3	62.3
3	29	7.8	1.33	2.67	2.00	1.5	51.8
4	39	7.7	2.80	1.90	0.68	0.8	70.4

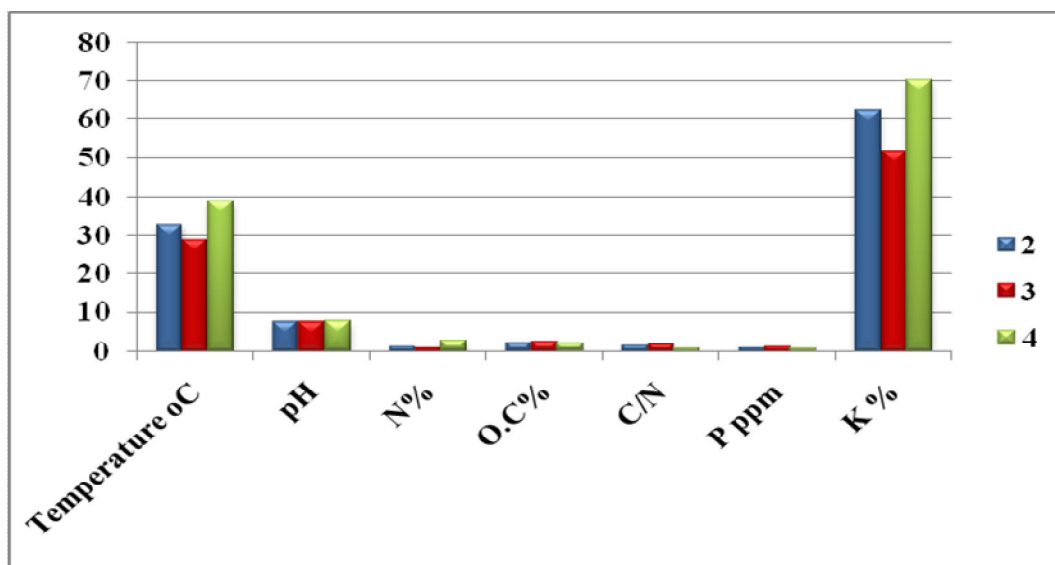


Fig. (2): Chemical properties of the compost during the first month.

4.1.2. Second Month

The data presented in table (4) show the numbers of fungi, actinomycetes, bacteria, with the depth of the pile and temperature fluctuations for the second month of composting. The results showed high growth of bacteria and very weak growth for actinomycetes during the fourth week of the second month. The growth of fungi, however, is too weak in the second and third week, while completely absent in the first and fourth week when the temperature range was (29-37 °C).

Bacteria dominate during the four weeks. These results are agreement with the finding of the research conducted by Ryckeboer *et al.*, (2003) and USDA (2000).

Table (4): Effect of time for microbial number during the second month of composting:

Week No.	Temperature °C	Fungi	Actinomycetes	Bacteria
1	37	0	8	222
2	33	3	5	320*
3	35	5	5	320*
4	29	0	25	320*

*320 refer to TMTC (Too much to count i.e. more than 300 CFU/plate).

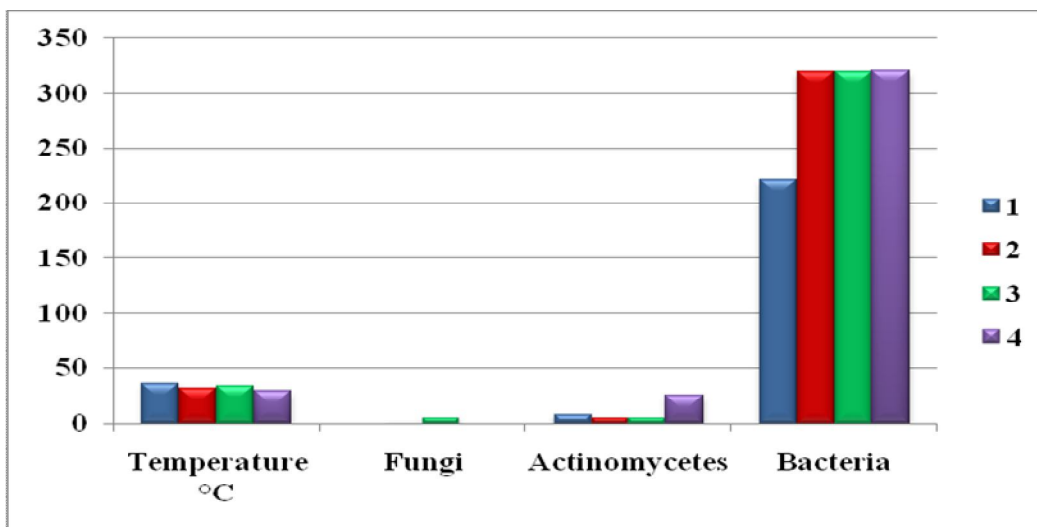


Fig. (3): Effect of time for microbial number during the second month of composting.

The data presented in table (5) show chemical properties of composting samples for the second month with temperature ranging from (29-37 °C). The results showed very low rates of phosphorus and high percentage of potassium through weeks of the month (78.9-84.1 %). The pH range was between (7.5-7.97). And weak ratios of nitrogen (2.5-4.3 %) and organic carbon (1.77 -2.03%) and C/N (0.46-0.79 %). However, both nitrogen and potassium levels showed a trend towards increasing by time and reached the maximum in the fourth week.

Table (5): Chemical properties of the compost during the second month:

Week No.	Temperature °C	pH	N%	O.C%	C/N	P ppm	K %
1	37	7.7	2.50	1.97	0.79	1.3	81.8
2	32	7.8	2.67	2.03	0.76	1.3	78.9
3	35	7.5	4.30	2.00	0.47	1.3	79.9
4	29	7.97	3.83	1.77	0.46	1.2	84.1

*Decrease temperature to 29°C in fourth week result to decrease air temperature.

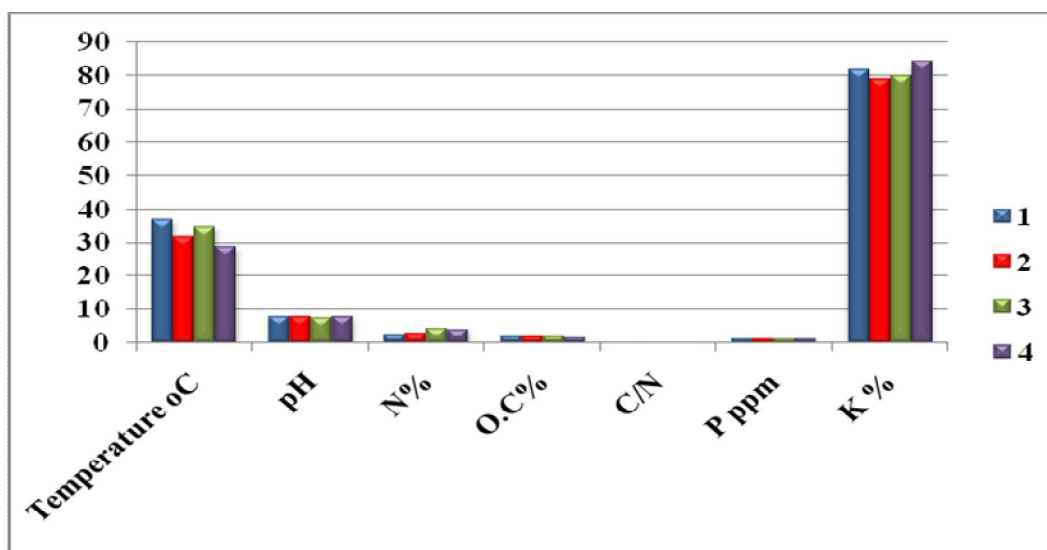


Fig. (4): Chemical properties of the compost during the second month.

4.1.3. Third Month

The data presented in table (6) show the counts of fungi, actinomycetes, bacteria numbers variation with the depth of pile and temperature for the third month of composting. The results showed a high growth of bacteria during the four weeks in the third month. The growth of fungi, however, is too weak in the first and fourth week, with complete absence in the second and third week. High growth of actinomycetes was noticed in the first and second week and very low growth in the third and fourth week. In addition, very low growth of worms in the second week in Petri dishes.

Bacteria dominate during the four weeks, and actinomycetes dominate during 1st and 2nd weeks with higher pH between 7-8. These results are agreement with the finding of the research conducted by Ryckeboer *et al.*, (2003) and USDA (2000).

Table (6): Effect of time for microbial number during the third month of composting:

Week No.	Temperature °C	Fungi	Actinomycetes	Bacteria
1	32	6	204	320*
2	32	0	106	320*
3	31	0	8	320*
4	32	8	3	320*

*320 refer to TMTC (Too much to count i.e. more than 300 CFU/plate).

*appearance of worms growth in second week result to some of Bermuda grass are begin to break down.

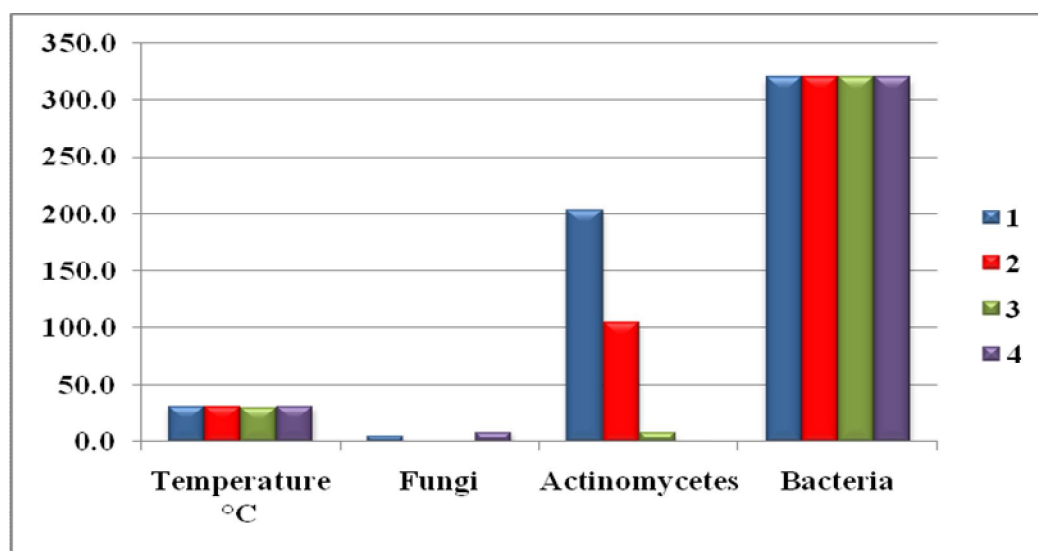


Fig. (5): Effect of time for microbial number during the third month of composting.

The data presented in table (7) show chemical properties of composting samples for the third month with temperature (31-32 °C). The results showed very low rates of phosphorus and high percentage of potassium through weeks of the month (46.6-75.4%). The pH ranging between (7.4-7.8). And weak ratios of nitrogen (0.4-2.47 %) and organic carbon (1.1-2.63 %) and C/N (0.45-6.58 %). However, potassium levels showed a trend towards increasing by time and reached the maximum in the fourth week.

Table (7): Chemical properties of the compost during the third month:

Week No.	Temperature °C	pH	N%	O.C%	C/N	P ppm	K %
1	32	7.4	0.40	2.63	6.58	2.3	75.4
2	32	7.8	2.47	1.10	0.45	1.5	46.6
3	31	7.8	2.07	2.03	0.98	5.1	52.1
4	32	7.4	1.93	1.87	0.97	5.1	65.2

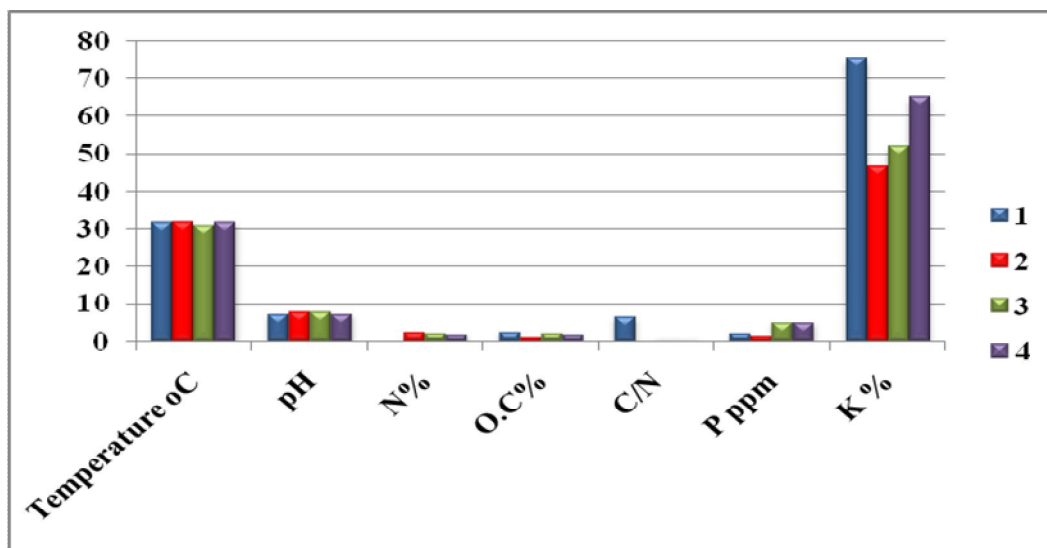


Fig. (6): Chemical properties of the compost during the third month.

4.1.4. Fourth Month

The data presented in table (8) show isolation of fungi, actinomycetes, bacteria, depth of pile and temperature for the fourth month of composting. The results showed a high growth of bacteria and weak growth for actinomycetes during the four weeks in the fourth month. And the absence of fungi growth in the first and second week with very weak growth in the third and fourth week. With temperature ranging from (31-36 °C).

Bacteria dominate during the four weeks, actinomycetes and fungi are present in some week with higher pH between 7-8. These results are agreement with the finding of the research conducted by partanen *et al.*, (2010), Ryckeboer *et al.*, (2003), USDA (2000).

Table (8): Effect of time for microbial number during the fourth month of composting:

Week No.	Temperature °C	Fungi	Actinomycetes	Bacteria
1	31	0	63	320*
2	36	0	0	320*
3	32	13	29	198
4	32	21	75	320*

*320 refer to TMTC (Too much to count i.e. more than 300 CFU/plate).

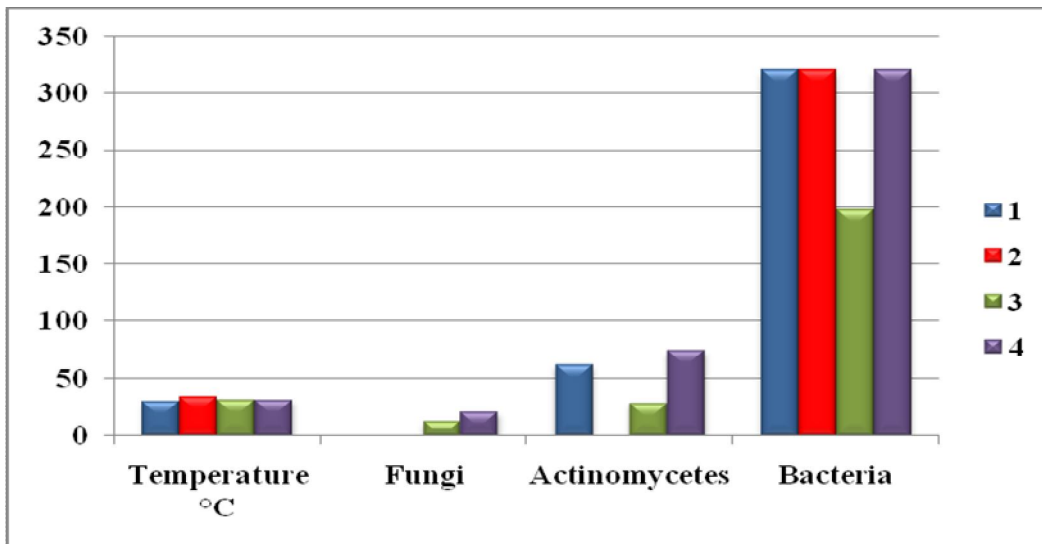


Fig. (7): Effect of time for microbial number during the fourth month of composting.

The data presented in table (9) show chemical properties of composting samples for the third month with temperature (31-36 °C). The results showed very low rates of phosphorus and high percentage of potassium through weeks of the month (59.0-73.4 %). The pH ranging between (7.4-8.2). And weak ratios of nitrogen (3.3-5.0 %) and organic carbon (2.03-2.17%) and C/N (0.43-0.66 %). However, both nitrogen and potassium levels showed a trend towards increasing by time and reached the maximum in the fourth week. And during the process the C/N ratio decreases and that is relevant for the ammonia losses from composting processes. This result agreement with (Thambirajah *et al.*, 1995; Larsen and McCartney, 2000; Tuomela *et al.*, 2000 and Barrington *et al.*, 2002).

Table (9): Chemical properties of the compost during the fourth month:

Week No.	Temperature °C	pH	N%	O.C%	C/N	P ppm	K %
1	31	7.4	4.50	2.03	0.45	3.3	59.0
2	36	8.2	3.30	2.17	0.66	3.7	63.0
3	31	7.9	4.03	2.13	0.53	4.1	67.4
4	32	8.0	5.00	2.13	0.43	4.7	73.4

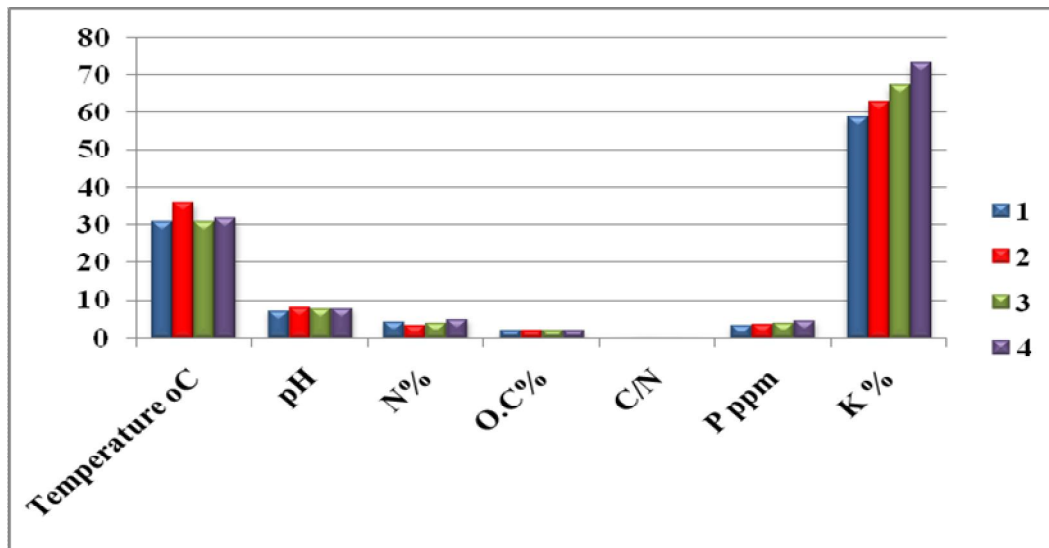


Fig. (8): Chemical properties of the compost during the fourth month.

Chapter five

Recommendation

1. Sampling during the maturation period of the compost is important to know the physical, chemical and biological properties. Also taking repeated samples.
2. As a result of manufacturing compost during the winter period the decomposition rate was slow, so recommended manufacturing compost during the summer to ensure high temperature inside the composting pile to lessen the maturation period.
3. To evaluate compost quality through seeing, touching and smelling, has a black or dark brown color and crumb-like structure and good smell like soil.
4. More research is needed in the field of manufacturing the compost in terms of the diversity of waste type selection and quantization according to their characteristics. This should be accompanied by experimentation in the field to be able to reach practical recommendation for the farmers.

REFERENCES

1. Ashraf, R., F. Shahid and T. A. Ali, (2007). Association of fungi, bacteria and actinomycetes with different composts. 39(6): 2141-2151. pp. 1-5.
2. Augustin, C. and S. Rahman, (2010). Composting Animal Manures: A guide to the process and management of animal manure compost. North Dakota State University, NDSU Extension Services. pp. 3-5.
3. Balasundaran, M. (2009). Development of microbial inoculants for aerobic composting. Kerala Forest Research Institute, Forest Genetics and Biotechnology Division. KFRI Research Report. Thrissur, Kerala. (324): 0970-8103. pp. 11-12.
4. Balasundaran, M., J. K. Sharma and K. C. Chacko, (1999). Chemistry and Process of Composting. In: (M. Balasundaran, J. K. Sharma and K. C. Chacko eds), Compost for Container Seedling Production in Forest Nurseries. Kerala Forest Research Institute, Peechi, Thrissur. pp. 31-36.
5. Barrington, S., D. Choinière, M. Trigui and W. Knight, (2002). Effect of carbon source on compost nitrogen and carbon losses. Bioresource Technology. (83):189-194.
6. Bass, L. (1999). Composting for home gardens. Extension Horticultural Specialist Department of Horticultural Science, North Carolina State University.
7. Beck, F. B., S. Smars, H. Jönsson and H. Kirchmann, (2001). Gaseous emissions of carbon dioxide, ammonia and nitrous oxide from organic household waste in a compost reactor under different temperature regimes. Journal of Agricultural Engineering Research. (78): 423-430.
8. Beck, F. B., S. Smars, H. Jönsson, Y. Eklind and H. Kirchmann (2003). Composting of source-separated household organics at different oxygen levels: Gaining an understanding of the emission dynamics. Compost Science and Utilization. (11): 41-50.
9. Boulter, J. I., G. J. Boland and J. T. Trevors, (2000). Compost: A study of the development process and end-product potential for suppression of turf grass disease. World J. Microbial. Biotechnology. (16): 115-134.
10. Butlera, T. A., L. J. Sikora, P. M. Steinhilber and L. W. Douglass, (2001). Compost age and sample storage effects on maturity indicators of biosolids compost. Journal of Environmental Quality. (30): 2141-2148.
11. Coyne, M. S. and J. A. Thompson, (2006). Math for soil scientists. Thomson Delmar Learning, Clifton Park, N.Y. pp. 176-190 and 199-208.
12. Day, M., M. Krzymien, K. Shaw, L. Zaremba, W. R. Wilson, C. Botden and B. Thomas (1998). An investigation of the chemical and physical changes occurring during commercial composting. Compost Science and Utilization. (6): 44-66.
13. Edwards, S. and H. Araya, (2011). How to make and use compost. Tigrinya booklet by Arefayne Asmelash (1994 EC/2002 GC). pp. 13-61.

14. Eltaib, I. A. O., M. A. Abdalla, M. M. A. Elballa, E. A. Elhadi and F. A. M. Rezig, (2014). Utilization of composted baggase, water hyacinth and banana wastes in reclamation of desert soils. I. effects on yield and nutrients uptake, M.sc. thesis, Desertification Research Institute, National Center for Research, Khartoum University, Khartoum, Sudan.
15. Eneji, A. E., S. Yamamoto, T. Honna and A. Ishiguro, (2001). Physicochemical changes in livestock feces during composting. *Common Soil Sci. Plant Anal.* (32): 477-489.
16. Epstein, E. (1997). *The science of composting*. Technomic Publishing Company, Inc. Lancaster, Pennsylvania, USA.
17. FAO. (1998). FAO Statistics. www.fao.org/stats/.
18. Food and Agriculture Organization of the United Nations (FAO). (2006). Fertilizer use by crop in the Sudan. Land and Plant Nutrition Management Service, Land and Water Development Division, Rome, Italy. PP. 10-24. First version.
19. Gajdos, R. (1992). The use of organic waste materials as organic fertilizers-recycling of plant nutrients. *Acta Hort.* (302): 325-331.
20. Hamad, N. E. (2008). Evaluation of maturing and nutrient content of farm manure composted with chicken manure, M.sc. thesis, faculty of agriculture, Khartoum University, Khartoum, Sudan. pp. 15.
21. Haug, R. T. (1993). *The practical handbook of compost engineering*. Lewis Publishers. Boca Raton. pp. 717.
22. Holt, J. G. and Krieg, N. R. (1994). *Bergey's manual of determinative bacteriology*. Nine editions, the Williams and Wilkins Co., Baltimore.
23. Hoorman, J. J. and R. Islam, (2010). Understanding soil microbes and nutrient recycling. The Ohio State University, the Midwest Cover Crops Council (MCCC), fact sheet Agriculture and Natural Resources. pp. 3.
24. Inbar, Y., Y. Chen and H. A. J. Hoitink, (1993). Properties of establishing standards for utilization of composts in container media. In: (H. J. Keener and H. A. J. Hoitink ed). *Science and engineering of composting*. Renaissance Publ. Worthington, OH. 669-694.
25. Keener, H. M., M. H. Wicks, F. C. Michel and K. Ekinci, (2011). New technologies and approaches for composting broiler manure. Paper presented at the first international poultry meat congress, Antalya, Turkey.
26. Larsen, K. L. and D. M. McCartney, (2000). Effect of C: N ratio on microbial activity and N retention: Bench-scale study using pulp and paper biosolids. *Compost Sci. Util.* 8(2):147-159.
27. Madigan, M. T., Martinko, J. M. and J. Parker, (2000). *Brock-rqBiology of microorganisms*. 9th Edition. Prentice-Hall. Upper Saddle River, N.J., USA. pp. 991.
28. Mahler, R. L. (1990). Fertilizer primer terminology, Calculations and application. pp. 1-2.

29. Michel, F.C. Jr. (2009). On farm-scale composting. Midwest manure summit, Green Bay, Wis. March 24-25, 2009.
30. Ministry of Agriculture and Food-British Columbia. (1996). the composting process. Factsheet composting. (382): 500-2. pp. 3.
31. Ministry of Agriculture, Food and fisheries-British Columbia. (1996). Composting methods. Factsheet composting. (382): 500-5. pp. 1.
32. Nakasaki, K. and A. Ohtaki, (2002). A simple numerical model for predicting organic matter decomposition in a fed-batch composting operation. *Journal of Environmental Quality*. (31): 997-1003.
33. Nalivata, P. C. (2007). Evaluation of factors affecting the quality of compost made by smallholder farmers in malawi, Ph.D. Thesis, National Soil Resources Institute, School of Applied Sciences, Cranfield University. pp. 34-35.
34. Nelson, V. E. I. T. (2002). Composting benefits and disadvantages. pp. 2.
35. Partanen, P., J. Hultman, L. Paulin, P. Auvinen and M. Romantschuk, (2010). Bacterial diversity at different stages of the composting process. pp. 1-4.
36. Peters, S., S. Koschinsky, F. Schwieger and C.C. Tebbe, (2000). Succession of microbial communities during hot composting as detected by PCR-single-strand-conformation polymorphism-based genetic profiles of small-subunit rRNA genes. *Appl. Environ. Microbiol.* 66(03): 930-936.
37. Reinhardt, T. (2002). Organic acids as a decisive limitation to process dynamics during composting of organic matter. In: (H. Insam, N. Riddech and S. Klammer eds). *Microbiology of composting*. Springer-Verlag, Berlin Heidelberg. pp. 177-188.
38. Rishell, E. (2012). Making compost from yard waste. Virginia Cooperative Extension, Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University. 426-703. pp. 1-2.
39. Ryan, J. S., G. K. Hannsen and A. Rashid, (1996). A soil and plant analysis laboratory manual adapted for the west Asia and North Africa region. ICARDA, Aleppo, Syria. pp. 27-30.
40. Ryan, J., G. Estefan and A. Rashid, (2001). Soil and plant analysis laboratory manual, Second Edition, ICARDA. PP. 55-81.
41. Ryckeboer, J., J. Mergaert, J. Coosemans, K. Deprins and J. Swings, (2003). Microbiological aspects of biowaste during composting in monitored compost bin. *J. Appl. Microbiol.* 94(1): 127-137.
42. Ryckeboer, J., J. Mergaert, K. Vaes, S. Klammer, D. De clerq, J. Coosemans, H. Insam and J. Swings, (2003). A survey of bacteria and fungi occurring during composting and self-heating processes, *Annals of Microbiology*. 53(4): 349-410.
43. Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science*. (295): 2019-2020.

44. Saravannan, S., T. Meenambal and R. N. Uma, (2003). Study on biodegradation of fruit waste aerobic composting. Proceedings of the Third International Conference on Environment and Health. Chennai, India.
45. Schloss, P. D. and L. P. Walker, (2000). Measurement of process performance and variability in inoculated composting reactors using Anova and power analysis. *Process Biochemistry*. (35): 931-942.
46. Smars, S. (2002). Influence of different temperature and aeration regulation strategies on respiration in composting of organic household waste, Ph.D. thesis, Agraria 324, Swedish University of Agricultural Sciences, Uppsala, Sweden.
47. Spinosa, L. and P. A. Vesilind, (2001). Sludge into biosolids: processing, disposal and utilization. IWA Publishing, London.
48. Stoorvogel, J. J., E. M. A. Smaling and B. H. Janssen, (1993). Calculating soil nutrient balances in Africa at different scales. I. Supranational scale. *Fertilizer Research*. (35): 227-235.
49. Sundberg, C. (2005). Improving compost process efficiency by controlling aeration, temperature and pH, Ph.D. thesis, Swedish University of Agricultural Sciences, Uppsala. pp. 13-30.
50. Sundberg, C. and H. Jönsson, (2003). Down-scaling a large composting plant to pilot-scale for systematic research. In: (P. Pullammanappallil, A. McComb, L. Diaz and W. Bidlingmaier eds). Proceedings of the 4th international conference of Orbit association on biological processing of organics. Murdoch University, Perth, Australia. pp. 388-397.
51. Taiwo, L. B. and B. A. Oso, (2004). Influence of composting techniques on microbial succession, temperature and pH in a composting municipal solid waste. *African Journal of Biotechnology*. 3(4): 239-243.
52. Thambirajah, J. J., M. D. Zulkali and M. D. Hashim, (1995). Microbiological and biochemical changes during the composting of oil palm empty-fruit-bunches. Effect of nitrogen supplementation on the substrate. *Bioresour. Technol.* (52):133-144.
53. The United States Composting Council (USCC). (2008). Compost and its benefits. USCC Factsheet. Excerpted from the field guide to compost use, The United States Composting Council. pp. 1-2.
54. Tiquia, S. M. and N. F. Y. Tam, (2000). Co-composting of spent pig litter and sludge with forced-aeration. *Biores. Technol.* (72): 1-7.
55. Tuomela M., M. Vikman, A. Hatakka and M. Itävaara, (2000). Biodegradation of lignin in a compost environment: A review. *Bioresour. Technol.* 72(2): 169-183.
56. United States Department of Agriculture-Natural Resources Conservation Service. (2000). Composting. *National Engineering Handbook-Part 637. Chapter 2.* pp. 12-32.

57. Waddington, S. R., W. D. Sakala and M. Mekuria, (2004). Progress in lifting soil fertility in southern Africa. Proceedings of the 4th International Crop Science Congress, 26 Sep. -1 Oct. 2004, Brisbane, Australia.
58. Walkley, A. and I. A. Black, (1934). An examination of the degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Sci.* (63): 251-263.
59. Weppen, P. (2001). Process calorimetry on composting of municipal organic wastes. *Biomass and Bioenergy.* (21): 289-299.
60. Whiting, D. (2013). Making compost. Colorado Master Gardener Program, Colorado State University Extension.
61. Wu, L. and L.Q. Ma, (2002). Relationship between compost stability and extractable organic carbon. *Journal of Environmental Quality.* (30): 222-228.

APPENDIX



Plate (1): Appearance of compost during the first week.



Plate (2): Appearance of compost during the final weeks.



Plate (3): Appearance of compost during the last week.



Plate (4): The high growth of actinomycetes and bacteria for one of the samples.

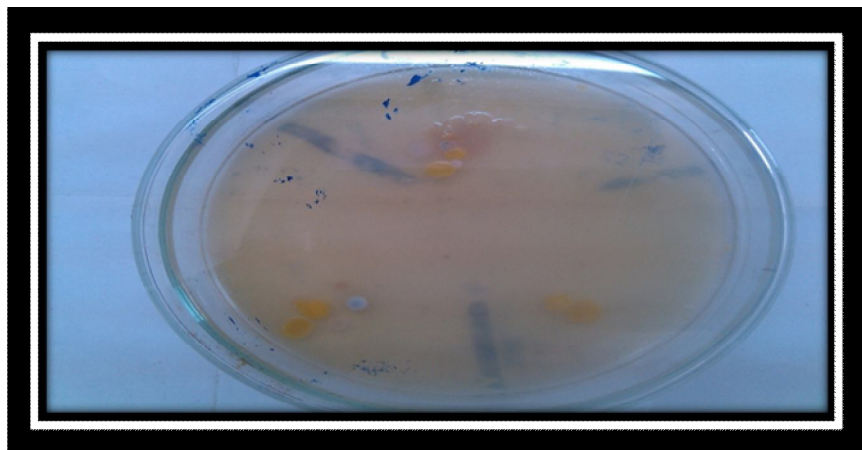


Plate (5): The growth of actinomycetes with various types of bacteria to one of the samples.