ASSESSMENT OF TOTAL AND MOBILE HEAVY METALS IN AMMENDED COMPOST OF WATER HYACINTH OBTAINED FROM LAKE VICTORIA, KISUMU COUNTY

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other University or for any other award.

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DEDICATION

This work is dedicated to my loving parents John Langat and Liza Langat whose words of encouragement, financial assistance and push for tenacity ring in my ears and to my siblings Timothy Kibet, Dorcas Chepngetich, Deborah Chepkoech and Tabitha Cherotich.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CMSFW	Compost Microbiology and the Soil Food Web
EEA	European Environmental Agency
EA	Environmental Agency
EM	Effective Microorganisms
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
FAAS	Flame Atomic Absorption Spectrophotometre
GEMS	Global Environmental Monitoring Systems
IAEA	International Atomic Energy Agency
LVB	Lake Victoria Basin
MAFF	Ministry of Agriculture, Fisheries and Food
MEMR	Ministry of Environment and Mineral Resources
LVBWHSMCS	Lake Victoria Water Hyacinth Surveillance, Monitoring and Control Strategy
PACE	Pan African Conservation Education
PTE	Potentially Toxic Elements
SAS	Statistical Analysis System
SFRC	School of Forest Resources and Conservation
TMECC	Test Methods for the Examination of Composting and Compost
TMESW	Test Methods for Evaluating Solid Wastes
UNEP	United Nations Environmental Programme

USCC	United States Composting Council

ABSTRACT

Water hyacinth (*Eichhornia Crassipes)* invasion in Lake Victoria has become a matter of concern over the last two decades. There has been suggestion on the possibility of producing compost from water hyacinth as a way of managing the weed cover in the lake and at the same time help local farmers in the region boost their agricultural production by supplementing the use of commercial chemical fertilizers. However, the safety of using water hyacinth's compost has to be investigated as studies have shown that water hyacinth accumulates heavy metals from the environment. The specific objectives of the study were to determine the total concentrations of heavy metals (Pb, Cd, Ni and Cu) in water hyacinth compost, to determine the effect of the carbonaceous materials (cattle manure and molasses), and effective microorganisms treatment of water hyacinth's compost feedstock materials on the mobile concentrations of heavy metals and to determine the relationship between total and mobile concentrations of heavy metals in compost. In the study, water hyacinth compost was prepared using commercial effective microorganisms (EM) solution and carbonaceous materials (cattle manure and molasses) separately as starter cultures for composting. Compost samples were digested with concentrated nitric acid to extract total metals and mobile concentrations were extracted using de-ionized water. Concentration of heavy metals in the compost was determined using Atomic Absorption Spectroscopy and the data collected was analyzed for significant differences ($p < 0.05$) using one-way Analysis of Variance (ANOVA) with Statistical Analysis System (SAS) Version 9.2 software. Means were separated using Tukey`s test at 5 % level. Pearson correlation analysis was also carried out to check the significances of the linear relations between total and mobile concentrations. Assessment of heat released during composting of water hyacinth showed that water hyacinth compost attained stability and thus maturity after 60 days of composting. The range of total heavy metals in compost samples were 1.23-1.46 mg/kg (copper), 0.32-0.35 mg/kg (cadmium), 0.25-0.32 mg/kg (nickel), 0.95-1.41 mg/kg (lead). The mean concentrations of the mobile heavy metals in mg/kg for the control, EM, manure and molasses treatments were copper: 0.054, 0.055, 0.027 and 0.049. Cadmium: 0.023, 0.032, 0.018, and 0.035. Nickel: 0.036, 0.027, 0.033, and 0.031. Lead: 0.043, 0.061, 0.023 and 0.093. There were significant differences in the mean concentrations of total and mobile concentrations of heavy metals between treatments. The total concentrations of heavy metals in water hyacinth compost, irrespective of treatments, were within acceptable limits and the addition of carbonaceous materials significantly affected the mobility of heavy metals. Nickel had an all positive relationship between total and mobile concentrations. However, for Cu, Cd and Pb an increase in total concentrations did not necessarily correspond to an increase in mobile concentrations. The mobile concentrations of heavy metals in compost were not predictable from their total content. Manure treatment had the least fraction of mobile heavy metals. It is therefore recommended that the composting of water hyacinth for organic fertilizer and as a way of disposing harvested water hyacinth biomass be done. The study also recommends amending of water hyacinth compost feedstock with cattle manure in order to reduce mobility of heavy metals in compost and consequently help alleviate possible adverse effects of compost on the environment.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Lake Victoria is the second largest fresh water lake in the world (Abila and Jansen, 1997). It provides several benefits to local communities that include source of water for domestic, industrial and agricultural uses. It is also a source of livelihood as majority of the population around the Lake Victoria Basin (LVB) relies on fishing as their main source of food and income (Bakema and Iyango, 2000). The spread of invasive alien species of water hyacinth in Lake Victoria threatens not only biodiversity but also economic development and human well being (UNEP, 2012). Over the last few years, water hyacinth invasion in Lake Victoria has threatened its capability to provide sustainable services for the communities that had long depended on the lake (LVBWHSMCS, 2012).

Water hyacinth invasion is considered one of the key pressures on world's biodiversity. It alters ecosystem services and processes, reduces native species abundance and genetic diversity of ecosystems (Rands *et al*., 2010; Vila *et al*., 2011). Water hyacinth infestation challenges the ecological stability of fresh water bodies by out-competing other species growing in the vicinity (Patel, 2012). This suppresses the growth of native plants and negatively affects microbes which consequently prevent the growth and abundance of phytoplankton ultimately affecting fisheries (Gichuki *et al.,* 2012; Villamagna and Murphy, 2010). Various methods have been used to eradicate the macrophyte but with little success mainly because of its regeneration ability from fragments of stems and its seeds that can remain viable for more than six years (Gunnarsson and Petersen, 2007).

Composting has been identified as the most promising technique for the control and treatment of water hyacinth infestation mainly because its organic substrates can be biodegraded and stabilized by composting and the final compost products can be applied to land as fertilizer or soil conditioner (Prasad *et al.*, 2013). The utilization of water hyacinth as an organic source of nutrients for crop production has been reported by Sasidharan *et al.* (2012) and its capability to accumulate plant nutrients and heavy metal contaminants present in water bodies is well known (Liao and Lian, 2004) making disposal of its biomass a major constraint (Sasidharan *et al.*, 2013).

The regions surrounding the water hyacinth infested parts of Lake Victoria does not enjoy technological advancement in terms of agriculture as compared to other agricultural regions in the country. The indigenous people of this region are hard working and have been managing their agricultural activities with their traditional know how and often do not get access to chemical fertilizers since most of them are resource poor (Osoro *et al*., 2014). Quality organic compost would be the basic requirement of effective and beneficial agricultural system that would enable the local smallholder farmers improve their agricultural production and at the same time help control the water hyacinth's impacts in the region.

1.2 Problem statement and justification

The spread of invasive alien species of water hyacinth threatens biodiversity and economic development, by limiting water transport thereby preventing people's access to fishing grounds (UNEP, 2012). To prevent water hyacinths' cover from impeding water transport, residents and organisations have been using several harvesting techniques, ranging from fishermen working with rakes to machines operating both from shore and floating on water. The harvested plants are later dumped on the beaches in large piles and there seem to be no disposal plan. High degree of pollution by plant nutrients such as nitrates, nitrites and phosphates has been found to sustain the prolific growth of water hyacinth (*Eichhornia Crassipes)* (Sasidharan *et al.,* 2013**)**.

Water hyacinth plants have natural high levels of nutrients (nitrogen and phosphorous) and dumping areas will therefore have a potential leaching risk. Nitrogen and phosphorous are the two nutrient elements most often associated with eutrophication and an escape of these substances will further contribute to an increased growth in already nutritious Lake. According to Nyananyo *et al*. (2007), water hyacinth besides being a nuisance in public water bodies has high protein and total organic matter content, which makes it a potential raw material for the production of a low cost alternative source of organic fertilizers. Composting of water hyacinth would be a good and feasible way of disposing harvested plants and can be carried out by mixing dried water hyacinth with other materials for effective and optimum decomposition (PACE, 2013).

Nevertheless, water hyacinth has been reported to have exceptionally high affinity and accumulation capacity for several heavy metals from the environment and it is known to affect metal fluxes through those ecosystems (Liao and Lian, 2004). Previous results of heavy metal analysis in river water and other drainage entering the wetlands of Lake Victoria Basin in Kenya showed contaminations with lead, nickel, cadmium and copper (Mutakyahwa *et al*., 2009). The wide distribution of heavy metals in water and atmosphere, make the raw materials for compost possible sources of heavy metal pollution (Chen *et al.*, 2010). Since the compost will be used on local crop fields it is important therefore, to ascertain that there are no harmful levels of potentially toxic elements (PTE´s), such as the trace elements; Cu, Cd, Pb and Ni in the compost that could accumulate in soil, cultivated crops and in the long term affect human beings.

Because of heavy metal risks, which could be associated with compost produced from water hyacinth, many countries in the world have established specific guidelines and standards for application of wastes and effluents in agricultural lands. However, these guidelines are lacking in most developing countries. These guidelines, which are generally based on phytotoxic effects and limited to plant uptake studies normally specify the maximum allowable total metal concentration and exhibit considerable variation (Mondol *et al*., 2011). Water-soluble metals represent the most mobile and immediately available fraction of the total content (Adekunle, 2009). This is mainly because soil solution is the interface between the root system and the soil, and therefore the concentration and chemistry of heavy metals in the solution form would be closely related to their mobility and bioavailability (Iwegbue *et al.*, 2007). In this study, water hyacinth's compost was assessed to establish whether the concentrations of heavy metals were within the acceptable limits and if amending with carbonaceous materials and treatment with effective microorganisms could help in immobilizing heavy metals. This study was also designed to investigate the relationship between total and mobile concentrations of heavy metals in compost (Cu, Cd, Ni and Pb).

1.3 Hypotheses

i) Heavy metal concentrations in water hyacinth's compost are within the acceptable limits.

ii) Addition of carbonaceous materials (molasses and cattle manure) and effective microorganisms to water hyacinth compost feedstock materials affects the concentrations of mobile heavy metals in compost.

iii) Total concentrations of heavy metals have no relationship with mobile concentrations of heavy metals in compost.

1.4 Objectives

1.4.1 General objective

To determine the total concentrations of heavy metals (Pb, Ni, Cu and Cd) and mobile concentrations in mature water hyacinth derived compost after treatment with carbonaceous materials (cattle manure and molasses) and inoculation with effective microorganisms.

1.4.2 Specific objectives

i) To asses water hyacinth compost stability.

ii) To determine the limit values for heavy metals (Pb, Cd, Ni and Cu) and how their concentrations conform to the acceptable limits of heavy metals in water hyacinth compost.

iii) To assess the effect of addition of organic amendments (cattle manure and molasses) and effective micro-organisms treatment to water hyacinth's compost feedstock materials on the concentration of mobile heavy metals in the compost.

iv) To determine the relationship between total and mobile concentrations of heavy metals in water hyacinth compost.

1.5 Significance of the study

The findings of the study will help establish the safety of using water hyacinth sourced from the Lake Victoria as compost material and in the disposal of harvested water hyacinth biomass. This is expected to go a long way in controlling the weed cover on the water body and at the same time help local farmers improve agricultural production in the region surrounding the water hyacinth infested part of Lake Victoria by providing a cheap and safe source of organic fertilizer. The evaluation of the composting process will provide theoretical reference and technical support for future production practice.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water hyacinth

2.1.1 Water hyacinth distribution

Water hyacinth (*Eichhornia crassipes)* is a free floating (but sometimes rooted) freshwater plant in the family *Pontederiaceae* (Plate 2.1). It has proven to be of significant economic importance and ecological burden to many sub-tropical and tropical regions of the world (Martinez and Gomez, 2007). Water hyacinth is listed as one of the most productive plants on earth and shows logistic growth as does other floating aquatic weeds. It has invaded freshwater systems in over 50 countries (Martinez and Gomez, 2007). It is pervasive especially throughout Southeast Asia, the South Eastern United States, Central, East and Western Africa and Central America (Gichuki *et al.,* 2012; Patel, 2012). While seeds may not be viable at all sites, water hyacinth commonly colonizes new areas through vegetative reproduction and propagation of horizontally growing stolons. In the early stages of infestation, the weed takes foothold on the shoreline in the areas where native aquatic plants thrive (Gichuki *et al.,* 2012). However, it is not restricted to shallow water, unlike many submerged and emergent macrophytes, because its roots are free-floating near the surface (Villamagna and Murphy, 2010).

The spread of invasive alien species of water hyacinth is neither easy to manage nor easy to reverse, threatening not only biodiversity but also economic development and human well being (UNEP, 2012). Native to the Amazon Basin in South America water hyacinth has emerged as a major weed in the tropical and subtropical regions of the world with profuse and permanent impacts (Shanab *et al*., 2010; Villamagna and Murphy, 2010).

Plate 2.1: Water hyacinth plant. Source: SFRC, 2013

2.1.2 Water hyacinth (*Eichhornia crassipes)* infestation in Lake Victoria, Kenya

Water hyacinth infestation has choked water ways and landings thereby hindering commercial transportation, especially movement by small boats which are the main means of transportation (Plate 2.2). Reduced accessibility to harbours has occasioned unprecedented delays in commercial water borne transport for people and goods resulting in losses for fishermen especially when their catches rot due to delays. The water hyacinth has also blocked access to water since traditional water collection areas and water pumping equipment are choked with the weed (UNEP, 2013).

Plate 2.2: Water hyacinth infestation in Lake Victoria. Source: UNEP, 2013

It has been reported that in Lake Victoria, floating mats of water hyacinth support organisms that are detrimental to human health (Minakawa *et al.*, 2008). The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria transmitting anopheles mosquito (Minakawa *et al.*, 2008). Mansonioides mosquitoes, the vectors of human lymphatic filariasis causing nematode, *Brugia*, breed on this weed (Chandra *et al.*, 2006; Varshney *et al.*, 2008). Snails serving as vector for the parasite of Schistosomiasis (Bilharzia) reside in the tangled weed mat (Borokini and Babalola, 2012). Water hyacinth has also been implicated in harbouring the causative agent for cholera (Feikin *et al.*, 2010). For example, from 1994 to 2008, the region in Kenya, bordering Lake Victoria accounted for a larger proportion of cholera cases than expected given its population size (38.7 % of cholera cases versus 15.3 % of national population). Yearly, water hyacinth coverage on the Kenyan section of the lake was positively associated with the number of cholera cases reported in the region around Lake Victoria (Feikin *et al.*, 2010). According to Keterega and Sterner (2009), fish catch rates on the Kenyan section decreased by 45 % because water hyacinth mats blocked access to fishing grounds, delayed access to markets and increased costs (effort and materials) of fishing (Kateregga and Sterner, 2009). It is estimated that the flow of water in the Nile could be reduced by up to one tenth due to increased losses from evapo-transpiration by water hyacinth in Lake Victoria (Ndimele *et al.*, 2011).

In the LVB the rivers infested with water hyacinth are a major source of the water hyacinth input into Lake Victoria. In the lake, the water hyacinth is spread rapidly by the south easterly winds and water currents influenced by the River Nile current system. This causes the spread of propagules into sheltered bays and inlets along the lake shores explaining the high density infestation in the Winnam Gulf, Kisumu (Gichuki *et al.*, 2012).

2.1.3 Previous attempts to control water hyacinth In Lake Victoria

Water hyacinth control is absolutely essential (Villamagna and Murphy, 2010). Control methods that have been employed before in Lake Victoria include mechanical (Plate 2.3) and biological control (Gichuki *et al.*, 2012). However, these methods have often been insufficient to contain the aggressive propagation of the weed and viability of its seeds despite substantial monetary investments over the years mainly due to lack of continued policy and management support by governments (Gichuki *et al.,* 2012). Efforts to control the weed have caused high costs and labour requirements, leading to nothing but temporary removal of the water hyacinth (Malik, 2007). Since most favourable conditions for the growth of the water hyacinth often are found in developing countries, very limited resources have been put into curbing them (Mironga, 2014). Scraping the water hyacinth does not generate income therefore it is left to cover the lakes. Conversely, the water hyacinth would have a great potential if seen as raw material for industries or if incorporated into agricultural practice (Gunnarsson and Petersen, 2007).

Plate 2.3: Manual removal of water hyacinth in L.Victoria. Source: UNEP, 2013

Developing countries utilize hand tools as the primary means of removal, but this can be time consuming and labour intensive. Manual and mechanical control is also limited to suitable weather conditions for removal (Malik, 2007). Innovations have been made in the creation of special equipment (grapplers, modified boats, conveyer belts), but mechanical removal is still viewed as costly and labour intensive (EEA, 2012). The primary benefit of manual and mechanical removal is that it has a minimal impact on the environment compared to other management practices (Malik, 2007).

2.1.3.1 Physical methods

Physical methods for control of water hyacinth may involve manual removal of the weeds or pulling with nets (Patel, 2012). Employing machines like weed harvesters, crusher boats and destruction boats have proved expensive, approximately US $ 600 - 1,200 per hectare, as well as unpractical for areas larger than a hectare given the rapid rate of increase of the weed (Malik, 2007; Villamagna and Murphy, 2010). There may also be additional fees for disposal of plant material. The cost of water hyacinth management in China was estimated to amount to 1 billion Euros annually (EEA, 2012). In Europe, management costs to remove 200,000 tonnes of the plant along 75 km in the Guadiana river basin on the Portuguese-Spanish border amounted to 14,680,000 Euros between 2005 and 2008 (EEA, 2012). Dagno *et al.* (2012) reported that mechanical management of the weed in Mali cost around US$ 80,000–100,000 per year. Maintaining a clear passage for ships to dock at Port Bell in Uganda is estimated to cost US$ 3-5 million per year (Mailu, 2001). Although mechanical removal has been effective to a considerable extent, the infestation soon return because shredded bunches of the weed are carried by waves to other unaffected areas where they establish and start proliferating (Shanab *et al.*, 2010).

2.1.3.2 Chemical management

Chemicals such as Paraquat, Diquat, Glyphosate, Amitrole, 2, 4-D acid have been used worldwide to reduce water hyacinth populations (Villamagna and Murphy, 2010). However, their use directly interferes with the biodiversity of the lake by destroying aquatic organisms and bio-control agents which may be deployed against this weed.

Long term use may degrade water quality and put aquatic life at risk with significant socio-economic impacts if beneficial or designated uses of the water body such as drinking and preparing food are affected (Malik, 2007; Dagno *et al*., 2012). Considering that hundreds of thousands of hectares have been invaded by the weed, it is unlikely that it will be controlled by chemical means alone (Borokini and Babalola, 2012).

2.1.3.3 Biological control

Biological control of water hyacinth has also received a great deal of attention. Biological control agents primarily include fungi and arthropods, although many other organisms have been researched (Villamagna and Murphy, 2010; Dagno *et al.,* 2012). The aim of any biological control is not to eradicate the weed, but to reduce its abundance to a level where it is no longer problematic. While there exists several native enemies of water hyacinth, two South American weevil beetles (*Neochetina eichhorniae* and *Neochetina bruchi*) and two water hyacinth moth species (*Niphograpta albiguttalis* and *Xubida infusella*) have had effective long-term control of water hyacinth in many countries, notably at Lake Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA), Mexico, Papua New Guinea and Benin (Williams *et al.,* 2007; Venter *et al.,* 2012; Gichuki *et al.,* 2012; Dagno *et al*., 2012). Control of water hyacinth using fungal pathogens has elicited interest in the management of the weed. Several fungal species among them *Cercospora rodmanii, Alternaria alternata* and *A. eichhorniae* have been recognized as potential mycoherbicide agents although no commercial mycoherbicide is available for water hyacinth (Dagno *et al.,* 2012).

2.1.3.4 Control of water hyacinth infestation through utilization

Research into the utilization and related technologies for the control of water hyacinth have been tested over the last few decades (Ndimele *et al.,* 2011). It is being speculated that the biomass can be used in waste water treatment, heavy metal and dye remediation, as substrate for bio - ethanol and biogas production, electricity generation, animal feed, agriculture and sustainable development (Patel, 2012).

2.2 Compost production and its use in agriculture

Composting is the process in which organic matter is transformed into compost by aerobic microorganisms. It comprises of three major phases: mesophilic, thermophilic and cooling phase (the compost stabilization phase) (Neklyudov *et al*., 2008). During the thermophilic phase, high temperatures accelerate the breakdown of proteins and complex carboydrates like cellulose and hemicellulose, the major structural molecules in plants. As the supply of these high-energy compounds becomes exhausted, the compost temperature gradually decreases and mesophilic microorganisms once again take over for the final phase of "curing" or maturation of the remaining organic matter. (Cai *et al*., 2007). Composting process can result in reduction of solid waste volume by up to 50 %. (Zorpas *et al*., 2002). If the final product contains high level of heavy metals, it often hinders application of compost in agricultural land and it may be noxious to soil, plants and human health. Heavy metals uptake by plants and successive accumulation in human tissues and biomagnifications through the food chain causes both human health and environment concerns (Wong and Selvam, 2006; Neklyudov *et al*., 2008). The composting process converts the readily degradable organic matter into less degradable humic material rich of nutrients required for the plants growth (Gunnarsson and Petersen, 2007). The important nutrients for the fertilizing character of the compost are nitrogen, phosphorus and potassium. During the composting process, nitrogen oxidizes into nitrate, which is not normally lost from the compost pile. While phosphorus and potassium are physico-chemically less mobile than nitrogen, these compounds remain in the compost unless lost through leaching (Gunnarsson and Petersen, 2007).

Composting systems utilize degradable constituents to produce carbon dioxide, water, ammonia and biological heat as the major products. The final product at the end of the maturation process should be stable and can be applied to soil to improve its physical, chemical and biological properties (Keumjoo, 2011). Stability of composts is the degree to which the organic fractions in composts have been stabilized during the process of composting (Gomez *et al*., 2006). Compost is considered unstable if it contains a high proportion of biodegradable matter that may maintain high microbial activity and is considered stable if it contains mainly recalcitrant or humus-like matter and it is not competent to uphold microbial activity (Kalamdhad *et al*., 2009). Nutrients, heavy metals, temperature, aeration rates, effective microorganisms (EM), odour generation and the cost of composting should be considered for the effective composting and stabilization of biological materials (Keumjoo, 2011).

The microorganisms needed for composting are found throughout the natural environment. They are present in compost feedstock, water, air, soil as well as the machinery the feedstock and compost are exposed to during processing (CMSFW, 2008). These sources ensure a high diversity of microorganisms, which help to maintain an active microbial population during the dynamic chemical and physical processes of composting such as shifts in pH, temperature, water, organic matter and nutrient availability (CMSFW, 2008). It has been reported that the dominant groups of bacteria during composting of water hyacinth are *Comamonas acidovorans*, *Sphingomonas paucimobilis*, *Stenotrophomonas maltophilia*, *Bacillus licheniformis*, *Pseudomonas sp.*, *B. mycoides and Providencia sp.* Fungi include *Syncephalastrum sp*., *Aspergillus fumigatus*, *A. terreus*, *A. flavus*, *A. clavatus*, *Aspergillus sp*., *Rhizopus sp*. and *Absidia corymbifera*. Actinomycetes include *Actinomadura sp*., *Streptomyces avermistitis*, *Streptomyces sp*., *Nocardiopsis sp.*, *Nocardiodes sp*., *Kineosporia sp*., *Pseudonocardia thermophila*, *Actinobispora sp*. and *Dactylosporangium vinareum* (Nieto *et al*., 2011).

The use of EM (effective microorganisms) in the decomposition of organic matter produces good results by taking advantage of their enzymatic activities, favouring the elimination of organic waste and providing beneficial metabolic products to the soil (Tiquia *et al*., 2002; Singh and Sharma, 2003). The enzymatic activities of these microorganisms play an important role in the degradation of complex substrates such as lignin and cellulose facilitating the degradation of aquatic macrophyte in the composting process (Nakamura *et al*., 2001; Tiquia *et al*., 2002). Effective microorganisms (EM) consist of mixed cultures of beneficial microorganisms mainly the photosynthesizing bacteria, lactic acid bacteria, yeasts actinomycetes and fermenting fungi (Zuraini *et al*., 2010). Effective microorganisms speed up the rate of decomposition by increasing the number of decomposers since bacteria, actinomycetes and fungi form part of the culture.

The microorganisms enhance the decomposing processes by generating hydrolytic enzymes such as cellulases, proteases, phosphatases, xylanases and lipases, breaking down the organic matter and releasing soluble substances such as sugars alcohol during anaerobic respiration, hormones and essential elements and heavy metals (Mondini *et al*., 2004).

Although organic matter can also be degraded under anaerobic condition, the degradation is slow and less efficient, and produces less heat and more undesirable products, including methane and nitrogen dioxide, which are greenhouse gases contributing to global warming (Hao *et al*., 2001). Considering that the end use of compost is primarily for nutrient recycling and promoting plant growth, aerobic stabilization process is the preferred method of composting to produce a stabilized or mature organic amendment.

The use of compost, as a soil fertilizer offers a number of advantages over other management alternatives because it reduces the use of chemical fertilizers and eliminates the necessity of its subsequent treatment or disposal (Hargreaves *et al*., 2008). Sewage sludge, manure and compost from green waste are the most common organic wastes applied either raw or composted. The application of such materials to soil provides nutrients, increases organic matter, improves soil structure and enhances nutrient absorption by plants (Singh and Agrawal, 2008). Therefore, the use of organic waste in agriculture or farming activities instead of using conventional chemical fertilizers should be preferred in terms of sustainability. These residues can also be used as amendments to regenerate infertile soils and for improving plant cover (Soliva and Paulet, 2001).

2.3 Availability and risks of heavy metal contamination in water hyacinth compost

The term heavy metal refers to any metallic element that has a relatively high density of more than 5 mg/ml and is toxic or poisonous even at low concentration (Athalye *et al*., 2001). World Health Organization in collaboration with United Nation Environmental Programme (UNEP) under the Global Environmental Monitoring Systems (GEMS) have identified metals such as lead (Pb), the fifth most utilized metal in the world, cadmium, nickel, copper, mercury and arsenic as detrimental to human health (Mehdra and Juneja, 2003). Their accumulation over time can cause serious illness, which may result in premature death. Lead poisoning has severe adverse health impacts and specifically neurological problems especially in children is the principal concern for chronic lead exposure, along with other health-endangering effects, such as blood enzyme changes, anaemia, hyperactivity seizure, coma and death (IAEA, 1997; Curtis and Smith, 2002). Cadmium has been implicated in hypertension, renal dysfunction, decreased haemoglobin levels, bone deformities and cardiovascular problems (Curtis and Smith, 2002; Mehdra and Juneja, 2003). Copper poisoning causes weakness, abdominal cramps, headache, nausea, dizziness and vomiting. Chronic nickel exposure causes chronic bronchitis which reduces lung function and cancer of the lung and nasal sinuses (Cempel and Nikel, 2006).

Trace metals composition of composts varies widely depending on the sources of materials and the composting process (Krogmann, 1999). Increasing metal concentrations and changes in its distribution in the compost and amended soil are generally reported to increase the concentration of metals in the tissues of plants growing in the soil. Organic matter and bioavailability of heavy metal are critical factors for the metal accumulation in both plants and animals (Chen *et al*., 2010).

2.4 Bioavailability of heavy metals in compost

Bioavailability of metals in the compost is a dynamic process that depends on specific combinations of chemical, biological and environmental parameters (Prabpai *et al*., 2009; Guala *et al*., 2010). The mobility of trace metals, their bioavailability and related eco-toxicity to plants depend strongly on their specific chemical forms or ways of binding (Fuentes *et al.,* 2004). Persistence of soluble organo-metal complexes in the compost added to soil have been found to increase potential toxicity because soluble material will tend to be more bio-available to receptor organisms (Zheng *et al*., 2007).

The action of microorganisms in composting also may make the metals more available due to metal release from the decomposed organic matter in the composted materials (Qiao and Ho, 1997). The metals bound to the carbonate fraction are very sensitive to pH change and leached at lower pH (Zheng *et al.,* 2007). Metals confined in the residual fraction are usually not expected to be released over short period of time under the natural conditions (Gupta and Sinha, 2007). The mobility of element by its capacity to pass into soil compartments where it is less energetically retained depends on factors which are related to the nature of the element, the soil properties (example pH, clay content and organic matter rate) and to the type and quality of soil amendments (Achiba *et al.*, 2009).

Water hyacinths have been reported to have the capacity to accumulate heavy metals (Liao and Lian, 2004) and this raises concerns about the adverse environmental impact as a result of application of compost generated from such plants to agricultural lands (Iwegbue *et al*., 2007). Studies on the concentration and speciation of metals (Cu, Pb, Ni and Cd) during composting shows that the contents of total metals concentration are increased during the composting process and the largest proportion of metals is found in the residual fraction which is a more stable form and is consequently considered largely unavailable for plant uptake (Singh and Kalamdhad, 2012). This gives a clear indication on the safety and thus possibility of using plants known to have the capacity to accumulate heavy metals such as water hyacinth as compost materials.

2.5 Immobilization of heavy metals in compost with organic amendments and bacteria

The use of organic amendments and other materials that bring about immobilizing effects and dilutions of mobile heavy metals in compost is valuable in reducing the risks posed by such metals in the environment. This is because studies show no evidence of increased metal release into mobile forms as organic matter degrades in soil once compost applications have ceased (Smith, 2009). The application of amendments is a remediation technique that has been found to have a reducing effect on both the mobility and bioavailability of trace elements (Vangronsveld and Cunningham, 1998). Stabilization can be achieved by adding amendments such as lime, zeolites and materials with high organic matter content such as cattle manure that are able to absorb trace elements. Manganese - Mn and iron - Fe oxides also complex and co-precipitate trace elements (Bolan and Duraisamy, 2003). Bacteria on the other hand during composting excrete a chelating agent called siderophore, a class of microbial chelating agents, which are low molecular weight ligands for capturing and supplying iron to support metabolic activity. Siderophores are able to bind to heavy metals such as lead and cadmium (Nair *et al*., 2008).

Incorporation of low-cost and widely available materials offers various potential advantages over other methods, such as cost, simple methodology and low environmental impact. In addition, organic amendments may enhance soil fertility and microbial activity (Clemente *et al.,* 2005). The effect of organic matter amendments, applied on compost feedstock materials, on heavy metal bioavailability depends on the nature of the organic matter, their microbial degradability, pH and redox potential as well as metals concerned (Walker *et al.* 2004). Their effect on the mobility of heavy metals are associated with the capacity of the amendments to immobilize metals in the compost through the transformations of metals in the potentially available pools into less bioavailable forms (Okieimen *et al*., 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

Composting was carried out at Korando Village, Korando sub location, Otonglo Division, Kisumu County in the Lake Victoria Basin. Laboratory analysis of compost samples were carried out at the Chemistry Department laboratories of Kenyatta University. The site was chosen based on the presence of water hyacinth plants along the shore lines of Lake Victoria in the outskirts of Kisumu town. Kisumu is a major fish landing site and where impacts of pollution and macrophyte encroachment are mostly felt in the Kenyan side of Lake Victoria (MEMR, 2008). Kisumu is also a centre of urban development with various industries and municipal treatment plants which discharges their wastes into the lake.

3.2 Compost preparation and sampling

3.2.1 Composting

Composting of water hyacinth was carried out between March 2013 and April 2013. The water hyacinth was harvested manually from the lake, then taken to the composting site and was sun-dried for seven days. It was chopped into small pieces of about 5 cm using a chaff cutter to increase the surface area for microbial action (FAO, 2004). Above ground closed aerobic heap design was used to prepare the compost. Sixteen heaps were prepared each having a uniform measurement of 1 m in the length and width and a height of 1.5 m. A chicken wire mesh was used to construct the heap stands with wooden posts and a well fitting nylon sack on the inner part but the upper part remained open to give room for turning the compost (Tumuhairwe *et al*., 2009).

Twenty kilograms of the dried and chopped water hyacinth plants were measured using a spring balance and put into the heap stands to form a layer of about 10 cm depth at the base and sprayed with 10 litres of Effective Microorganisms (EM) solution prepared in the ratio of 1:50 for commercial EM: water. Commercial EM contained *Lactobacillus plantarum*, *Lactobacillus casei*, *Streptococcus lactis*, *Bacillus subtilis*, *Bacillus stearothemophilus*, *Rhodopseudomonas palustrus*, *Rhodobacter spaeroides*, *Saccharomyces cerevisiae*, *Candida utilis*, *Streptomyces albus*, *Streptomyces griseous*, *Arpergillus oryzae*, *Arspegillus fumigatus*, *Sporotrichum thermophilus*, *Penicillium sp.* and *Mucor hiemalis* (Zuraini *et al*., 2010). This was repeated until the heap got to 1.2 m high holding 240 kg of the hyacinth in twelve layers per heap. The moisture content was maintained at sixty percent throughout composting and monitored with a pin type moisture meter. Temperature changes were monitored daily at 10.00 am using a Reotemp probe digital thermometer (HH503 model from USA). Fifteen centimetres steel probe was inserted into the four sides of the heap and at the top centre of the heap and the thermometer reading were recorded. The average temperature reading from the five points was determined.

The heaps were turned as the compost begins to cool on the twenty fourth, thirty first, thirty eighth and forty eighth day of composting onto a new base “upside down and inside out’’. Turning was manually carried out using forked shovel to increase aeration and subject all the material to uniform temperatures, as well as mixing the materials during the composting process (Singh and Kalamdhad, 2012). The composting process was monitored for sixty days. The other heaps were also set up and monitored in the same way but instead of using EM as a treatment, molasses prepared in a 1:50 dilution ratio with water (Rumapar *et al*., 2014), cattle manure (5 kg after every water hyacinth layer amounting to 60 kg per heap) (Deka *et al.*, 2011) and water were added as treatments separately. Control heap (without any treatment) was set up with 240 kg of water hyacinth. Each of the four treatments was replicated four times totalling to sixteen heaps.

3.2.2 Sampling

On maturation, a one dimensional sampling was carried according to Test Methods for the Examination of Composting and Compost (TMECC, 2002) set by the United States Composting Council (USCC). The compost piles were well mixed and 16 samples (equally spaced samples) of 100 grams each was removed along the edge into polythene lined bucket. In the polythene lined bucket, the sample was further mixed to come up with the 1st composite sample of 1.6 kg. Following the collection of the 1st composite sample, the pile was again mixed and following the above procedure the second and the third composite sample were immediately obtained from the same pile. These gave a total of 48 composite samples arising from the 16 compost piles of well mixed mature water hyacinth's compost pile.

3.2.3 Total heavy metal digestion and extraction

One gram of water hyacinth compost sample was placed in a 250 ml digestion tube and 50 ml of concentrated nitric acid was added (Zeng, 2004). The sample was then heated for 45 min at 90 ^{o}C and the temperature was increased to 150 ^{o}C at which the sample was boiled until a clear solution was obtained. Concentrated nitric acid was added to the solution (5 ml added three times) and digestion was left to take place until the volume was reduced to about 5 ml. The interior walls of the tube were washed down with distilled water and the tube was swirled throughout the digestion to keep the wall clean and prevent the loss of the sample. After cooling, 5 ml of 1 % nitric acid was added to the sample. The solution was filtered with Whatman No. 42 filter paper and a 0.45 μm Millipore filter paper. The solution was quantitatively transferred to a 25 ml volumetric flask by adding distilled water for instrumental analysis (Pollack and Favoino, 2004).

3.2.4 Mobile metal extraction

The single extraction method was carried out according to the procedure described by MAFF (1986). Five grams of the air dried and ground water hyacinth compost sample was placed in a 250 ml digestion tube and extracted with 50 ml of de ionized water for two hours, filtered and 10 ml of concentrated nitric acid was added to the sample and heated for 30 min at 90 ^{o}C. The solution was filtered through a 0.45 μm filter and transferred quantitatively to a 25 ml volumetric flask by adding de-ionized water (Kumar *et al*., 2011).

3.2.5 Determination of metals by Flame Atomic Absorption Spectrometre (FAAS)

The concentration of total and mobile heavy metals was determined using Buck Scientific 210VGP Flame Atomic Absorption Spectrometre. The operating parameters of the machine shown in Table 3.1 were set according to the manufacturers specifications (Buck Scientific Manual, 2003). Samples were mixed vigorously before aspiration into the flames of an Atomic Absorption Spectrometre for specific metal concentration determination. Values were expressed in mg/kg.

Table 3.1: Set analysis for the various metals

Parameter	**Wavelength (nm)**	**Source (nm)**	**Lamp current (A)**	**Fuel system**
Copper (Cu)	324.8	0.7	1.2	Air/Acetylene
Cadmium (Cd)	228.8	0.7	1.2	Air/Acetylene
Lead (Pb)	283.3	0.7	1.2	Air/Acetylene
Nickel (Ni)	232.0	0.2	1.2	Air/Acetylene

3.2.6 Data analysis

The data collected was analyzed for significant differences ($p < 0.05$) using one-way Analysis of Variance (ANOVA) and means were separated using Tukey`s test at 5 % level. Pearson correlation analysis was also carried out to check the significances of the linear relations between total and mobile concentrations. Statistical Analysis System (SAS) Version 9.2 software was used for the analysis.

CHAPTER FOUR

RESULTS

4.1 Temperature changes during composting of water hyacinth

Temperature changes related to the progress of composting in the treatments (EM, molasses, manure and control) showed that temperature in each pile group increased, reached the maximum value, decreased gradually and finally tended to stabilize (Figure 4.1). Temperature changes during composting showed that the control had the highest mean temperature of 33.52 ºC, followed by molasses 30.26 ºC, EM 30.21 ºC and lastly manure 29.97 ºC. After 2 days, the pile temperature of the control group reached a maximum of 37.2 ℃, which was 4 ℃ higher compared to the EM inoculated pile, 3 ℃ higher compared to the manure treated and molasses treated pile. The thermophilic phase in the treatments lasted approximately for 10 days in manure, EM and molasses treatment, however in control it lasted for approximately 20 days. The 60th day was considered the end of composting as all the piles showed temperature stability, compost appeared granular, became much darker in colour and homogeneous compared with the feedstock materials (Plate 4.1).

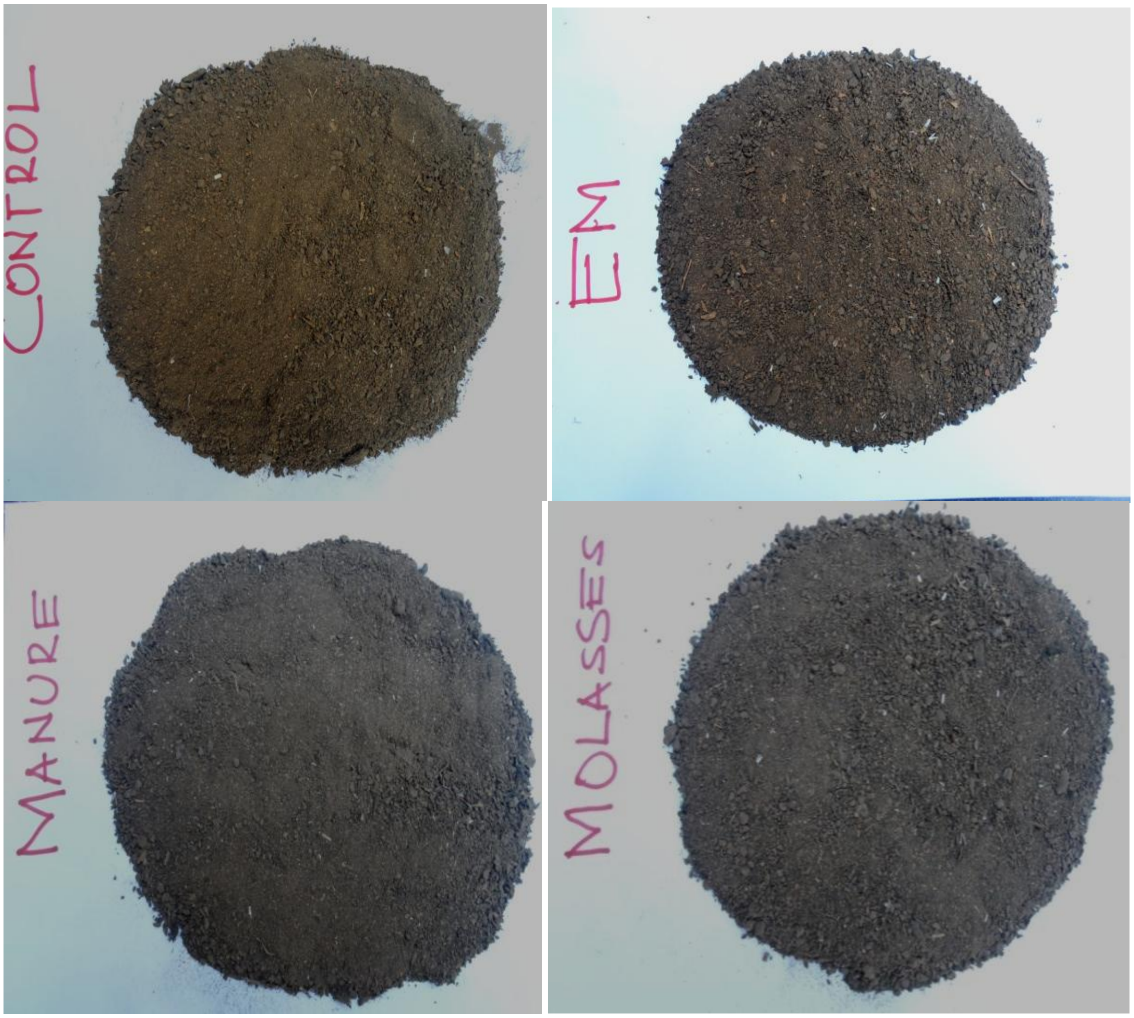

Plate 4.1: Mature compost samples prepared using manure, molasses, EM-effective microorganisms and control treatments.

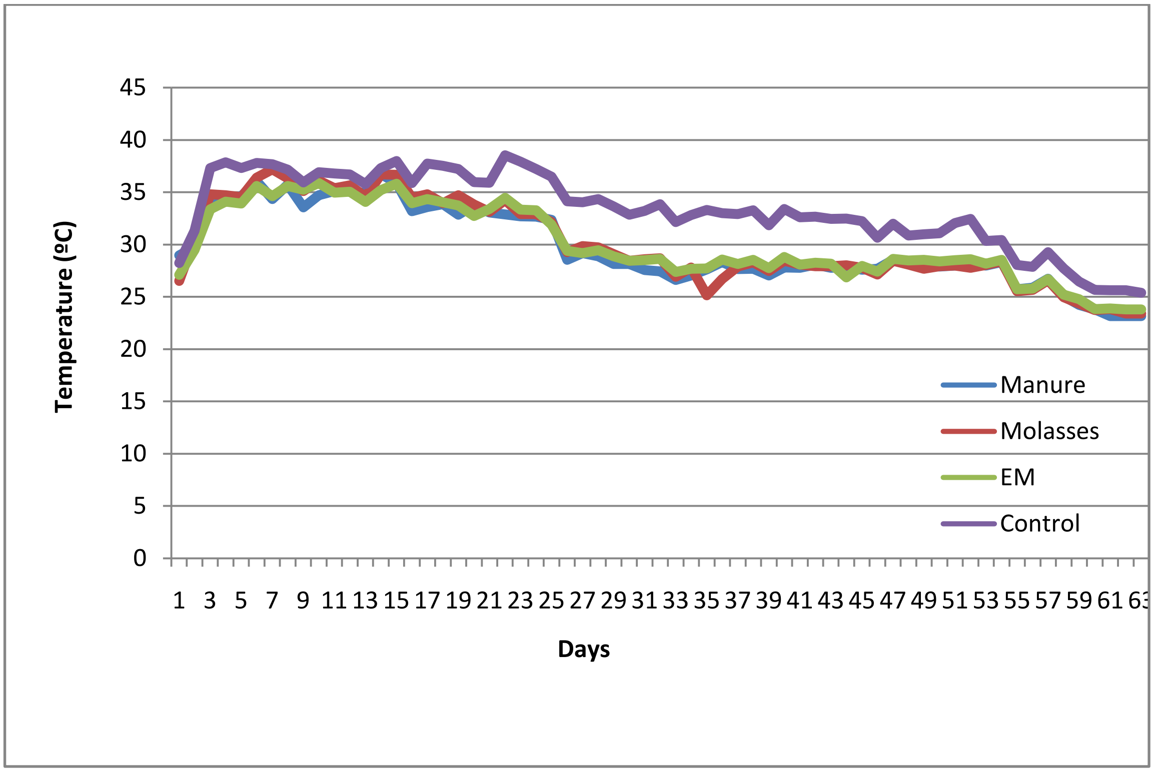

Figure 4.1: Temperature evolution in water hyacinth compost prepared using different treatments. EM-effective microorganisms.

4.2 Total heavy metal concentrations in water hyacinth compost

The mean range of total heavy metals in water hyacinth compost samples was 1.23-1.52 mg/kg (copper), 0.32-0.35 mg/kg (cadmium), 0.25-0.32 mg/kg (nickel) and 0.95-1.41 mg/kg (lead) (Table 4.1). The mean concentrations of total copper (mg/kg) in compost from various treatments were 1.40, 1.52, 1.24 and 1.23 for control, EM, manure and molasses respectively. Treatments had a significant effect on the total copper concentrations ($p = 0.0006$). Effective microorganism treatment had significantly higher concentration of Cu compared to manure and molasses treatment but not significantly different from the control. Cadmium mean concentrations (mg/kg) in the treatments were 0.34, 0.33, 0.32 and 0.35 for control, EM, manure and molasses respectively.

Treatments had a significant effect on the total Cadmium concentrations (p = 0.040). Manure treatment had significantly lower concentration of Cadmium compared to manure, molasses and control treatment. Nickel mean total concentrations (mg/kg) in the compost for various treatments were 0.32, 0.25, 0.32 and 0.30 for control, EM, manure and molasses respectively. Treatments had a significant effect in the total Ni concentrations (p = 0.0012). Water hyacinth compost prepared using EM had significantly lower total concentration of nickel compared to the compost prepared using molasses, manure and control treatment. Lead mean total concentrations (mg/kg) for various compost treatments were 0.95, 1.09, 1.41 and 1.07 for control, EM, manure and molasses respectively. Treatment had a significant effect on the total lead concentrations (p = 0.0058). Water hyacinth compost prepared using manure treatment had a significantly higher total concentration of lead compared to the compost prepared using molasses, manure and control treatment.

Table 4.1: Mean total concentrations of heavy metals (mg/kg) in water hyacinth compost

Treatment	**Copper** mean± SE^x	**Cadmium** mean± SE^x	**Nickel** mean± SE^x	**Lead** mean± SE^x
Control	1.40±0.03^{ab}	0.34±0.01^a	0.32±0.01^a	0.95±0.08^b
EM	1.52±0.07^a	0.33±0.01^a	0.25±0.01^b	1.09±0.11^b
Manure	1.24±0.01^{bc}	0.32±0.00^b	0.32±0.01^a	1.41±0.01^a
Molasses	1.23±0.02^c	0.35±0.01^a	0.30±0.00^a	1.07±0.06^b
P value	<0.001	0.040	0.001	0.006

EM - effective microorganisms.

Means followed by the same letter within the same column do not differ significantly according to Tukey’s test at 5 % level.

4.3 Effect of treatments on the bio-availability of heavy metals in water hyacinth compost

4.3.1 Mobile concentrations

The mean range of mobile concentrations of heavy metals in water hyacinth compost samples was 0.027-0.055 mg/kg (copper), 0.018-0.035 mg/kg (cadmium), 0.027-0.036 mg/kg (nickel) and 0.023-0.093 mg/kg (lead) (Table 4.2). The mean concentrations of mobile copper (mg/kg) in compost from various treatments were 0.054, 0.055, 0.027 and 0.049 for control, EM, manure and molasses respectively. Treatment had a significant effect on the mobile copper concentrations (p = 0.0001). Effective Microorganisms, molasses and the control treatments had a significantly higher mobile concentration of Cu compared to manure treatment. Mobile cadmium mean concentrations (mg/kg) in the treatments were 0.023, 0.032, 0.018 and 0.035 for control, EM, manure and molasses respectively. The results showed that there was significant differences in the mobile Cd concentrations of the treatments (p = 0.020). Compost prepared using molasses treatment had a significantly higher mobile concentration of Cd compared to that of manure but not significantly different from that prepared using EM and control. Mobile nickel mean concentrations (mg/kg) in the compost for various treatments were 0.036, 0.027, 0.033 and 0.031 for control, EM, manure and molasses respectively. Treatments had a significant effect on the mobile Cd concentrations (p = 0.001). The compost in the control experiment had a significantly higher mobile concentration of nickel compared to the compost prepared using EM and manure treatment but not significantly different compared to molasses treatments. The mean mobile lead concentrations (mg/kg) in compost were 0.043, 0.061, 0.023 and 0.093 for control, EM, manure and molasses treatment respectively. The results showed that there existed significant differences in the mobile Pb concentrations of compost prepared using the four treatments (p = 0.0002). Significantly higher mobile concentration of lead was recorded for the compost prepared using molasses compared to that of manure and control but not significantly different compared to EM treatment (Table 4.2).

Table 4.2: Effect of treatments on the concentration of mobile heavy metals (mg/kg) in water hyacinth compost

Treatment	Copper	Cadmium	Nickel	Lead
	mean± SE ^{x}	mean± SE ^{x}	mean± SE ^{x}	mean± SE ^{x}
Control	0.054±0.003 ^{a}	0.023±0.001 ^{ab}	0.036±0.021 ^{a}	0.043±0.013 ^{bc}
EM	0.055±0.003 ^{a}	0.032±0.005 ^{ab}	0.027±0.016 ^{bc}	0.061±0.004 ^{ab}
Manure	0.027±0.004 ^{b}	0.018±0.000 ^{b}	0.033±0.016 ^{c}	0.023±0.002 ^{c}
Molasses	0.049 ±0.000 ^{a}	0.035±0.004 ^{a}	0.031±0.013 ^{ab}	0.093±0.014 ^{a}
P value	< 0.001	0.020	0.001	< 0.001

EM-effective microorganisms.

Means followed by the same letter within the same column do not differ significantly according to Tukey's test at 5 % level.

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4.3.2 Relative mobility of heavy metals in compost

Relative mobility of different heavy metals expressed as water soluble/Total concentration (Table 4.3) was greater for Cu, Cd, Ni and Pb in the compost prepared using molasses treatment while least for Cu, Cd, Ni and Pb in manure treatment.

Table 4.3: Water-extractable metals fractions (mg/kg) relative to the total metal concentrations (mg/kg) in the water hyacinth compost

Treatment	Copper	Cadmium	Nickel	Lead
Control	0.039	0.068	0.113	0.047
EM	0.036	0.087	0.108	0.057
Manure	0.023	0.058	0.072	0.016
Molasses	0.040	0.100	0.104	0.087

EM-effective microorganisms.

4.3.3 Percentages of mobile heavy metals in water hyacinth compost

The ratios of mobile heavy metals expressed as percentages showed that the range of mobile concentrations of heavy metals in compost samples was 2.3-3.9 % (copper), 5.8-10 % (cadmium), 7.2-11.3 % (nickel) and 1.6-8.7 % (lead) (Figure 4.2). The percentages of mobile copper in compost prepared were 3.8, 3.6, 2.3 and 4.0 for control, EM, manure and molasses respectively. Percentages of mobile cadmium in the treatments were 6.8, 8.7, 5.8 and 10 for control, EM, manure and molasses respectively. Percentages of mobile nickel in the treatments were 11.3, 10.8, 7.2 and 10.4 for control, EM, manure and molasses respectively. Percentages of mobile lead in various compost treatments were 4.7, 5.7, 1.6 and 8.7 for control, EM, manure and molasses respectively. Compost prepared using manure treatment had the least percentages of mobile heavy metals irrespective of the heavy metal compared to other treatments (EM, molasses and control) (Figure 4.2).

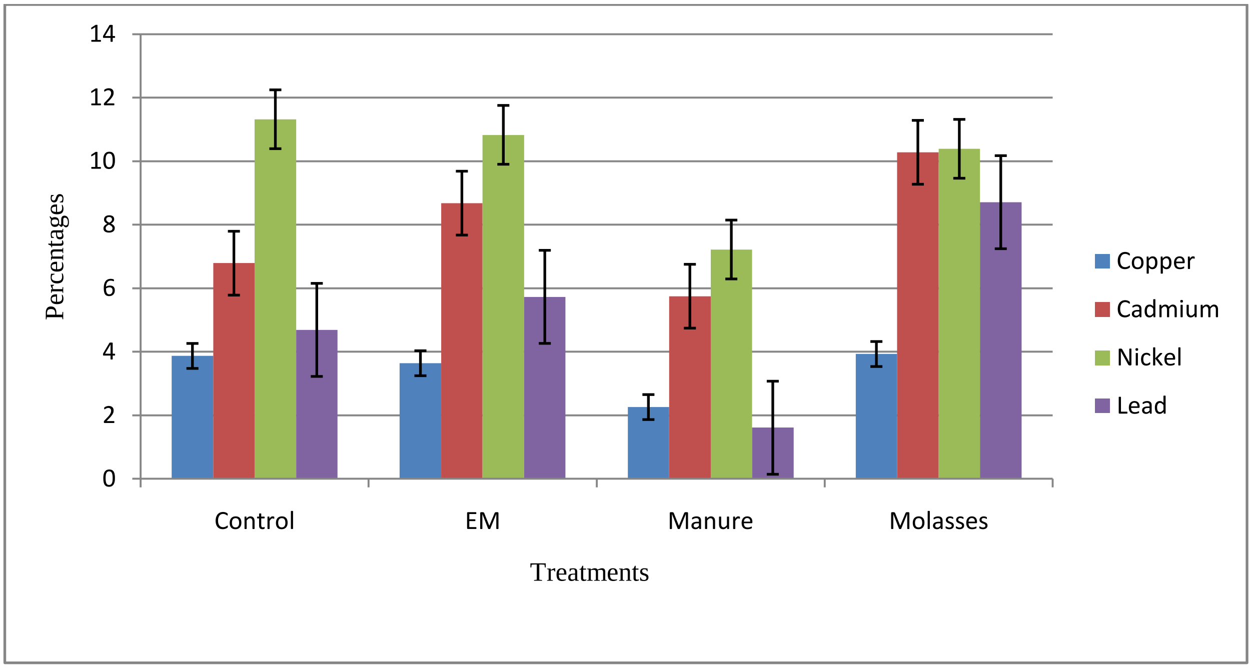

Figure 4.2: Percentages of mobile heavy metals in water hyacinth compost prepared with various treatments. EM-effective microorganisms.

4.4 Relationship between total and mobile concentrations of heavy metals in various treatments

The correlation coefficients (r) between total and mobile concentrations of copper were -0.021, 0.031, 0.601 and 0.293 for control, EM, manure and molasses treatments respectively (Table 4.4). There existed significant relationship between total and mobile concentrations of copper only in manure treatment. In the cases of molasses, EM and manure treatments, total concentrations were positively related to the mobile concentrations. The relationship was however negative between total and mobile concentrations of copper in the control treatment. The correlation coefficients between total and mobile concentrations of cadmium were -0.382, 0.394, -0.360 and -0.304 for control, EM, manure and molasses treatments respectively (Table 4.4). There was no significant relationship between total and mobile concentrations in all treatments. Pearson correlations showed that, in the cases of control, manure and molasses treatments, total concentrations were negatively related to the mobile concentrations. The relationship was however positive between total and mobile concentrations of cadmium in the EM treatment. The correlation coefficients between total and mobile concentrations of nickel were 0.476, 0.710, 0.513 and 0.376 for control, EM, manure and molasses treatments respectively (Table 4.4). There existed a significant relationship between total and mobile concentrations of nickel only in EM treatment. Pearson correlations showed that in all treatments, total concentrations were positively related to the mobile concentrations. The correlation coefficients between total and mobile concentrations of lead were -0.056, 0.797, 0.403 and -0.173 for control, EM, manure and molasses treatments respectively (Table 4.4). There existed a significant relationship between total and mobile concentrations of lead only in molasses treatment. Pearson correlations showed that, in the cases of control, EM and manure treatments, total concentrations were positively related to the mobile concentrations. The relationship was however negative between total and mobile concentrations of lead in the molasses treatment (Appendix I).

Table 4.4: Pearson's moment correlation coefficients (r) between total and mobile heavy metals concentrations (mg/kg) in water hyacinth compost

Treatment	**Copper**	**Cadmium**	**Nickel**	**Lead**
Control	-0.021	-0.382	0.476	0.056
EM	0.031	0.394	0.710**	0.797**
Manure	0.601*	-0.360	0.513	0.403
Molasses	0.293	-0.304	0.376	-0.173

EM-effective microorganisms.
*significant correlation. **highly significant.

The coefficients of determination (r^2) between total and mobile copper in compost were 0.000, 0.001, 0.362 and 0.086 for control, EM, manure and molasses respectively (Table 4.5). For cadmium, coefficients of determination were 0.146, 0.155, 0.130 and 0.093 for control, EM, manure and molasses respectively (Table 4.5). Nickel had coefficients of determination of 0.277, 0.505, 0.263 and 0.141 for control, EM, manure and molasses respectively Coefficients of determination for lead were 0.003, 0.636, 0.163 and 0.030 for control, EM, manure and molasses respectively (Table 4.5).

Table 4.5: Coefficients of determination (r^2) between total and mobile concentrations of heavy metals (mg/kg) in water hyacinth compost

Treatment	**Copper**	**Cadmium**	**Nickel**	**Lead**
Control	0.000 (0.0)	0.146 (14.6)	0.277 (27.7)	0.003 (0.3)
EM	0.001 (0.1)	0.155 (15.5)	0.505 (50.5)	0.636 (63.6)
Manure	0.362 (36.2)	0.130 (13.0)	0.263 (26.3)	0.163 (16.3)
Molasses	0.086 (8.6)	0.093 (9.3)	0.141 (14.1)	0.030 (3.0)

EM-effective microorganisms.
Values in parentheses represent percentages.

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Temperature evolution during composting

In the present study, there was an initial mesophilic phase which was succeeded by rapid change due to a thermophilic phase before the temperature dropped again to a second mesophilic phase and continued into the compost maturation phase irrespective of the treatments used. Early thermophilic phase was observed within 0–3 days of the composting process in all the trials. Increase in temperature comes as a result of the heat produced by microorganisms during composting being trapped within the composting mass, leading to the phenomenon of self-heating (Semple *et al*., 2001). The pattern of temperature change was consistent with that of other composting studies (Tognetti *et al.,* 2007; Prasad *et al.,* 2013).

In the present study the highest temperature recorded in the thermophilic phase was 38 °C in the control group. This was lower compared to 44.4-59 °C reported by Singh and Kalamdad (2013a) during their water hyacinth composting using rotary drum. Variation in the maximum temperatures attained during composting has previously been found to be influenced by the type of feed stock materials composted and the composting process adopted (Umsakul *et al*., 2010). Composting temperature of below 50 °C during thermophilic phase, a criterion met in the present composting process, is considered optimum for composting (Nwankwo *et al*., 2014). This is because higher temperatures have been reported to inhibit the activity and the growth of nitrifying bacteria during the thermophilic phase (Sanchez-Monedero *et al*., 2001).

The thermophilic phase was sustained differently in the compost piles of different treatments, approximately 10 days in manure, molasses and EM treatments while in control it lasted approximately 20 days. The ability of composting mass to sustain heat differently could be attributed to the difference in the insulating properties of the composting matrices in the different treatments (Nwankwo *et al*., 2014). The thermophilic phase started slightly earlier in control treatment and later in molasses, manure and EM treatments. This was an indication of quick microbial establishment in control and microbes taking slightly more time for acclimatization with molasses, cattle manure and EM treatments. The low mean temperature in manure treatment could have been as a result of bulking effect, known to increase the transport of mass and energy to the atmosphere as reported by Villasenor *et al.* (2011).

Following thermophilic phase was a period of cooling, the period when compost is believed to be reaching maturity. The temperature decrease could be because of readily available organic substrate becoming rate-limiting factor resulting in a decrease in microbial activity as well as heat produced (Nwankwo *et al.*, 2014). At the end of composting, all trials attained ambient and stable temperature at 60 days, indicating a good degree of stability and thus maturity (Waikhom *et al*., 2012). Compost stability and maturity are important factors affecting the successful use of composts in agriculture (Mathur *et al*., 1993). This is because the application of unstable composts can cause low plant growth rates and damage crops by competing for oxygen or causing phyto-toxicity in plants due to insufficient biodegradation of organic matter (Keeling *et al*., 1994).

5.1.2 Total heavy metal concentrations in water hyacinth compost

The total metal concentrations in all treatments were much below the critical limits stipulated in compost standards for countries which have enacted legislations on commercial composting (Table 5.1). Considering total concentrations of heavy metals (Cu, Ni, Pb and Cd), the studied composts (irrespectively of compost treatment) may be classified to the first class on the basis of limits stated in the EU regulations (Hogg *et al.*, 2002). First class compost based on heavy metals limits refers to organic amendments that can be used for horticultural and agricultural purposes.

Table 5.1: Heavy metals limits (mg/kg) for countries with compost standards

Element	**A Class^1**	**A Class^2**	**B Agr**	**B park**	**CH**	**DK**	**F**	**G**	**I**	**NL A**	**NL AA**	**SP**	**CAN**
Cadmium	4	1	5	5	3	1.2	8	105	105	2	1	40	3
Copper	400	100	100	500	150	-	-	100	300	300	90	1750	100
Lead	500	150	600	1000	150	120	800	150	140	140	120	1200	150
Nickel	100	60	50	100	50	45	200	50	50	50	20	400	-

Vander Derf *et al.* (2002).
Country codes: A-Austria; B-Belgium; CH- Switzerland; DK-Denmark; F-France; G-Germany; I- Italy; NL-Netherlands; SP-Spain; CAN-Canada.
Class ^{1} versus class^{2} or class A versus AA; Agr- agricultural use; Park-horticultural use.
Class^2 and Class AA are calculated on 30 % organic matter basis.

Copper metal was present in highest concentrations as compared to other heavy metals studied (Ni, Pb and Cd) (Table 4.1). This occurrence of copper could be attributed to the nutritional role Cu plays in water hyacinth plants and thus the high bio-concentration factor (BCF) water hyacinth plants have for copper (Sasidharan *et al*., 2013). In plants, copper in low concentration activates enzymes which are involved in lignin synthesis. It is also required in photosynthesis, respiration and assists in plant metabolism of carbohydrates and proteins (Yruela, 2005). Chaohua *et al*. (2007) reported that water hyacinth had a strong capability of absorbing Cu from the environment.

Manure treatment had the lowest concentrations of total copper and cadmium metals. Concentrations were however, higher for nickel and lead. Molasses treatment also had similarly low concentration of copper with manure but higher concentrations of cadmium. Addition of amendments (manure) to compost feedstock materials have previously been reported to have dilution effect on total concentrations of heavy metals in the compost (Huang *et al.,* 2005) which could explain the low concentrations of copper and cadmium in Manure. Molasses addition could have also had similar effect on copper. However, the role of amendments (manure and molasses) in contributing to the increased concentrations of lead and nickel in the treatments could not be ascertained since no analysis on the concentrations of heavy metals was ever carried out on the amendments before composting. Nevertheless, Muhammad *et al*. (2013) reported trace contaminations of lead in cattle manure which could be the reason for the increased concentration of lead in manure treatment. Effective microorganism and control had some of the highest concentrations of copper and nickel respectively in the treatments. Previously decomposition microorganisms have been implicated in the increase of heavy metal concentration during composting (Qiao and Ho, 1997). It can therefore be suggested that the concentration of heavy metals in the treatment with EM could have been more enhanced considering the ligno-cellulolytic properties of EM (Nair and Okamitsu, 2010). The increase in concentrations of heavy metals would be a result of the volatilisation of the feedstock materials due to transformation of organic carbon to carbon dioxide and methane resulting in mass loss (Smith and Hall, 1991). It is also important to note that control treatment had attained the highest temperature during thermophilic phase which could have increased the loss of organic materials through volatilization (Pagans *et al*., 2006).

The total lead concentration obtained in the present study agrees with the finding by Sasidharan *et al*. (2013). It differed however, in the concentrations of copper, nickel and cadmium. Sasidharan *et al*. (2013) reported concentrations of 63.4 mg/kg, 0.05 mg/kg, 0.26 mg/kg and 0.05 mg/kg for Cu, Ni, Pb and Cd respectively. The results of this study were also much lower compared with the results reported by Singh and Kalamdhad (2014) which had values of 100 mg/kg, 220 mg/kg, 1500 mg/kg and 80 mg/kg. Variation in total concentrations of heavy metals in water hyacinth composts, has been reported to be contributed by factors such as the differences in the composting processes used in thestudies (Singh and Kalamdhad, 2013b), extraction methods (Zeng, 2004) and contamination levels in the environments from which the water hyacinth was collected (Vitoria *et al*., 2010) and the same could have contributed to the findings obtained in the present study.

5.1.3 Concentrations of mobile heavy metals in compost

Manure treatment had both the least concentrations in total and percentage of mobile copper while molasses treatment had the most mobile percentage represented as percentage of the total copper concentrations (Table 4.2). These results indicate manure treatment in this study could have substantially reduced the solubility of copper with consequent redistribution of its water soluble fraction into more stable forms and thus less soluble concentrations (Prasad *et al*., 2013). Previously in a study on mobility of Cu with cattle manure amendment in municipal solid waste composting, Guan *et al*. (2011) concluded that the groups of –OH and –COOH supplied by cattle manure increased the binding sites and combined with Cu to form immobile complexes. Furthermore, addition of a proportion of cattle manure to water hyacinth feedstock could have enhanced the composting process and consequently improved humic substance formation during the process (Liu *et al*., 2008). Humic substances generally have higher affinity to complex with copper. This is because humic substances have been found also to have contents of carboxyl groups, which are always ready to complex with Cu (Liu *et al*., 2008) and thus the concentration of free Cu^{2+} could be decreased and the potential environmental risk drastically reduced in manure treatment.

The percentages of mobile Cu ranged from 2.3-3.9 % in the present study, indicating that greater bulk of Cu in water hyacinth compost, irrespective of the treatments could be in the more stable forms considered unavailable for plant and underground water contamination. This could be explained by the fact that during composting, significant concentrations of copper could be transferred from mobile fractions to other less mobile forms that are strongly bound to the organic substances (Nomeda *et al.*, 2008). Cai *et al*. (2007) reported that the sum of the oxidizable, carbonate and residual fractions in compost accounted for 95 % of the total Cu. Hsu and Lo (2001) and Fuentes *et al*. (2004) also concluded that the greatest amount of Cu in compost was in the oxidizable fraction, the fraction that can only be degraded under extreme oxidizing conditions to release soluble metals given the affinity of organic matter for Cu and consequential formation of stable complexes with copper. The mobile Cu concentrations expressed as a percentage of the total concentration were in agreement with 3 % obtained by Hsu and Lo (2001).

Effective microorganisms treatment had the least concentrations of mobile nickel while manure treatment had the least percentage of mobile nickel an indication that manure amendment in this study could have substantially had reducing effects on the solubility of nickel. Manure treatment could have provided optimum conditions in the study necessary for the conversion of organo-metallic complexes of nickel to forms that are more stable and are less mobile (Prasad, *et al*., 2013). The percentages of mobile nickel in the treatments that ranged from 7.2-11.32 % in the study were some of the highest mobile percentages compared to other key metals studied. Nickel has been reported to be the weakest bound element in compost matrix, (Smith, 2009), a property that could have influenced its solubility in compost matrix of the present study. Previously in a study on the solubility of heavy metals in compost Kabata and Pendias (1999) found nickel to be fairly soluble and in more association with soluble organic matter of compost.

The higher percentages of mobile nickel in water hyacinth compost does not necessarily limit its use considering the fact that percentages of mobile concentration above 30 % in nickel have been found to cause environmental toxicity (Venkateswaran *et al*., 2007). Nickel attracts a very low hazard ranking to the human food-chain or terrestrial ecosystems relative to other principal heavy metals (Smolders *et al.*, 2004). The range of mobile nickel percentages obtained in the study (7.2-11.3%) was consistent with 11.3 % reported by Tisdell and Breslin (1995). This range shows that the bulk of Nickel in water hyacinth compost could be in association with the more stable forms of compost that is insoluble and thus considered largely not easily available. In municipal solid waste compost, Wong and Selvam (2006) reported that after composting, the majority of nickel resided in the residual and other low availability fractions.

The concentrations and percentages of mobile cadmium showed significant variations across treatments, an indication that treatments may have had effect on the mobility of Cd. Manure treatment had both the lowest concentration of mobile Cd and mobile percentage (0.018 $mg \cdot kg^{-1}$ and 5.7 %), while EM treatment and molasses treatments had the highest concentration and mobile percentage of Cd respectively (0.035 $mg \cdot kg^{-1}$ and 10.3 %). Variations in the water soluble Cd concentrations in compost have previously been attributed to the formation of organo-metallic complexes of different solubilities in compost (Singh and Kalamdhad, 2013b). Haroun *et al.* (2007) reported that reduction of water soluble (mobile) fractions of Cd in compost was due to its ability to chemically bond strongly with organic materials, suggesting in the study, organic matter transformation in water hyacinth compost with manure amendment could have resulted in formation of more stable organo-cadmium complexes and thus less mobile Cd concentrations compared with other treatments with more mobile content. The 5.8-10 % of mobile fraction reported in this study also demonstrates that greater bulk of cadmium in water hyacinth compost could be in associations with less soluble forms considered less mobile. Cd in compost had previously been found to occur mainly in the reducible and residual fractions (Ciba *et al*., 1999; Fuentes *et al*., 2004).

The range (0.018-0.035 mg/kg) of soluble Cd concentrations obtained in this study was consistent with 0.02 mg/kg reported by Fuentes *et al.* (2004). However, this differs with the results by Singh and Kalamdhad (2014) whose concentrations were below detection limit, an occurrence that could be attributed to them incorporating a natural zeolite to the compost feedstock materials of water hyacinth. Zeolite is a material known to have ability for uptake of heavy metals which are in easily available fractions in compost.

There were significant differences in the concentrations of mobile lead and their percentages in the treatments. Compost prepared using manure treatment had both the least concentration and mobile percentage of lead. Molasses treatment had the highest concentration of mobile lead though with less total of concentration of lead compared to EM and manure treatment. This is an indication that the different organic amendments and Effective Microorganisms applied on the water hyacinth feedstock materials might have also had effect on the mobile concentrations and consequently percentages of mobile lead. Previously differences in lead mobile concentration in amended water hyacinth compost have been associated with mass loss and formation of humic substances forming complexes with lead during the composting process (Singh and Kalamdhad, 2013b)**.**

Tordoff *et al.* (2000) also reported that the high proportion of humified organic matter in cattle manure amendments played a role in reducing the bioavailable concentrations of lead in compost amended soil. It could therefore, be suggested in this study that, varying concentrations and percentages of the mobile Pb could have been as a result of variations in the amount of soluble Lead-humus complexes formed as a result of organic matter transformations in the treatments and that manure treatment could have had less soluble lead-humus complexes (Xiong *et al.*, 2010). On the other hand, amending compost feed stock materials with molasses increase microbial activity leading to higher production of acidic intermediate compounds (Torkashvand, 2010). Acidic intermediates during composting have previously been associated with increase in the soluble concentrations of lead in municipal solid waste compost (Hargreaves *et al*., 2008). This could explain for the high concentration of mobile lead in molasses treatment despite the lower total concentrations compared to EM and manure treatments.

The percentage of 1.6-8.7 lead obtained in water hyacinth compost in this study indicates that Pb in water hyacinth compost may not be bioavailable and that the compost could be safe for environmental use (Jimoh and Sabo, 2013). The percentages of mobile lead obtained in the study (range 1.6-8.7 %) were consistent with 5 % and 2.8 % reported by Singh and Kalamdhad (2013a) and Sims and Kline (1991).

In the study manure treatment had the least percentages of mobile heavy metals compared with other treatments. Previously the use of amendments on compost feedstock materials have been found to decrease heavy metal bioavailability by shifting them from plant available forms to fractions associated with organic materials, carbonates or metal oxides (Walker *et al*., 2004). However, the effect of such amendments in heavy metal solubility and thus mobility has been found to be influenced largely by the type and property of the amending materials (Clemente *et al*., 2005). Reduction of water-soluble forms of copper, cadmium, nickel and lead during the process may be attributed to the binding of the metals with the –OH and –COOH groups enriched by cattle manure. These groups and the newly formed humus increase the binding sites and combined with metals (released during mineralization of organic biomass) to form insoluble and immobile complexes (Guan et al. 2011; Singh and Kalamdhad 2013b)

5.1.4 Relationship between total and mobile concentrations of heavy metals

The significant relationship between total and mobile concentrations of lead and nickel in EM and copper in manure treatments indicates that the total concentrations of heavy metals could have had some influence on the mobile concentrations of Pb and Ni in EM and Cu in manure treatments. The positive relationship between total and mobile concentrations of heavy metals in the treatments indicated that, any increase in total concentration of heavy metals could result in a subsequent increase in mobile concentrations. Nickel metal in compost is considered potentially labile (Smith, 2009; Hanc *et al*., 2012) and any increase in total concentrations is expected to have some positive effect on the mobile concentrations. This could explain for the all positive relationship between total and mobile concentrations of nickel in all treatments. The total nickel metal concentration in compost would therefore be important in controlling its mobility in composted water hyacinth and strategies that include low metal amending materials, which could bring about dilutions in the initial concentration of heavy metal (Ni) are likely to inherently lower the overall mobile concentrations (Smith, 2009). For heavy metals such us Cd, Cu and Pb whose type of relationships varied with treatments, amendments that bring about conditions favouring transformation of mobile heavy metals into stable forms are likely to lower the overall mobile concentrations (Smith, 2009).

Mobile fractions of most heavy metals were poorly predictable from their total content. Coefficients of determination showed that 0.0 %, 0.1 %, 36.2 % and 8.6 % of the total variations in mobile concentrations for control, EM, manure and molasses respectively, could be explained by the linear relationship between total and mobile concentrations of copper (Table 4.5). For cadmium, 14.6 %, 15.5 %, 13.0 % and 9.3 % of the total variations in mobile concentrations for control, EM, manure and molasses respectively could be explained by the linear relationship between total and mobile concentrations (Table 4.5). Coefficients of determination for nickel showed that 27.7 %, 50.5% 26.3 % and 14.1 % of the total variations in mobile concentrations for control, EM, manure and molasses respectively could be explained by the linear relationship between total and mobile concentrations (Table 4.5). For lead, 0.3 %, 63.6 %, 16.3 % and 3.0% of the total variations in mobile concentrations for control, EM, manure and molasses respectively could be explained by the linear relationship between total and mobile concentrations (Table 4.5). The relationships between total and mobile concentrations were in agreement with the findings by Amir *et al*. (2005). According to Amir *et al*. (2005), mobile fractions of metals in compost were poorly predictable from their total content.

5.2 Conclusion

i) The minimum time required for water hyacinth composts to reach maturity when composting is done using an above ground aerobic design is 60 days. It can also be concluded that, after 60 days of composting, water hyacinth compost can be used for agricultural purposes without the limitation of eliciting competition for oxygen and nitrogen between growing plants and microorganisms in the soil.

ii) The total concentration of heavy metals were within acceptable limits which might indicate that none of these metal ion compounds pose a risk to accumulate on agricultural land when using water hyacinth compost as soil improvers. Thus, can be concluded that, the water hyacinth (*E. crassipes)* biomass from Lake Victoria can be converted to a safe form organic fertilizer.

iii) The organic amendments (cattle manure and molasses) and EM treatments had varying effects on the mobility of heavy metals and thus their bio-availabilities. It is therefore reasonable to believe that by modifying compost feedstock materials with cattle manure, more mobile concentrations of heavy metals could be transformed into stable forms and consequently the possible adverse effect of water hyacinth compost could be alleviated. It could also be concluded that, the small percentage of mobile heavy metals obtained in the studied compost shows that heavy metals studied could be complexed in stable structures and thus unlikely to be readily available in water hyacinth compost.

iv) The relationship between total and mobile concentrations of heavy metals in water hyacinth compost showed that, the mobile concentrations were poorly predictable from the total contents. The bioavailability of heavy metals was therefore not dependent on the total content of heavy metals in compost. The mobility dependent on the treatments and type of metal involved. It could also be concluded that, by amending or treating water hyacinth compost feedstock, with materials that brings about dilutions and transformations of mobile heavy metals into stable forms, risk from the mobile forms of Ni, Cu, Pb and Cd could effectively be reduced.

5.3 Recommendations

i) It is recommended that water hyacinth feedstock materials should be composted for at least sixty days for them to reach maturity.

ii) Water hyacinth organic materials from Lake Victoria can be composted for a safe organic fertilizer and as a way of disposing harvested water hyacinth biomass. The product is safe as has been proven from the present study to have minimum concentrations of both total and mobile concentrations of heavy metals and stable.

iii) It is recommended that composting of water hyacinth should be carried out using cow manure. It is widely available and offers advantage over other materials such as low environmental impact in terms of heavy metal toxicity.

iv) Studies should be undertaken to determine specific microorganisms in the compost which are able to convert easily available (exchangeable) fraction of heavy metals into less mobile (reducible and oxidizable) or inert (residual) fractions.

v) Although the compost produced posed no risk based on the heavy metal contamination obtained, there is need for further studies to examine its nutritional content and effect on soil quality before application as organic fertilizer.

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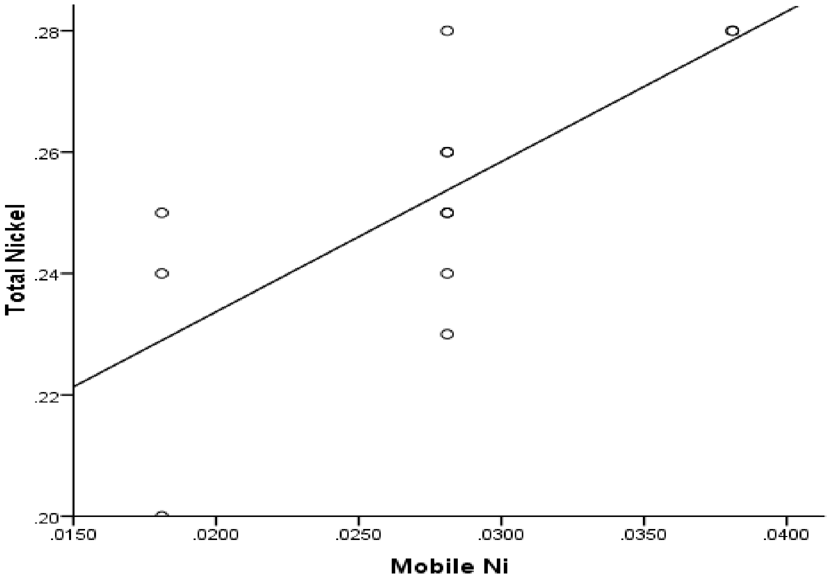
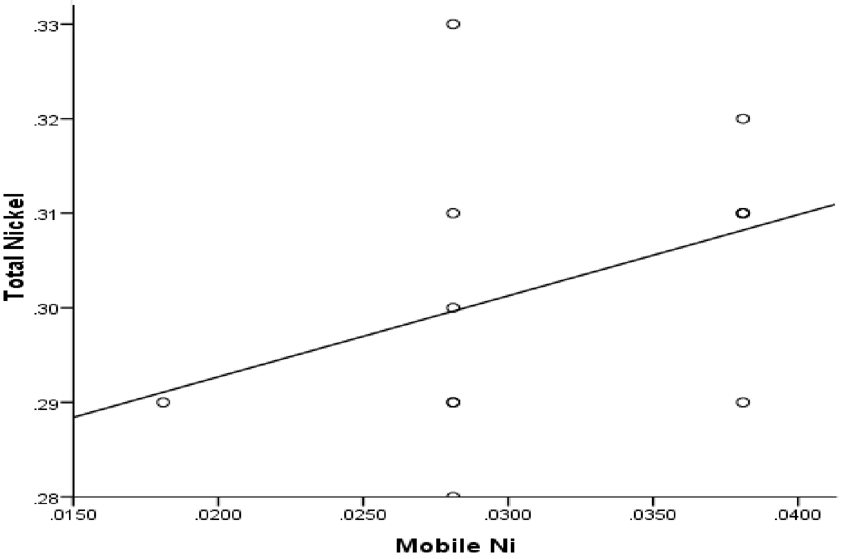
APPENDICES

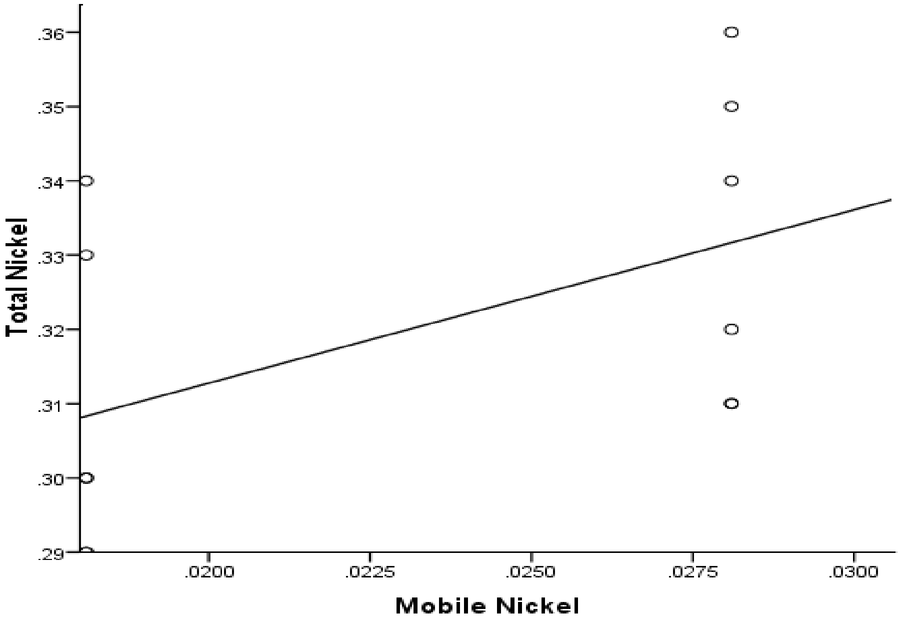
Appendix I: Scatter graphs showing the correlation between total and mobile concentrations of heavy metals in water hyacinth compost



Nickel in EM treatment



Nickel in molasses treatment.



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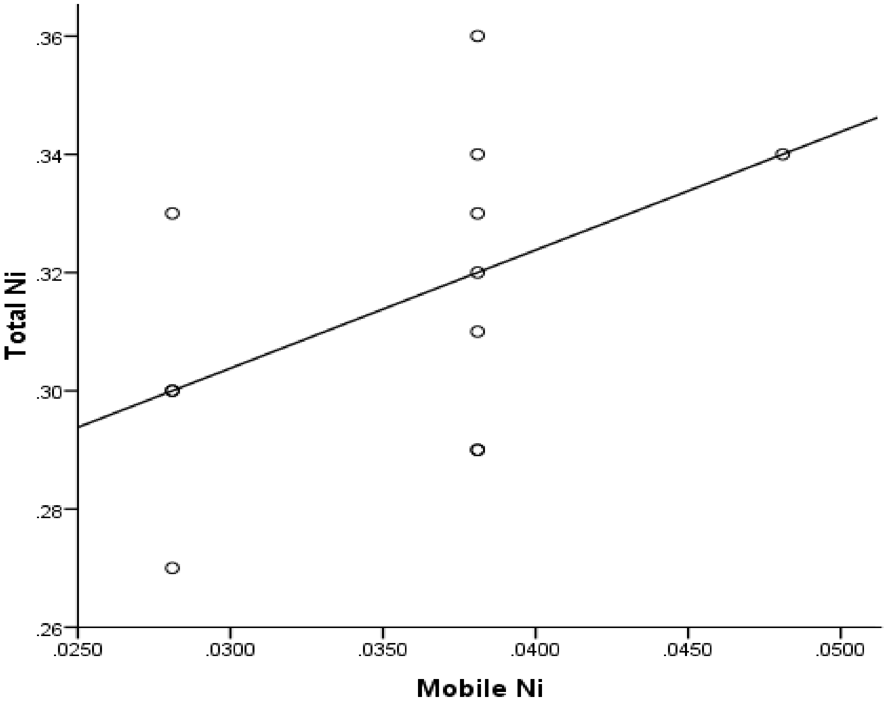
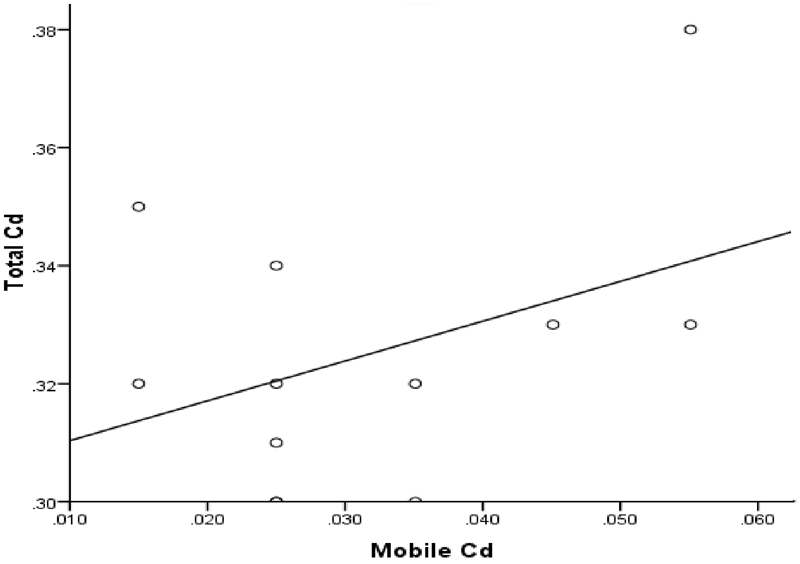
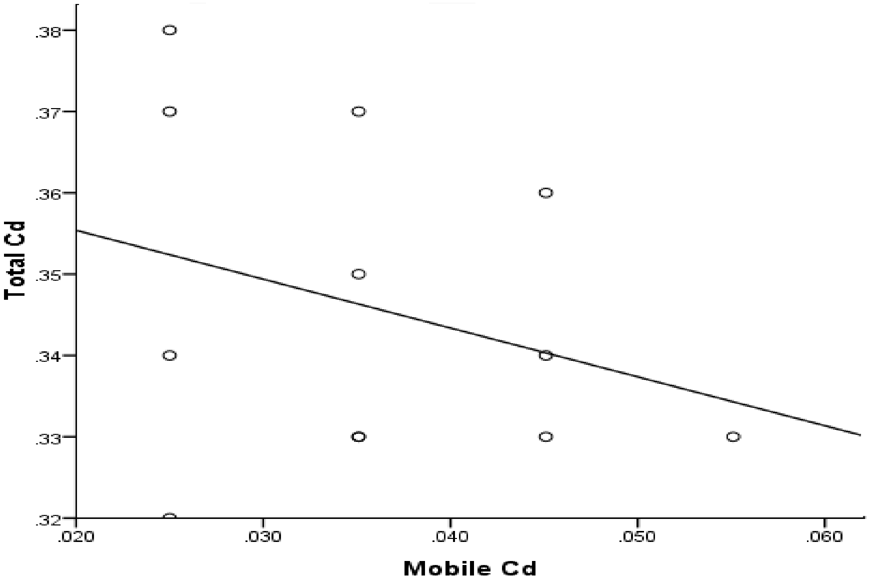


Nickel in manure treatment.



Cadmium in EM treatment



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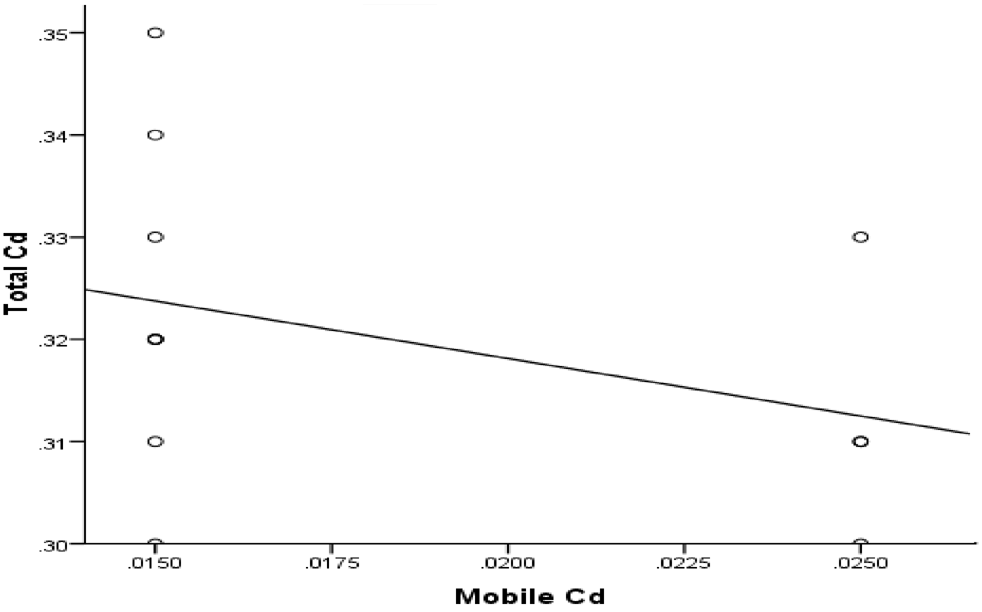
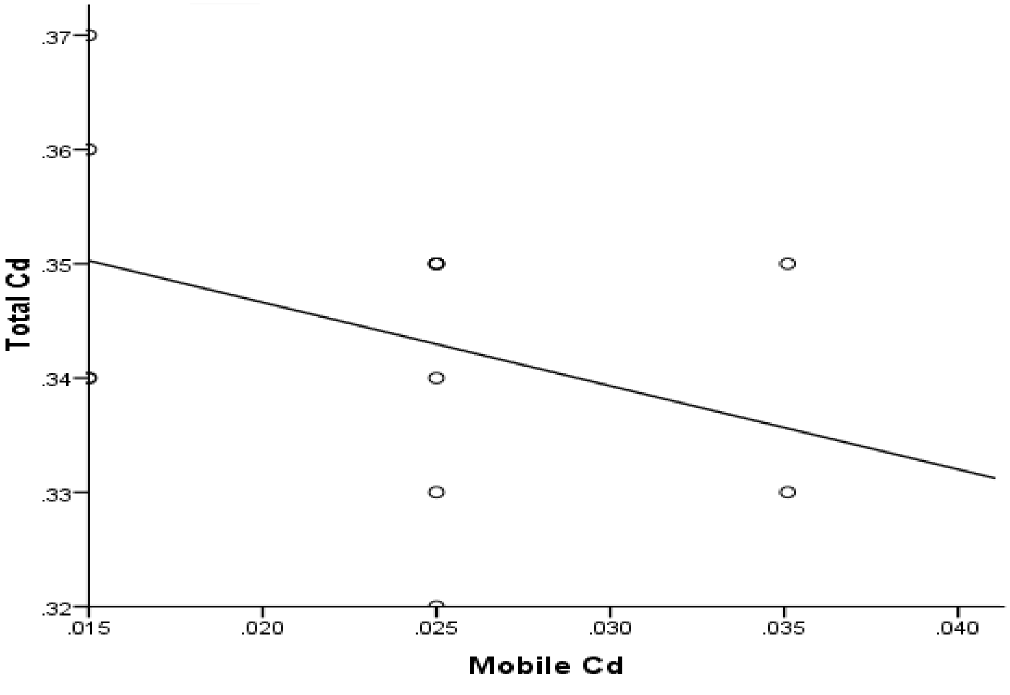
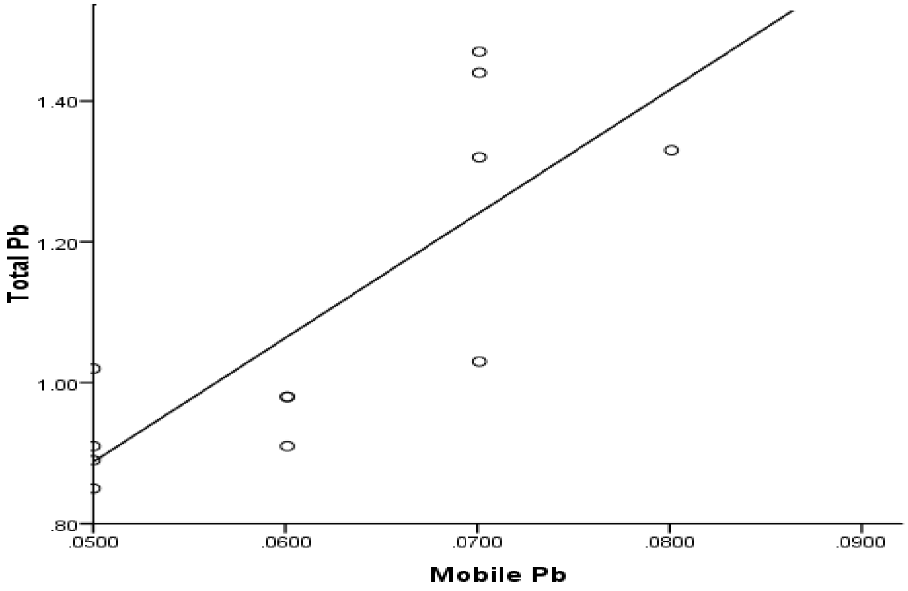


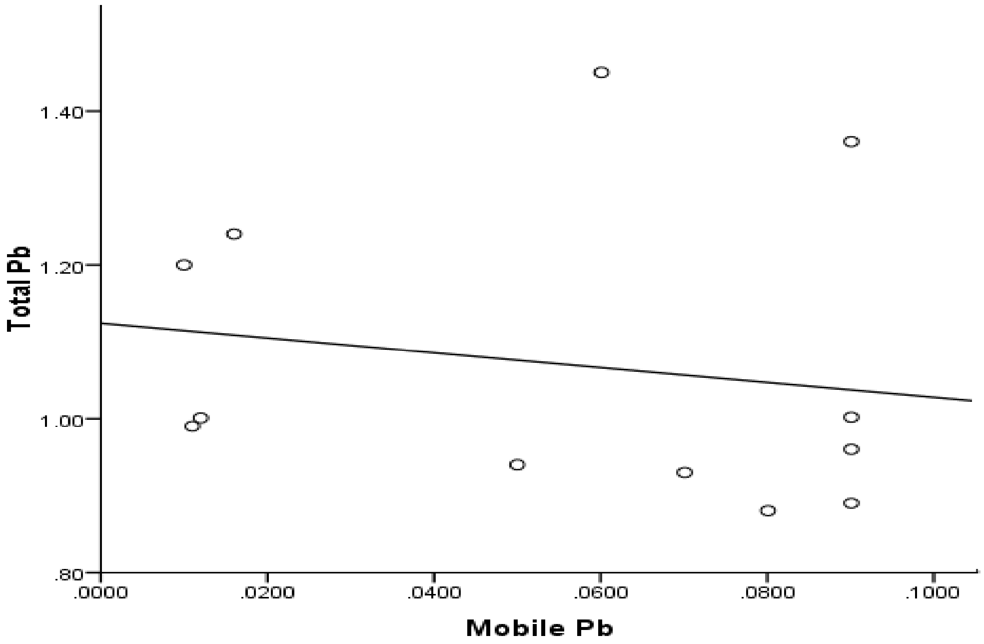
Cadmium in manure treatment.



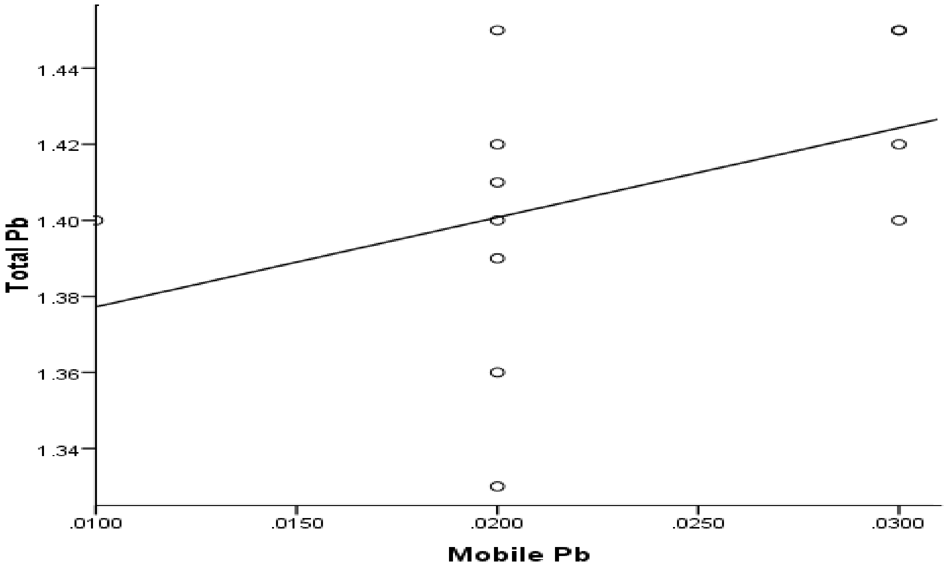
Cadmium metals in control treatment.



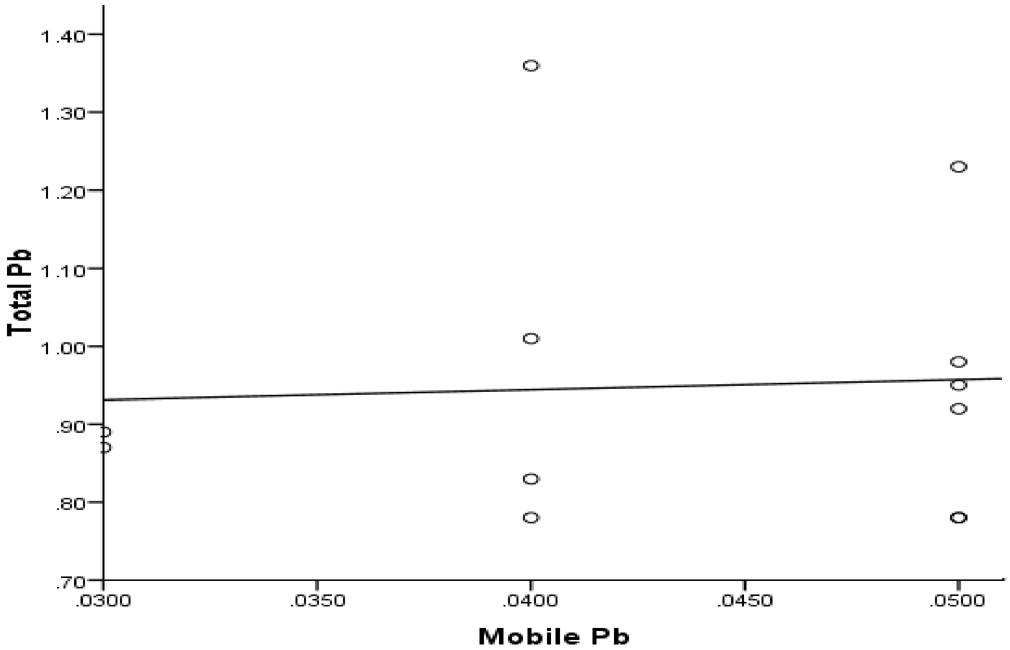
Lead metals in EM treatment



Lead in molasses treatment



Lead in manure treatment



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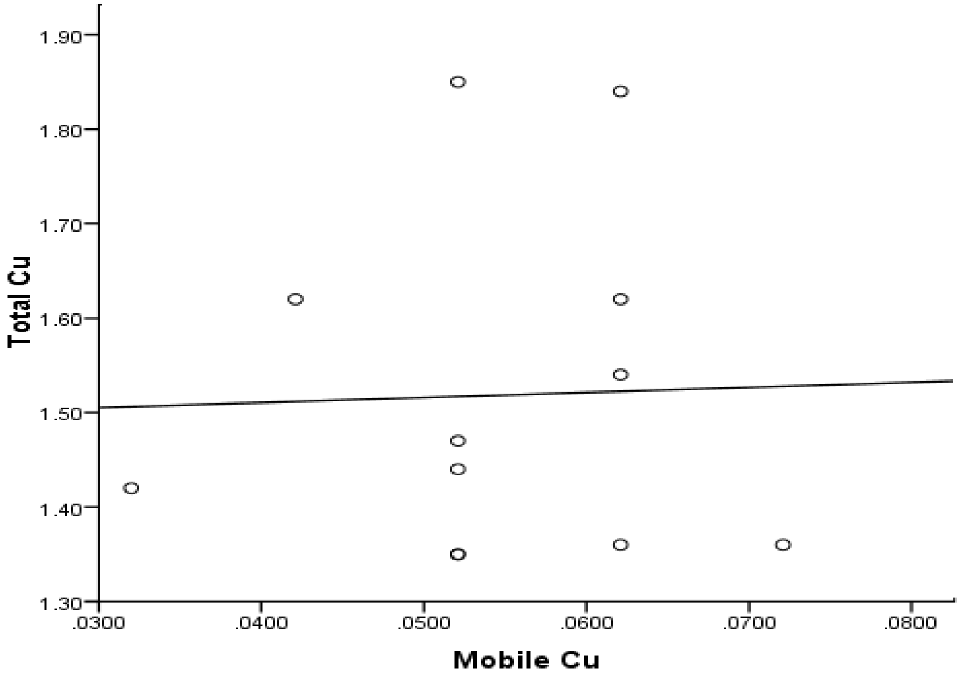
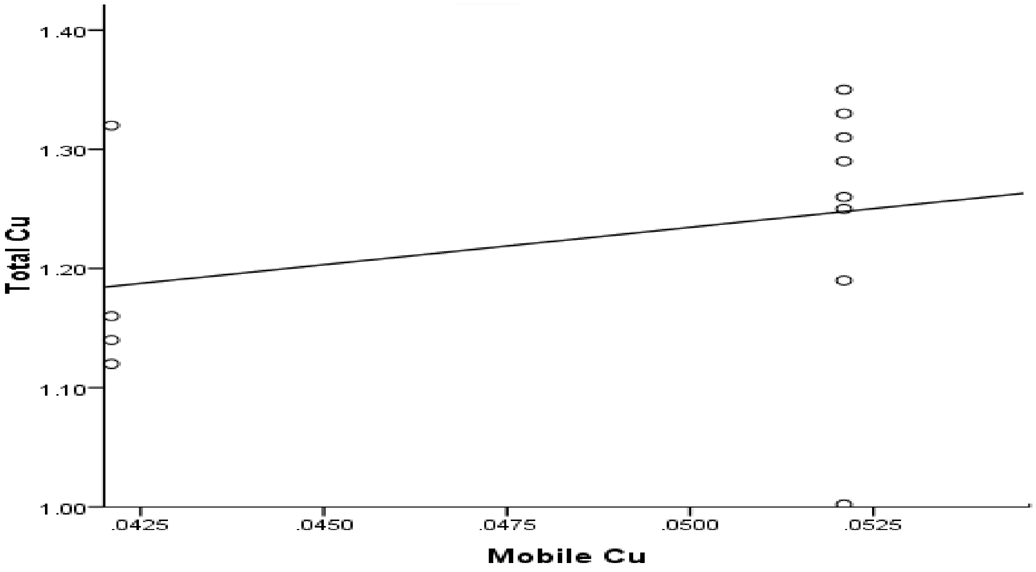
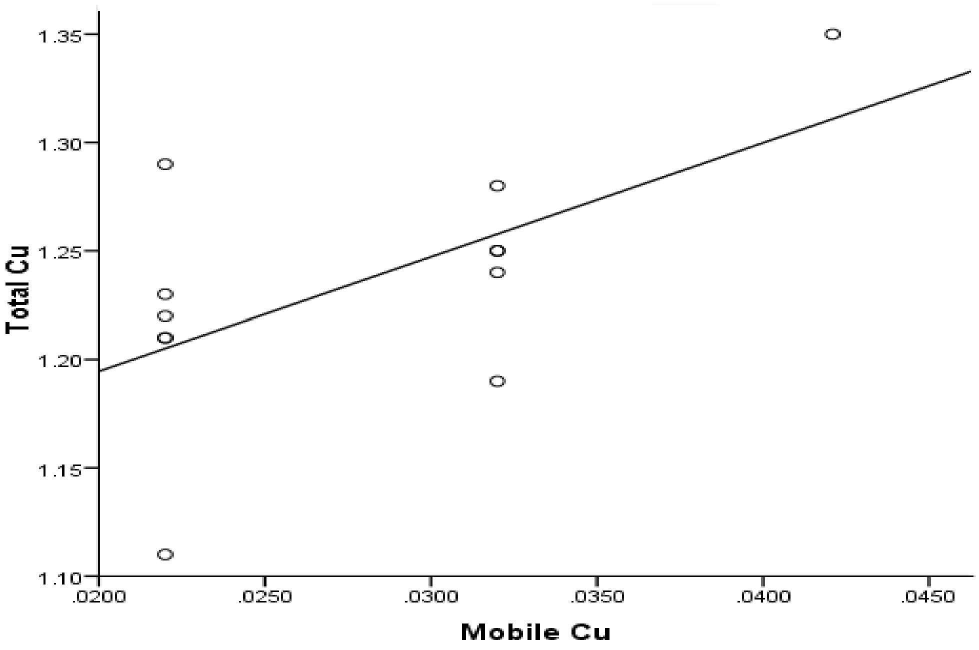


Copper in EM treatment



Copper in molasses treatment



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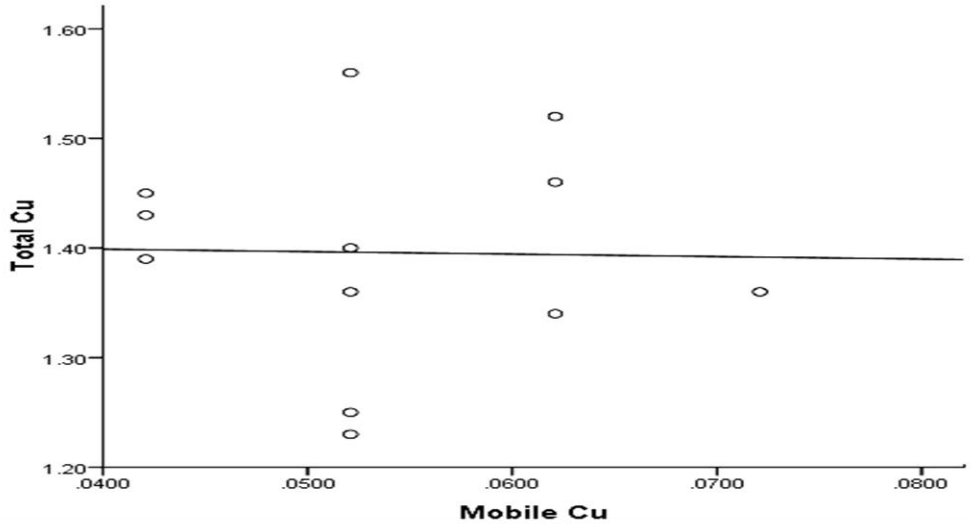

Copper in control treatment