EVALUATING THE AGRONOMIC EFFECTIVENESS OF HUMAN FAECAL COMPOST ON MAIZE YIELDS, ITS INFLUENCE ON SOIL CHEMICAL PROPERTIES AND SOIL FAUNA ABUNDANCE

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DECLARATION

I hereby declare that this is my original work and has not been submitted for the award of a degree in any other university.

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DEDICATION

I dedicated this work to my daughter, Bravian.

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LIST OF ABBREVIATIONS

RPM	Revolutions per minute
NPK	Nitrogen, Phosphorus, and Potassium
FAOSTAT	Food and Agriculture Organization Statistics Division
SSA	Sub Saharan Africa
NGOs	Non-Governmental Organizations
FYM	Farm Yard Manure
GENSTAT	General Statistical Package
ISFM	Integrated Soil Fertility Management
UN Habitat	United Nations Human Settlements Programme
SOM	Soil Organic Matter
TDS	Total Dry Solids
TSBF	Tropical Soil Biology and Fertility Institute
Ppm	Parts Per Million
DAP	Diammonium Phosphate
AAS	Atomic Absorption Spectrophotometer

ABSTRACT

Low soil fertility status has been stated as the main cause of poor crop yields in many sub-Saharan countries. This challenge can be addressed by using cheap and readily available options. One such option is human excreta. Human excreta contain millions of tons of nutrients. It is estimated that in a year, humans excrete an equivalent of 20 -30% of global annual fertilizer industry production. Unfortunately, most of the nutrients end up in water bodies through wastewater and surface runoff. A study was conducted at Kabete, Nairobi Kenya to evaluate the response of crops to application of human faecal compost, herein after referred to as peepoo compost, as well as its influence on soil fertility and soil fauna diversity and abundance. The treatments included two composts; Peepoo compost (from human fecal matter) and commercial compost (vermitech compost), two manures; cow manure, poultry manure, inorganic fertilizer (DAP), and no-input control. Peepoo compost was prepared using human excreta collected in peepoo bags from Kibera. The treatments were in 5 m by 4 m plots replicated three times in a randomized complete block design. Organic amendments were applied at the rate of 5 t ha^{-1}, while fertilizer at the recommended rate of 26 kg P ha^{-1} at planting and 60 kg N ha^{-1} for topdressing. Maize (*Zea mays*) was used as test crop. The soil samples were analyzed for chemical and biological parameters. Soil macrofauna were collected using soil monoliths, while nematodes were sampled using steel core ring samplers and extracted using the centrifuge technique. The crop yield, soil chemical and soil fauna data obtained was then subjected to statistical analysis using Genstat statistical software, 14th edition.

Amending soil with peepoo and vermitech compost, poultry and cow manure, had significant effect on soil chemical properties (*P*=0.005). There was an increase in soil total N across all treatments with Peepoo compost recording the highest increase of 19 % compared to the control. Plots treated with vermitech compost and cow manure recorded 16 % and 6 % increases in N, respectively while poultry manure and inorganic fertilizer recorded the lowest values for total N. The highest organic carbon values were recovered from plots amended with Peepoo and vermitech compost and cow manure (25.8, 25.1, and 25.1 g kg^{-1} respectively. Peepoo compost treated plots recorded the highest P value of 24.45 mg kg^{-1}, followed by poultry manure treated plots (14.50 mg kg^{-1}), cow manure (12.20 mgkg^{-1}) and vermitech compost (14.32 mgkg^{-1}). Earthworms were significantly higher in plots that were treated with composts and manures. Peepoo compost recorded 53 individuals m^{-2} while vermitech compost, poultry, and cow manure amended plots had earthworm densities of 49, 42, and 38 individuals m^{-2} respectively. The control and fertilizer recorded 32 individuals m^{-2} and 27 individuals m^{-2}. Application of organic amendments also increased free-living nematodes coupled by a decline in plant parasitic nematodes.

Maize grain yield was also significantly different (*p*<0.001) across the treatments. Plots treated with Peepoo compost recorded the highest grain yield of 8.8 t ha^{-1} , followed by Vermitech compost 7.1 t ha^{-1}, poultry manure (6.4 t ha^{-1}), cow manure (5.5 t ha^{-1}) and inorganic fertilizer(4.9 t ha^{-1}). Control plots recorded the lowest grain yield of 2.2 t ha^{-1}.These results show that Peepoo compost made from sanitized human excreta is a good fertilizer that can be used to substitute and/or supplement commercial fertilizers, a starting point towards improving soil and crop productivity in Kenya.

CHAPTER ONE

1. INTRODUCTION

1.1. Background information

Declining crop yields and productivity in African countries, is largely a result of low soil fertility due to nutrient mining by crops coupled with sub-optimal fertilizer use (Fosu*et al*., 2007). This is aggravated by the high population leading to small land holdings that are less than one hectare (Gikonyo and Smithson 2004), resulting in continuous farming and nutrient mining. (Lekasi *et al*., 2001; Braun *et al*., 1997). Continuous farming on poor soils without replenishing the nutrients that are lost through crop harvest causes low agricultural productivity due to declined soil fertility (Twomlow and Bruneau, 2000; Bationo *et al*., 2012). Studies particularly with crops such as maize, rice and grain legumes have shown that use of fertilizer is essential to enhance productivity in sub-Sahara Africa (SSA) (Sanchez *et al*. 1997). Fertilizers widely regarded as an essential input in crop production. However, studies have shown that fertilizer application cannot be relied on alone to address the challenge of low soil fertility in SSA (Jenssen 1993). They are frequently unavailable and unaffordable to most smallholder farmers (Bationo *et al*., 2012). Africa's average annual fertilizer use is only at 20 kg ha^{-1} compared to the global average of 96 kg ha^{-1} (Heisey and Mwangi 1996; Camara and Heinemann 2006). For instance, in central highlands of Kenya, farmers who use inorganic nitrogen fertilizers, apply at rates between 15-25 kg N ha^{-1}, which is below the recommended 40 kg N ha^{-1} (Kimani *et al*, 2004

In an effort to produce enough food that will meet the rising demand, more chemical fertilizers continue to be applied to the soil. Continuous monocropping without application of organic inputs such as poultry manure, farmyard manure, and composts results in mining of plant macro and micronutrients and depletion of soil organic matter. Use of composts, animal manures, and human waste may be a significant step in soil fertility improvement under intensive farming as it restores some of the exhausted nutrients from the soil. Organic sources supply nutrients through mineralization and in the process improve physicochemical and biological properties of the soil. In addition, these organic fertilizers release nutrients gradually in synchrony with crop demand (Bationo *et al.*, 2012). Organic fertilizers also play a very important role in enhancing productivity of many tropical farming systems through decomposition and subsequent release of nutrients to the soil (Cheryl *et al*., 2001). The major challenge associated with the use of organic materials is that they occur in insufficient amounts (Otinga *et al*., 2013) and use of human faecal waste which is a continually produced resource could bridge the gap. Its use is jeopardized by the negative image coupled by concerns on its effects on the environment and health risks.

Studies on use of human feacal matter as a fertilizer have been reported. Guzha *et al.* (2005) reported an improvement of soil qualities and increased maize yields as a result of application of human faeces and urine combined than only fertilizing with urine. Kutu *et al*. (2010) observed increase in spinach yields only when faeces were applied in combination with urine. Other studies have shown that human excreta is rich in major macronutrients (N, P, and K) as well as micronutrients (Schouw *et al.*, 2002). One person produces approximately 5.7 kg of nitrogen, 0.6 kg of phosphorus and 1.2 kg of potassium per year (Wolgast, 1993).

Negative attitudes as well as concerns about environmental and health hazards have greatly hindered the use of human faecal matter as a valuable source of nutrients for crops. To improve this situation, attempts have been made to find novel ways of treating and enhancing the quality of human excreta to make it safe for use as a fertilizer. Such approaches include urine separation from excreta, composting alone or mixed with other organics (Malkki 1999) and sanitization of human waste using ammonia-based method (Nordin 2010).During composting, the high temperatures accumulated kill pathogens present thus sanitizing the material. Human excreta used in this study was sanitized using the ammonia technology. Inactivation of pathogens was achieved using urea (6g per peepoo bag) which is broken down by enzymes which are naturally occurring in feaces to form ammonia and carbonates. Ammonia inactivates the pathogens (bacteria, virus and parasites) within two to four weeks. As urea is broken down, the pH value of the material increases and the hygienisation process begins. Increase in pH is very important in determining the availability of ammonia that inactivates the pathogens.

$Co\ (NH_2)_2 + \ 3H_2O \xrightarrow{urease} 2NH_4^+ + OH^- + HCO$................................Equation 1

Another major obstacle in the reuse of human waste is social acceptance. Education, sensitization, and addressing concerns of target consumers are important ways to successfully build acceptance of human waste reuse (Murray 2011).

1.2. Problem statement and Justification

Declining soil fertility poses a major challenge to increased food production by small-scale farmers in sub-Saharan Africa (Sanchez *et al*., 1997; Sanginga and Woomer 2009). Other constraints such as low nutrient holding capacities, high acidity, low organic matter, poor soil structure, and low water-holding capacity also play a role in reducing productivity of the soils (Mafongoya *et al*., 2007). Effective soil fertility management remains a big challenge in Africa despite the major efforts from research centers, NGOs, Governments and farmers and their organizations (Onduru *et al*., 2007). Though use of commercial fertilizers offer a possible option of reversing the trend, their high cost poses a major challenge to small-scale farmers in this region. Identifying alternative means of addressing this challenge is very important (Bationo *et al.,* 2004; FAOSTAT, 2004; Kimani *et al*., 2007). The alternative identified should be efficient, effective, affordable, and accessible to resource poor farmers (Bationo *et al*., 2007). Human waste is one such alternative whose value is highly underestimated in many tropical developing countries thus stagnating its use as a source of nutrients for plant growth.

According to the Kenya National Census (2009), Kenya's population has grown from 10.9 Million in 1969 to 38.6 Million in 2009. More than 34% (13 million) of Kenya's total population lives in urban areas (UN-Habitat, 2009). Managing human waste in urban areas that are densely populated and with limited infrastructure is posing a big challenge especially in the urban informal settlements. Mineral fertilizers and organic materials such as manure and crop residues have been used to a large extent to enhance soil fertility status and thus improve crop yields (Bationo *et al.,* 2007, Okalebo *et al.,* 2004). The ever-increasing costs, scarcity, and competition for alternative uses of these materials necessitate the search for local, readily available, and cheap nutrients sources (Bationo, 2012; Okalebo *et al.*, 2006).One such alternative is human waste that is produced daily in any given society and can be recycled thus harvesting the nutrients therein. Human waste has been reported to be rich in major macronutrients (N, P, and K) as well as micronutrients (Schouw *et al.,* 2002).

A study by Rockström *et al.* (2005) showed that annual excreta production in sub-Saharan Africa is so high that it corresponds to more than 100% of the local application of mineral fertilizers. If this is applied to the soil, then agricultural production can be enhanced at a low cost. Countries such as China have been able to maintain their soil fertility status, regardless of the high population through reuse of human waste (Bracken *et al.,* 2007). Recycling excreta into soils may help to reduce overreliance on chemical fertilizers besides protecting water bodies against contamination by human waste (Nordin, 2010). Use of human waste in agriculture may not only provide a simple solution to sanitation problems but will also enhance soil fertility (Nordin 2010). If human wastes, animal manure, and crop residues are recycled, then the fertility of arable land can be maintained, because the recycled products contain the same amounts of plant nutrients as were taken up by the crops and animals (Jonsson *et al.*, 2004). The annual per capita waste is about 520 kg, which contain approximately 5.7 kg of nitrogen, 0.6 kg of phosphorus and 1.2 kg of potassium per year (Wolgast, 1993) and some micronutrients in a form useful to plants. If the nutrients in the faeces of one person were used for grain cultivation, it would support one person grain requirement of 250 kg per year (Wolgast 1993). However, the risks associated with its handling, such as disease transmission, as well as cultural barriers limit exploitation of the resource. Nutrients removed by crops have to be replaced in order to maintain high agricultural yields over the years. Otherwise, the result is an annual net loss of nutrients from the soil. Therefore, it is important that nutrients from human excreta be recycled, to close the nutrient loops of society (Nordin 2010).

Recycling of organic waste returns nutrients back to the soil, rather than burying them in the subsoil where they may be leached to groundwater therefore contaminating the aquifers (Kuo *et al.*, 2004). The offensive odour from some fresh organic wastes also makes it unpleasant for people handling the wastes. Stabilization of organic wastes prior to land application is highly desirable to eliminate odor and vector attraction and to make nutrients in the wastes, particularly N, readily available for plant use. Stabilization of organic wastes is possible through composting, which is a microbiologically mediated process (Kuo *et al.*, 2004).

1.3. Objectives

1.3.1. Overall objective

Production of high quality compost from human excreta for use by smallholder farmers in Kenya

1.3.2. Specific objectives

1. Determine effects of human faecal compost on soil chemical properties.
2. Evaluate agronomic effectiveness of compost from human faecal matter on maize yield.
3. Evaluate influence of human faecal compost on abundance and diversity of soil fauna.

1.4. Hypotheses

1. Human faecal compost will significantly improve soil nutrient status and maize yields.
2. Soil fauna diversity will increase in response to application of human faecal compost.

CHAPTER TWO

LITERATURE REVIEW

2.1. Soil fertility management for sustainable agriculture

Soil fertility depletion is "the fundamental biophysical root-cause of declining per capita food production in Africa" according to Sanchez *et al*. (1996). Kenya is among those countries that lose large amounts of nutrients annually on average 42 kg N, 3 kg P and 29 kg K ha^{-1} per year through erosion, volatilization, and leaching (Smaling, 1993). Poor management of available resources has damaged the environment due to further land degradation. In developed countries, for example, over-application of inorganic and organic fertilizer has led to environmental contamination of water supplies and soils (Conway and Pretty 1991; Bump and Baanante, 1996). On the contrary, in developing countries, harsh climatic conditions, population pressure, land constraints such as small land holding sizes, and abandonment of the traditional soil management practices have often reduced soil fertility (Stoorvogel and Smaling 1990; Bump and Baanante 1996). Soil fertility decline processes include nutrient depletion, and nutrient mining (removal of nutrients without inputs), acidification (decline in soil pH), loss of soil organic matter (SOM), and increase in toxic elements such as aluminum (Hartemink, 2006).

Despite the fact that Sub-Saharan Africa is clearly identified as a future hotspot for food insecurity due to the low agricultural yields, countries in these region can increase their food production both at national and household level by adopting` integrated soil fertility management (ISFM) (Bationo and Waswa, 2011). Use of inorganic fertilizer has been responsible largely, for sustained increases in per capita food production in Asia, Latin America as well as for commercial farmers in southern Africa (Sanchez *et al*., 1997). They are also considered to be the most efficient way to reverse soil nutrient depletion (Bationo *et al*., 2007). However, other studies have shown that continuous use of inorganic fertilizers causes soil deterioration with regards to its chemical, physical, and biological properties and health (Mahajan *et al*., 2008). The adverse negative impacts of inorganic fertilizers together with their ever increasing prices have necessitated the use of organic fertilizers as a source of nutrients (Bationo *et al*., 2012, Satyanarayana *et al*., 2002). Organic materials such as FYM have traditionally been used by farmers to enhance soil fertility (Satyanarayana *et al*., 2002).

Integrated soil fertility management entails the use of mineral fertilizers, organic inputs, and improved germplasms combined with the knowledge on how to adapt these practices to local conditions, which aim at optimizing efficient agronomic use of the applied nutrients and thereby improving crop productivity. Alternative uses of crop residues and other organic materials from the field for use as animal fodder, firewood, or as construction material is one major factor that limits their use in soil fertility management and soil conservation (Kirchhorf and Odunze 2003). Use of human waste to substitute other organic materials such as cow manure, poultry manure and crop residues, will ensure a sustainable supply of organic manure for use in ISFM. The concept of ISFM focuses on how to manage these scarce nutrient resources efficiently (Bationo *et al*., 2012, Bationo *et al*., 2011). The overall strategy for increasing crop yields and sustaining them at a high level must include an integrated approach to the management of soil nutrients, along with other complementary measures, which recognizes soil as the storehouse of essential plant nutrients and that the way in which nutrients are managed will have a major impact on crop production, soil fertility, and agricultural sustainability.

2.2. Organic soil amendments as nutrient sources

The use and management of organic inputs for supply of crop nutrient and soil improvement has been in existence for a long time just like arable agriculture itself (Cheryl *et al*., 2001). In addition to supplying nutrients, organic inputs have other benefits. These benefits include: replenishing soil organic matter, increasing the crop response to mineral fertilizer, improving the soil's moisture storage capacity, regulating soil chemical and physical properties that affect nutrient storage and availability as well as root growth, supplying essential elements not contained in mineral fertilizers, improving the availability of phosphorus for plant uptake, and ameliorating problems such as soil acidity (Bationo *et al*., 2012).

Organic inputs used in soil fertility management consist of livestock manures, crop residues, household organic refuse, composted plant materials, and other plant biomass harvested from within or outside the farm for purposes of improving soil productivity (Kihanda *et al*., 2004). Organic inputs derived from plant remains provide most of the essential nutrient elements, but usually in insufficient quantities. Because of their richness in carbon, organic resources provide an energy source for soil microorganisms.

The microorganisms drive the various soil biological processes and therefore affect nutrient transformation in the soil. As these organic materials undergo the process of decomposition in soil, they contribute to the formation of soil organic matter (SOM) (Bationo *et al.*, 2012). During decomposition, the organic materials interact with soil minerals forming complex substances that influence nutrient availability; for example binding toxic chemical elements such as aluminum or releasing phosphorus bound to soil mineral surfaces (Bationo *et al.*, 2012). Nutrients from organic resources are slowly released compared with mineral fertilizers. This enhances continuous supply of nutrients throughout the growing season. The slow release further reduces nutrient losses, for instance through leaching (Bationo *et al.*, 2012).Under undisturbed natural vegetation such as permanent forests or grasslands, the nutrients are recycled within a closed loop since little or no residues are taken out of the system. However, in arable system, the rate of SOM formation is usually low and the nutrient release cannot match crop nutrient demand. Organic inputs applied to the soil control the rate, pattern, and extent of growth and activity of soil organisms and provide the source of carbon, energy and nutrients for the synthesis of soil organic matter (Kimani *et al.*, 2004). The practice of applying organic material to soil can increase the humus content of soils by 15-50%, depending on soil type, in addition to increasing soil aggregate stability and root permeability (Kimani *et al.*, 2004). However, these organic materials occur in insufficient amounts and have other competitive alternative uses such as construction, source of fuel and animal feed.

This constraints their use and human excreta therefore becomes important due to its availability and quantities produced.

2.1. Use of human excreta

Human excreta contain elements that can be used as fertilizer for growing crops (Heinonen-Tanski and Wijk-Sijbesma, 2005). Since matter can neither be created nor destroyed, consumed plant nutrients such as nitrogen, phosphorus, potassium, and micronutrients leave the human body in form of excreta, with only a small proportion stored in cells or excreted via respiration or sweat (Jönsson *et al.,* 2004). If human and animal excreta were to be treated or composted and used as a fertilizer, it would be possible to increase crop yields in a cost-effective way as well as protect water bodies from contamination (Winker *et al.*, 2009). Use of human excreta as fertilizer has been in practice since time immemorial ((Muskolus, 2008) in European cities, towns and rural areas. In China, Vietnam and Japan, human excreta are used frequently as ‘night soils’ generally, without any known problems for agricultural productivity. With continued use of human excreta, China has been able to maintain their soil fertility status despite the high population. However, poor handling is often associated with health problems such as high prevalence of enteric pathogens in the population, noted in China by Xu *et al.* (1995) and increased intensity hookworm infection in Vietnamese women (Humphries *et al.*, 1997).

Human excreta have been reported to have excellent plant nutritional value in terms of providing nitrogen (N), phosphorus (P) and potassium (K) (Kirchmann and Pettersson, 1995; Mnkeni and Austin, 2008; Kutu *et al.,* 2011). Besides supplying macro- and micronutrients, human faeces contain organic matter, which is important in increasing the water-holding and ion-buffering capacity of the soil, serves as food for the microorganisms and improves the soil structure (Jönsson *et al.,* 2004). Reports indicate that one person produces 41–93 g faeces day^{-1} (total dry solids) and 0.6–1.2 L urine day^{-1} (Schouw *et al.,* 2002). Human waste contains as much as 60–70% of nutrients from agricultural fields which are waste (Kirchman and Petterson,1995). Human waste, both urine and faeces, have a great potential for improving fertility status of impoverished soils. Urine is reported to have a high content of readily available N, P, and K and its fertilizing effect is similar to that of nitrogen-rich chemical fertilizers. On the other hand, faeces have high contents of phosphorus and potassium in organic form. However, nitrogen is only slowly released since it is organically bound in undigested food remains (Kirchman and Petterson, 1995). Reuse of human excreta will reduce the pollution effects that result from unsafe excreta disposal and excess use of chemical fertilizers and protect surface and groundwater. Effective reuse of human excreta would also reduce the waterborne enteric microbiological diseases, as there would be less contaminated wastewater (Heinonen-Tanski and Wijk-Sijbesma, 2005).

Human excreta are by products of human metabolism and are products formed every day in every human society (Heinonen-Tanski and Wijk-Sijbesma, 2005; Jönsson *et al.*, 2004

Schouw *et al.,* 2002). Human excreta is a potential source of nutrients for growth of crops (Schonning and Stensrom 2007; Winker *et al.*, 2009). Unlike other organic materials for instance cow manure and crop residues that are limited and have other competitive uses such as use as fuel and building materials, human waste is available in abundance and has no other known use yet. This implies that it can be used in agriculture to enhance crop performance as much as possible and needed. Rapid growing world population and urbanization, makes management of human waste challenging especially in urban areas of sub-Saharan Africa. However, this challenge can be taken as an opportunity to generate more human fertilizer to increase crop yields and thus feed that high population The fertilizer value of human waste has been highly under-estimated in agriculture and horticulture, more especially in many tropical developing countries. Despite being often seen as an urgent disposal problem, it is important to note that human waste has vast and diverse potential for resource recovery (Murray, 2011). Nutrients in faeces should be used in plant production, instead of ending up in wastewater treatment plants, to follow the principles of sustainability (Heinonen-Tanski *et al*., 2010: Winker *et al.*, 2009). Wastewater reuse dates back 5000 years to the Minoan Civilization in ancient Greece where it was used for agricultural irrigation and this is still practiced in developing and developed countries (Murray, 2011). Land application of treated sludge is also widely practiced in many regions of the world. Human faeces are considered a valuable nutrient source in a number of countries such as China, Japan, Korea, South-America and some African countries such as Ghana (Malkki 1999; Murray 2011)and South Africa (Mnkeni *et al.,* 2008). Applying faecal sludge to land is an effective way of utilizing its nutrients resources. In Ghana, faecal sludge is collected from on-site sanitation systems and discharged onto farmers' fields. The high temperatures in the area are an added advantage for the inactivation of pathogens in the sludge (Murray 2011). Negative attitudes as well as concerns about environmental and health hazards have greatly hindered use of human faecal matter as a valuable source of nutrients for crops. To improve this situation, attempts have been made by enhancing the quality of human excreta and finding new treatment methods. Human excreta processing is also important in minimizing health risks from enteric bacteria, viruses, protozoa and helminthes eggs (Malkki 1999).One such attempt is composting and urine separation that has made it possible to reclaim and utilize human excreta (Malkki 1999). Composting can be used to sanitize human faeces and hence safe for human handling. Composting is also a method to balance the relation of carbon and nitrogen and if there is excess nitrogen, its portion is reduced. Composting can be done in the latrine pit or in a separate heap either alone or combined with other household organic wastes. If composting is done in the latrine pit, there should be another pit so as to ensure that there is no addition of fresh faeces and therefore allow contents of the first pit are given sufficient time to compost. This will not only reduce the time required for the compost to mature but also increase chances of eliminating enteric pathogens.

Use of human excreta as a fertilizer has been studied; Ghuza *et al*. (2005) reported an increased in maize yield as a result of treatment of soil with human excreta. The report also indicated that maize grown using human excreta used the least water amount per unit of grain produced. Kutu *et al*. (2010) showed that the application of human faeces and urine, either separately or in combination, resulted in increased fresh and dry matter yields of spinach. Cofie and Adamtey (2009), also demonstrated a two -threefold increase in yields of crops (maize, sorghum and cabbage) grown on faecal sludge-treated soils as compared to untreated soils. However, there are no studies to demonstrate long-term beneficial effects that human faecal compost will have on soil chemical, biological, and physical properties of soils.

2.2. Nutrient release from organic matter

The amounts of nutrients released from organic materials used as fertilizers depends on their chemical composition, application rate and prevailing environmental conditions (Nhamo *et al*., 2004). Determining N release patterns of organic manures can give an estimate of the amount of N that given manure can potentially release for crop uptake. The release patterns of organic manures can be useful in describing the quality of materials and predict rates of decomposition and N release (Palm and Sanchez, 1991; Mafongoya *et al*., 1998). The rate at which N and P is released from organic materials depends mainly on microorganisms that transform organic forms to mineral plant available N and P (Havlin *et al.*, 1999). Most of the organic fertilizers have a low fraction of soluble inorganic forms of nitrogen (N); therefore, they have to go through a decomposition process before becoming plant available. This happens in two steps, mineralization in which NH_4^+ is made available and nitrification that makes NO_3^-

available. In mineralization, organic N is converted to ammonium (NH_4^+) and nitrates (NO_3^-) mediated by autotrophic bacteria, actinomycetes, and fungi. Nitrification on the hand involves the oxidation of $NH_4^+$to nitrate (NO_3^-), mediated by two groups of autotrophic nitrifying bacteria; *Nitrosomonas* spp. which first oxidizes NH_4^+ to nitrite (NO_2^-), and *Nitrobacter* spp. which oxidizes NO_2^-), to NO_3^-.

2.3. Influence of organic inputs on soil macrofauna

Application of organic inputs has been shown to increase the abundance, diversity, and biomass of soil macrofauna such as earthworms and termites. For instance, Ayuke, 2010 reported over 100% increase in faunal population on addition of organic residues compared to the no input control which was attributed availability of food substrates. Ayuke *et al.* (2003) reported an increase in earthworm abundance following the application of plant residues and farmyard manure. Font *et al*. (2009) also reported that tomato mulch increased abundance and diversity of earthworms and Ayuke (2000), observed that *Senna* and *Tithonia* residues increased the faunal population by 100% above the control.

Soil fauna breakdown organic resources and therefore determine the diversity and abundance of other soil organisms through enhanced availability of nutrient (Lavelle *et al*., 1997). Because of their large body size, fast turnover rate as well as their role in soil fertility management, they have been considered as important early warning indicators of declining soil fertility. The soil fauna are responsible for ecosystem services such as nutrient cycling, decomposition, and mineralization for subsistence. Thus, soil macro fauna play an integral role in farming systems. Their abundance and diversity is suggested to be an indicator of functional status of the soil (Tabu *et al*., 2004). Use of organic materials has profound effects on the activities of soil fauna such as earthworms and termites, which in turn affect the soil structure and thus its water holding capacity as well as aeration (Ayuke *et al*., 2009). Soil invertebrate fauna, particularly earthworms and termites, play a vital role in the decomposition of organic residues and the formation of soil structure and thus affect soil quality for crop production (Ayuke, 2010).

Earthworms and termites are among the most active components of the soil fauna and therefore have significant influence on soil structure and SOM dynamics (Lavelle *et al*., 1997). Earthworms are especially active within the upper 10 to 20 cm of soil while termites are active throughout the soil profile and their effects on soil structure and SOM dynamics are manifested on short-term and long-term basis. Earthworm activities are rather uniformly distributed on a horizontal dimension whereas termite activities are concentrated in their nests and galleries. The earthworm communities of the humid tropics are largely dominated by endogeic populations that feed on SOM, while the temperate areas are dominated by epigeic that feed on surface leaf litter and anecic populations, which make permanent burrows within mineral soil (Lavelle,1997). Earthworms and termites are involved in modification of soil environment as they ingest soil creating organo-mineral structural units (Ayuke, 2010), which in turn create microhabitats that facilitate colonization by other microorganisms such as the actinomycetes that thrive well on worm casts. Termites can affect the soil through their burrowing activities in searching for food, or constructing nests either below or aboveground (Mando *et al*., 1997). Soil structure stability, porosity, organic matter decomposition, and chemical fertility are altered to a great extent by termite activities where they are numerous and active (Mando *et al*., 1997).

Influence of organic fertilizers on nematodes

Most kinds of soil nematodes do not parasitize plants but are very important and beneficial in the decomposition of organic material and the recycling of nutrients in soil (Abrams and Mitchell, 1980).These nematodes are often referred to as free-living nematodes. Free-living nematodes : bacterivores and fungivores do not feed directly on soil organic matter, but on the bacteria and fungi that decompose organic matter. The presence and feeding of these nematodes accelerate the decomposition process. Their feeding recycles minerals and other nutrients from bacteria, fungi, and other substrates and returns them to the soil where they are accessible to plant roots. Numbers of free-living nematodes increase rapidly in the soil following the addition of the inorganic fertilizers (Agyarko and Asante, 2005). This is due accumulation of specific compounds, resulting from organic matter decomposition, that may be nematicidal thus negatively affecting nematode populations (Akhtar and Malik, 2000).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Site Description

The study was conducted at the University of Nairobi's Upper Kabete field station. The farm is located about 10 km north of Nairobi on latitude 1° 15' S and longitude 36° 41' E, with an elevation of 1940 m above sea level. The area receives an average annual precipitation of 1000 mm in a bimodal rainfall pattern; the long rains occurring between March – May, while the short rains between October – December (Taylor and Lawes 1971). The minimum and maximum mean temperature average is 13.7° C and 24.3° C, respectively. Soils are predominantly eutric Nitisols characterized by deep red coloration, are highly weathered with 60 – 80% clay. The clay mineral is predominantly kaolin and the parent material is the Kabete *trachyte (*Michieka ,1977).

3.2. Baseline soil analysis

3.2.1. Soil sampling

Before setting up the study, soil samples were taken randomly from the experimental site and thoroughly mixed to obtain two composite samples. These samples were sealed in labeled sampling bags, and then transported to the laboratory for analysis. The parameters analyzed from the samples include; available N, total N, Phosphorous, soil organic carbon, the bases (K, Na, Mg and Ca) and pH.

3.2.2. Procedures for Chemical Analysis

Total nitrogen (N) determined by wet oxidation using Kjeldahl digestion and distillation procedures by Parkinson and Allen (1975). Available N was determined using steam distillation method as described by Bremner and Keeney (1965); organic carbon (C) by wet oxidation using modified Walkley-Black method (Okalebo *et al*., 2002) and Phosphorus (P), potassium (K), sodium (Na) exchangeable calcium (Ca) and magnesium (Mg) was extracted by Mehlich-3 procedure (Mehlich, 1984) and then measured colorimetrically using the *Atomic Absorption Spectrophotometer*.

3.2.2.1. Total Nitrogen

Approximately 1 g of air-dried soil was weighed and transferred into Kjeldahl digestion tubes.. Catalyst (mixture of selenium and copper sulphate) and concentrated sulphuric acid were added. The flasks were placed in a fume chamber and gently heated for 6 hours. After completion of digestion, about 10 ml of the digest was transferred using a pipette into a 300 ml Kjeldahl flask and phenolphthalein indicator added. 10 M sodium hydroxide (NaoH). This was mounted onto the distillation unit to start the distillation process. Distillation was done over 20 ml of 4 % Boric acid with 3 drops of mixed indicator. The contents of the conical flask were titrated with 0.01 N Hcl to the end-point. The volume of the acid used was recorded and % N calculated. A blank distillation and titration was also done. The % n in the soil was then calculated using the formula;\

$$\%\text{ N in soil} = \frac{(V_{sample} - V_{blank}) * \text{Molarity of acid} * 1.401}{\text{Weight of air-dried soil sample}} \quad \text{..........................Equation 1}$$

Where;

$\underline{V}_{sample}$= Volume in mls of the acid used in titrating the sample.

$\underline{V}_{blank}$ = Volume in mls of the acid used in titrating the blank.

1.401 =1 ml of the volumetric solution is equal to 1.401 mg of N.

3.2.2.2. Determination of mineral Nitrogen ($NH4^+$ and $NO3^-$)

Mineral Nitrogen in the soil was extracted using 2 M potassium chloride (extracting solution) in the ratio of 1:5 (soil: extracting solution) and determined by steam distillation. Ten grams of soil was weighed and transferred to 250 ml conical flask and 50 ml of Kcl added. The mixture was shaken in an orbital shaker for 1 hour and filtered using Whatman's filter paper number 42. The filtrate was divided into two portions for the determination of NH_4^+ and NO_3^-. The ammonia gas released was trapped in 20 ml of 1 % boric acid to which an indicator was added. The distillate was then titrated against 0.01 N H_2SO_4 to determine the amount of ammonia present. The actual amount of NH_4^+ and NO_3^- were calculated using the formula shown below;

$$\mathrm{NH_4^+ - N/NO_3^- - N\ (mg/kg)} = \frac{(\mathrm{V_{sample} - V_{blank}}) \times \mathrm{N} \times \mathrm{V_{extract}} \times 14 \times 1000}{\mathrm{G} \times \mathrm{V_A}}$$

..................Equation 2

Where:

V_{sample} =Volume of the standard H_2SO_4 used in titration of the sample in mls

V_{Blank} =Volume of the standard H_2SO_4 used in titration of the blank.

N =Normality of H_2SO_4

$V_{Extract}$ =Total volume of the extract in mls

G = Weight of air-dry soil used for NH_4^+ -N /NO_3^- N extraction in grams

V_A =Volume of aliquot of extract taken for NH_4^+ -N /NO_3^- N determination in mls.

14=Molar mass of nitrogen.

1000= conversion factor to mg/kg

3.2.2.3. Organic carbon

Soil organic carbon was determined using the modified Walkley-Black method (Okalebo *et al*., 2002; Nelson and Sommers (1982) that involves wet oxidation of organic matter by Potassium dichromate ($K_2Cr_2O_2$) and concentrated H_2SO_4 followed by titration with ferrous ammonium sulfate. Approximately 0.5 g of dry 0.5 mm sieved soil was weighed and transferred into a clean and dry conical flask. Ten ml of potassium dichromate and 20 ml concentrated Sulphuric acid were added. The reagents were also added to a blank conical flask (without soil). Ten mls of Orthophosphoric acid, Barium and two drops of diphenylamine indicator were added and drop-wise titration done with ferrous sulphate until the colour of the solution turned from purple to dark green at the end-point. The volume of $FeSO_4$ solution used in the titration was recorded. The organic carbon present in the sample was then calculated using the formula:

$$C\,(\%) = \underline{(\text{M.e dichromate} — \text{m.e } FeSO_4)} \times 0.3 \text{.............................Equation 3}$$

Weight of dry soil used in grams

m.e = milliequivalent weight

0.3 = conversion constant

3.2.2.4. Soil pH

The soil pH was measured in water in the ratio of 1:2.5(soil: water) using a glass electrode pH meter. Approximately 6 g of soil was weighed into small 20 ml plastic shaking bottles and 15 mls of distilled water added to the soil. This soil-water solution was shaken thoroughly for about 30 minutes then left to settle for 20 minutes. The pH of the supernatant was measured with a glass electrode calibrated with buffers of pH 4.0 and 7.0.

3.2.2.5. Extractable P

Approximately 5g of air-dried soil samples ground and passed through 2 mm sieve were weighed into a 100-ml extracting tube and 50 ml of double acid reagent(mixture of 0.95 N HCL and 0.025 N H_2SO_4) added to the soil samples in the ratio of 1:10(soil :solution). The tubes were stoppered tightly and shaken for 30 minutes in a mechanical reciprocating shaker, after which they were filtered through Whatman No. 42 filter paper and filtrate collected in specimen bottles.

Several 100-ppm P standards were prepared to which, 5 ml of double acid was added followed by 20 ml of distilled water mixed and allowed to stand for 15 minutes after which the reading (absorbance) was taken using the spectrophotometer.

3.2.2.6. Exchangeable bases (Ca, Mg, and K)

The exchangeable bases were extracted using the Mehlich -3 method. Approximately 3 g of air-dried soil was ground and passed through 2 mm sieve and transferred into 250 ml erlenmeyer conical flasks. Approximately 30 ml of extraction solution was added to the samples at a ratio of 1:10 (soil: extraction solution). The flasks were tightly stoppered and shaken in a reciprocating shaker at 120 oscillations per minute. The soil extraction mixture was then filtered into plastic bottles using Whatman filter paper number 42. The elements (Ca, Mg and K) were analyzed using an Atomic Absorption Spectrophotometer (AAS).

3.3. Selection of treatments

Two commonly used manures by farmers; cow and poultry manure were selected based on their availability. Poultry manure was obtained for the poultry section while cow manure was collected from the cattle shed at the University of Nairobi field station. Vermitech compost was obtained from Finlays Naivasha for comparison with peepoo compost that was prepared at the university.

3.4. Human excreta source and the composting process

Human excreta used to prepare the compost were obtained from Kibera, an informal settlement in Nairobi Kenya. The excreta were collected in peepoo bags that are single use toilets that are in form of slim elongated bags. The bags are made of biodegradable bioplastic, are self-sanitizing and used once by one person .The Peepoo compost was prepared at the field station farm in Upper Kabete by composting Peepoo bags for three months. Composting was done using pit method (Nzuma *et al.*, 1998). Four pits each measuring 2m long by 2m wide and 0.5 m deep were prepared. Peepoo bags containing human excreta were then laid in two layers and covered by a thin layer of soil. The contents were transferred into another pit after 3 weeks and to the third pit and allowed to cure for a month after which it was uncovered and packed in big bags ready for use.

3.5. Experimental design and treatments

The study was conducted at Kabete during the short and long rains with the following treatments using maize (*Zea mays* L.) hybrid as the test crop. The experiment was conducted on plots measuring (5 × 4) m^2 laid out in a randomized complete block design with three replications. There were six treatments comprising cow manure, poultry manure, Vermitech compost, fertilizer, Peepoo compost, and a no-input control. Cow and poultry manure were obtained from the University of Nairobi’s Upper Kabete campus cattle shed and the Poultry unit, respectively. The selection criterion for cow and poultry manure was based on the ease of availability of the two resources. The Vermitech compost was obtained from Finlays in Naivasha. Composts and manures were applied at the rate of 5 t ha^{-1} while fertilizer were applied at the recommended rate of 60 kg N ha^{-1} and 26 kg P ha^{-1} (Okalebo *et al.,* 2007). Mavuno fertilizer was applied at planting and it contained 10 % N, 26 % P, and 4 % MgO while 0.5 kg of CAN was used for top dressing and it contained 26 % N, 16 % CaO and 5 % S.

The treatments used were:

1) control: with no external inputs
2) fertilizer input : 0.2 kg of DAP applied at planting and 0.5 kg of CAN for topdressing per plot
3) Peepoo compost: 10 kg applied per plot
4) Vermitech compost: 10 kg applied per plot
5) Poultry manure: 10 kg applied per plot
6) Cow manure : 10 kg applied per plot

3.6. Land preparation, planting, weeding and harvesting

The study was conducted on land that was previously under cultivation. Prior to the study, potatoes had been grown on the site and chemical fertilizers added. Before planting, land was prepared to the required tilth through hand hoeing. The site was sub-divided into 18 plots each measuring (5 × 4) m^2. Maize (Pioneer® hybrid - PHB 3253) was planted on 23 rd March 2014 at the beginning of long rain season. Furrows were made on each plot in preparation of planting and treatments placed along the furrows, thoroughly mixed with the top soil before seeds were planted. The seeds were planted at a spacing of 75 cm (inter-row spacing) by 30 cm (intra-row space). Composts were applied at a rate of 5 t ha^{-1} while fertilizer was applied at the rate of 60 kg N and 26 kg P ha^{-1}.For the manures and composts plots, 10 kg of the treatments were added per plot. Two hundred grams of Mavuno fertilizer was applied to fertilizer treated plots at planting and 0.5 kg of CAN was used for topdressing. The maize crop was weeded twice during the growth period at 4 and 8 weeks after planting. Top dressing was done at week 6 after planting using Calcium Ammonium Nitrate (CAN) in plots where fertilizer had been applied at planting. Harvesting was done at the end of the season when the cobs were dry. Five sub-samples of maize cobs were taken from each plot. Maize grains were then separated from the cobs by shelling and the weight of the grains was recorded. The total maize grain yield was adjusted based on the moisture loss.

3.7. Soil macrofauna sampling

Soil monoliths (25 cm x 25 cm x 30 cm) were used to sample soil macro fauna and this was done twice during the cropping season: at the start of the experiment before application of the treatments and at eight weeks after planting, the time during which most macrofauna are active and earthworms mature for taxonomic identification. Two soil monoliths were excavated per plot and soil removed in layers of 0-10 cm, 10-20 cm and 20-30 cm according to the standard TSBF method (Moreira *et al.*, 2008). The soil from each depth was placed in different plastic trays and large clods broken to facilitate hand picking of the soil macrofauna. Earthworms were placed in 70% ethanol and later fixed with 4% formaldehyde for long term storage so that they do not rot ,and stored in sealed vials. The other macro fauna were placed in 70% ethanol and stored in labeled vials before identification in the laboratory.

3.7.1. Assessment of soil nematodes

Two circles of radii 1.5 m and 3 m were marked out in each plot. Using a soil auger, two equidistant samples of soil were taken from the inner circle while four were taken from the outer one. The soil was thoroughly mixed and a composite sample placed in labeled soil sampling polythene bags, sealed and taken to laboratory for extraction and identification. The extraction of nematodes was done following centrifugation technique (Carter and Gregorich, 2008). Approximately 200 g of the soil was mixed with 5 litres of water in a basin to disaggregate the particles. The suspension was then sieved off using different sieve sizes; while ensuring that the 38- µm sieve was the last at the bottom, so as not to lose any of the nematodes. The final soil concentrate in the 38-µm sieve was transferred into the centrifuge vials. The first spin was performed at 1750 r.p.m. for 7 minutes after which the top solution was decanted and the pellet retained for second spinning. Sugar solution was added up to the 30 ml mark into each of the vials to equal volumes and mixed thoroughly after which the second spinning was performed at 1750 RPM for 3 minutes. The supernatant was retained by running it through the 38-micrometer sieve and backwashing to get the final nematode concentrate. This concentrate was transferred into labeled vials. The contents of the vials were then reduced to about three milliliters by siphoning excess water, after they had settled. The nematodes were fixed for long-term storage and maintaining the numbers using the Double TAF (Triethanolamine and Formaldehyde) solution that was prepared by mixing 40% formaldehyde, Triethanolamine and distilled water. About 3 ml of the prepared hot fixative solution was added to the nematode concentrate. The vials were then stored in refrigerator at 4^0 C ready for use in identification and enumeration. This was done by pipetting about two milliliters of suspension into a counting slide.

3.8. Chemical characterization of soils after treatment

Soil samples for chemical analysis from each plot were taken three times during the season; before planting, at silking stage and at harvesting. Fifteen soil samples were recovered from the 0–30 cm depth from each plot in a zigzag pattern using a soil auger. The samples were spread on a clean polythene sheet, mixed thoroughly and approximately 500 g composite sample recovered. A 50 g sub-sample was removed from the composite sample for inorganic N determination and stored in the refrigerator at 4°C . The remaining soil was air-dried by spreading it on clean polythene sheets. It was ground using a mortar and pestle then passed through 2 mm and 0.5 mm sieves. The two sub-samples were used in the determination of soil chemical parameters.

The soil samples were analyzed for available N, Total N, Phosphorous, organic carbon, and the exchangeable bases (Ca, Mg, K and Na).The analyses were carried out at KARI laboratories Muguga. The analysis of these parameters was done as already explained in the section 3.2.

3.9. Plant sampling

Plant samples for above and below ground biomass were taken at week 3, 6, and 9 after crop emergence. Three plants were sampled from each plot. The sub-samples of stover were chopped into smaller pieces, packed in brown sampling bags and then oven-dried at

70° C. The ratio of dry weight to fresh weight and plot fresh weights were used to estimate the maize stover yield in tonnes per hectare. Five sub-samples of maize cobs were taken from each plot at harvesting for grain yield determination that was adjusted based on moisture loss.

3.10. Statistical analysis and data management

The data on soil chemical properties, macro fauna and crop yields was entered into excel and then subjected to analyses of variance (ANOVA) using the GENSTAT 14 statistical package. Treatment differences were evaluated using Fisher’s least significant difference ($LSD_{0.05}$).

CHAPTER FOUR

RESULTS

4.1. Soil chemical properties from the study area

Table 1 shows selected soil chemical properties obtained from the initial soil analysis. The soils at Kabete have pH of 5.2 and with low extractable P of 0.60 mg kg^{-1}. Exchangeable bases were also found to be low with exception of calcium that was higher than the other bases. Cation Exchange Capacity (CEC) was 5.1 cmol kg^{-1}. Organic C and total N were also low at 0.05% and 2.29% respectively .Inorganic NH_4^+ -N was 8 mg kg^{-1} compared to 2 mg kg^{-1} for nitrate nitrogen.

Table 1: Chemical characteristics of soil from Kabete field Station

Characteristics	**Contents**
$pH_{(water)}$ (1 : 2.5)	5.2
Extractable P (mg kg^{-1})	0.60
Exchangeable K (g kg^{-1})	0.55
Exchangeable Na (g kg^{-1})	0.10
Exchangeable Ca (g kg^{-1})	3.55
Exchangeable Mg (g kg^{-1})	0.45
CEC (cmol (+) kg^{-1})	5.10
Total N (g kg^{-1})	1.0
Organic C (%)	1.3
NH_4^+ - N (mg kg^{-1})	8.0
NO_3^- - N (mg kg^{-1})	2.0

4.2. Chemical characteristics of manures and composts

The results of analysis of composts and manures that were used in the study are presented in Table 2. Peepoo compost and cow manure contained high Phosphorus (P), Manganese (Mn), Boron (B), and Iron (Fe) content as compared to other treatments used. However, the two organic materials had very low Potassium (K) and Calcium (Ca) contents. Peepoo compost had the highest concentration of micronutrients; Fe, B, and Mn .Poultry manure had a very high content of Calcium (Ca), Copper (Cu) Magnesium (Mg) and Boron (B).

Analysis of the composts and manures showed that vermitech compost had the highest p-H of 10.2 followed by cow manure, poultry manure, and lastly peepoo compost. P was highest in cow manure with the trend being, cow manure >peepoo compost >vermitech compost > poultry manure. K was found to be highest in vermitech compost (52.5 g kg^{-1}) followed by poultry manure, cow manure and lowest in peepoo compost. Total N was found to be highest in cow manure (3.2 %) and lowest in peepoo compost.

Table 2: Chemical characteristics of composts and manures used in the study

Characteristics	**Composts and manures**				**Statistical analysis**		
	PPC	VTC	CM	PM	Sed	Lsd$_{5\%}$	P-value
pH$_{(water)}$ (1 : 2.5)	6.1	10.2	7.5	7.1	0.89	2.46	0.087
P (mg kg^{-1})	6.6	4.3	9.0	3.4	1.25	2.86	0.019
K (g kg^{-1})	3.6	52.5	5.4	29.4	6.79	19.29	0.018
Na (g kg^{-1})	0.7	4.3	4.1	3.5	1.45	4.02	0.791
Ca (g kg^{-1})	19.1	34.4	17.6	97.0	9.57	27.34	0.057
Mg (g kg^{-1})	5.3	6.8	2.4	11.9	1.53	4.26	0.013
Mn (g kg^{-1})	5.3	1.8	1.8	0.5	0.90	2.16	0.042
Zn (g kg^{-1})	0.3	0.3	0.2	0.4	0.08	0.22	0.163
Fe (g kg^{-1})	43.9	23.1	33.3	3.3	6.59	17.96	0.029
Cu (mg kg^{-1})	36.0	29.2	32.0	82.0	10.89	30.23	0.022
B (mg kg^{-1})	61.6	76.4	55.0	48.3	6.70	17.7	0.049
% DM content	63.4	88.4	50.0	54.4	4.67	12.97	0.008
C:N (ratio)	13.7	15.3	7.5	12.2	1.61	4.48	0.085
Total N (%)	1.3	1.7	3.2	2.4	0.25	0.70	0.006
Organic C (%)	17.3	26.5	24.1	29.6	1.79	5.52	0.071

Key: CM = Cow Manure, PM = Poultry Manure, PPC= Peepoo Compost, VTC=Vermitech compost.

4.3. Effect of compost and manure application on soil chemical properties

Soil chemical characteristics after application of amendments are given in Tables 3a and 3b. Addition of composts and manures had a positive significant effect on the soil chemical characteristics.

4.3.1. Effects of amendments on Nitrogen

In the first season, application of manures and composts led to an increase in soil total N except for T4 that showed a slight decrease (3 %) when compared to the control (Table 3a). T3 recorded the highest total N (3.7 g kg^{-1}) which was a 19 % increase as compared to the control. This was followed by T4, which recorded 16 % increase (3.6 g kg^{-1} total N). Cow and poultry manure had 3.3 and 3.0 g kg^{-1} total N respectively. Inorganic fertilizer had the lowest value, 2.9 g kg^{-1} representing a 6 % decrease compared to the control. Available N (NH_4^+ and NO_3^-) contents were also significantly different ($p<0.001$) across all the treatments in season 1 (Table 3a). The highest NH_4^+ (6.30 mg kg^{-1}) was recorded from soils that were amended with poultry manure followed by plots treated with peepoo compost at (5.55 mg kg^{-1}) and vermitech compost at 5.01 mg kg^{-1}.Fertilizer and cow manure treated plots had values that were much lower than control plots. Fertilizer amended plots recorded the lowest value of 3.07 mg kg^{-1}. Soil NO_3^- though it followed a similar trend as with NH_4^+ -N.

In season 2, an increase in total N was observed in plots to which composts and manures were added (Table 3b). Peepoo and vermitech compost recorded an equal increment of 19 % compared to the control. Cow and poultry manure on the other hand also recorded an equal increment of 9 %. There was no change recorded in plots to which fertilizer had been added. Available N (NH_4^+ and NO_3^-) increased when soils were amended except in plots amended with cow manure that recorded a decrease in NH_4^+-N of about 8 % compared to the control. The trend for NH_4^+-N content was fertilizer > poultry manure >vermitech compost >Peepoo compost > control > cow manure. The trend for NO_3^-‾N was different with poultry manure recording the highest value >vermitech compost>Peepoo compost> fertilizer > cow manure >control.

4.3.2. Organic carbon

Analysis of organic carbon showed that there were significant differences between treatments (*p*=0.05). Addition of treatments in the first season led to an increase in organic carbon content across all treatments except for fertilizer and poultry manure amended plots that recorded 8 and 11% decrease compared to the control (Table 3a). The highest organic carbon values were obtained from plots amended with vermitech compost, Peepoo compost and cow manure (25.8, 25.1, and 25.1 g kg^{-1} respectively) which was 8 and 5 % increase compared to the control. The rest of the treatments; cow manure, control and poultry manure had values within the range of 21.1 and 23.9 g $kg^{-1.}$ Cow manure and fertilizer amended plots recorded the lowest organic carbon content.

In season 2, an increase in carbon content values was observed across all treatments. Vermitech compost gave the highest value (30.8 g kg^{-1}), followed by Peepoo compost.

Cow and poultry manure recorded 25.8 and 23.3 g kg^{-1} respectively. The lowest value was observed in fertilizer amended plots but it was higher than for the control plots.

4.3.3. Phosphorus

There was significant effects on soil's P content (p=0.004) after amending soil with different treatments (Table 3a and b). All the treatments led to an increase in soil P in the first season. The highest increment was recorded in plots under Peepoo compost treatment (24.45 mg kg^{-1}) followed by poultry manure (14.50 mg kg^{-1}). Plots amended with cow manure, Vermitech compost and fertilizer had P content values in the range of 11.54 and 14.32 mg kg^{-1}. The no–input control recorded the lowest P content (9.05 mg kg^{-1}).In season 2, Peepoo compost recorded the highest value followed by poultry manure and fertilizer. Cow manure recorded the lowest value.

4.3.4. Exchangeable bases (Ca, Mg, and K)

Application of treatments had significant effect on K (P<0.001) but no significant effect on Ca and Mg (Table 3a and b). In the first season, an increase in K content was observed in all treatments except poultry manure treated plots that showed a decline. The highest value was obtained from vermitech compost treated plots and the trend was vermitech compost > cow manure > fertilizer >peepoo compost > control > poultry manure. A similar trend was observed in the second season with all treatments recording higher values than the control. Exchangeable Ca and Mg contents increased for only peepoo and vermitech compost in the first season (Table 3a). The rest of the treatments showed a decline in the contents. A similar trend was observed in the second season but poultry manure also recorded an increase (Table 3b).

4.3.5. Soil pH

Application of manures and composts led to a decline in significantly lowered the soil pH. The highest pH value, 5.3, was recorded with addition of Vermitech compost followed by cow manure amended plots and no input control (5.1). Plots amended Peepoo compost and fertilizer recorded the same pH value of 5.0. Poultry manure gave the lowest pH value of 4.9. The amendments resulted in reduction of soil pH.

Table 3a:Chemical properties of soils treated with manures and composts(season 1)

	Treatment						**Statistics**		
Parameter	T1	T2	T3	T4	T5	T6	SED	Lsd	P-value
Total N (%)	3.1	2.9	3.7	3.6	3.0	3.3	0.03	0.06	0.05
Organic C (g kg^{-1})	23.9	21.9	25.1	25.8	21.1	25.1	0.26	0.36	0.05
NH_4^+-N (mg kg^{-1})	4.51	3.07	5.55	5.01	6.30	3.52	0.97	2.06	0.001
NO_3^--N(mg kg^{-1})	22.35	20.04	29.73	29.45	22.57	22.80	15.34	31.33	0.001
pH $_{\text{(water)(}}$1:2.5)	5.12	5.03	4.98	5.29	4.86	5.06	0.34	0.70	0.001
Extr. P (mg kg^{-1})	9.05	11.54	24.45	14.32	14.50	12.20	6.70	13.68	0.30
Exc. K (mg kg^{-1})	414.59	544.00	427.00	673.02	405.13	621.62	84.33	172.22	0.01
Exc. Ca (g kg^{-1})	1.38	1.42	1.47	1.58	1.17	1.36	2.99	6.10	0.82
Exc. Mg (mg kg^{-1})	375.38	363.27	408.47	412.91	355.73	362.64	47.01	96.00	0.73

Key: T1= control, T2=Fertilizer, T3= Peepoo compost, T4 =Vermitech compost, T5 = Poultry manure, T6=Cow manure, Exc=Exchangeable and Extr= Extractable

Table 3b: Chemical properties of soils treated with manures and composts season two

	Treatment						**Statistics**		
Parameter	T1	T2	T3	T4	T5	T6	SED	Lsd	P-value
Total N (%)	3.1	3.1	3.7	3.7	3.4	3.4	0.03	0.07	0.253
Organic C (g kg^{-1})	19.6	21.3	29.8	30.8	23.3	25.8	0.51	1.11	0.238
NH_4^+-N (mg kg^{-1})	12.12	25.51	13.46	14.49	24.99	11.08	6.76	14.73	0.173
NO_3^--N(mg kg^{-1})	5.97	10.49	11.30	13.42	33.36	8.29	6.89	15.03	0.020
pH $_{(water)(}$1:2.5)	4.56	4.27	4.77	5.12	5.11	4.78	0.22	0.471	0.015
Extr. P (mg kg^{-1})	12.39	28.83	74.42	15.42	70.32	7.22	19.25	41.94	0.012
Exc. K (mg kg^{-1})	266.79	311.25	281.61	644.73	629.91	563.21	99.70	217.23	0.004
Exc. Ca (g kg^{-1})	0.98	0.79	1.21	1.31	1.13	0.98	0.21	0.46	0.234
Exc. Mg (mg kg^{-1})	364.09	301.59	468.25	455.36	434.72	345.24	52.83	115.11	0.043

Key: T1= control, T2=Fertilizer, T3= Peepoo compost, T4 =Vermitech compost, T5 = Poultry manure, T6=Cow manure, Exc=Exchangeable and Extr= Extractable

4.4. Agronomic effectiveness of manures and composts on growth of maize at the field Station, Kabete

Table 4 summarizes the dry maize biomass values obtained from the study at 3, 6, and 9 weeks after crop emergence. The analysis of results showed that there were significant differences in root and shoot biomass across all the treatments.

Vermitech compost produced the highest biomass yield of 71.4 g per plant in the sixth week. Root biomass followed a similar trend with the highest biomass recorded on the three treatments and lowest on control plots. Cow and poultry manure performed poorly compared to the three treatments, but better than control plots.

Table 4: Maize dry biomass yield from Kabete field trials at 3, 6 and 9 weeks after planting (mean of two seasons)

Treatment	**Dry shoot biomass (g)**			**Dry root biomass (g)**		
	3 wks	**6 wks**	**9 wks**	**3 wks**	**6 wks**	**9 wks**
T1	1.03	14.9	40.9	3.42	3.47	16.13
T2	3.74	62.48	95.08	12.77	16.30	53.53
T3	3.34	66.4	106.5	12.17	26.37	52.07
T4	1.98	71.43	75.15	5.83	20.12	60.73
T5	2.61	46.67	90.55	9.40	13.82	63.15
T6	1.72	31.52	65.48	5.17	11.62	47.13
Sed	0.37	8.86	9.702	1.344	5.162	15.57
Lsd (5%)	0.806	19.31	21.14	2.929	11.24	33.92
P-value	< 0.001	< 0.001	< 0.001	< 0.001	0.015	0.001

4.5. Grain yield and stover weight

Table 5 presents stover and grain yield. There were significant differences ($P < 0.001$) between the treatments with respect to grain and stover yield. Plots that were treated with Peepoo compost significantly ($P = 0.001$) produced grain yield of 8.8 t ha^{-1} compared to the control that recorded 2.2 t ha^{-1} of grain yield. This shows that there was an increase of 300% .Vermitech compost, poultry manure, cow manure and inorganic fertilizer recorded an increase ranging from 123-223% .Peepoo compost outperformed Vermitech compost, poultry manure, cow manure and the inorganic fertilizer by 1.7, 2.4, 3.3 and 3.9 t ha^{-1} of maize grain, respectively. The stover yields followed the trend; Peepoo compost > poultry manure > inorganic fertilizer >Vermitech compost > cow manure >control plots.

Table 5: Maize stover and grain yield in response to manures and composts (mean of 2 seasons)

Treatment	**Grain yield(tons/ha)**	**Stover weight (tons/ha)**
Control	2.2	5.2
Fertilizer	4.9	14.8
peepoo compost	8.8	19.5
Vermitech compost	7.1	14.7
poultry manure	6.4	10.0
cow manure	5.5	18.3
Lsd $_{0.05}$	3.349	5.387
Sed 5%	1.503	2.4
P- value	0.024	0.001

4.6. Effects of manures and composts on fauna in soils of Kabete field station

4.6.1. Effects of organic amendments on soil macro fauna abundance

Analysis of data obtained from the study site across the two seasons showed that there was a significant different across the treatments with regards to abundance of macrofauna belonging to orders Oligochaeta, Isoptera, Hymenoptera ,and Coleoptera. The Isopterans were the most dominant group (table 6). They represented about 52.3% of the total soil macrofauna in the first season and 45% in the second season. The Oligochaeta constituted about 20 % of the total in the first season and 22 % in the second season; Coleopterans 13.2% and 17.4% and Hymenopterans 9.1 %and 9.2 %in the first and second season, respectively. The rest of macro fauna: Orthoptera Blattodea, Hemiptera, Chilopoda, Diplopoda, and Araneae constituted less than 10% of the total soil macrofauna.

Poultry manure recorded the highest density (339) followed by vermitech compost. Peepoo compost and cow manure had the lowest numbers (136 and 126 respectively) in the first season. In the second season, there was an increase in abundance and diversity of soil fauna with the numbers doubling up. There was a significant difference across all treatments with respect to macrofauna in the orders Oligochaeta, Isoptera, Hymenoptera, Coleoptera, Diplopoda, and Araneae. Peepoo compost recorded the highest numbers while fertilizer recorded the lowest numbers (Table 6 a and b).

Table 6: Soil macrofauna abundance across the different treatments

a) Season 1

Macrofauna group/order	**Treatment type**						**Summary of statistical analysis**				
	T1	T2	T3	T4	T5	T6	Total	% Total	Lsd	Sed	P-value
Oligochaeta	32	27	53	49	41	37	239	19.9	22	11.29	0.001
Isoptera	115	119	28	113	243	12	630	52.3	62	125	0.008
Hymenoptera	13	7	16	21	27	25	109	9.05	25	12.7	0.024
Coleoptera	27	25	29	19	20	39	159	13.2	12	25.5	<0.001
Orthoptera	1	1	0	0	0	1	3	0.3	3	1.3	0.700
Blattodea	0	0	0	0	0	0	0	0	0	0	-
Hemiptera	0	1	1	0	0	0	2	0.2	2	1.1	0.554
Chilopoda	9	1	4	4	4	4	26	2.2	8	4	0.510
Diplopoda	5	4	5	5	3	5	27	2.2	7	2.51	0.009
Araneae	1	3	0	1	1	3	9	0.8	2	2.3	0.007
Mean total	203	188	136	212	339	126	1204	100	-	-	-

b) Season 2

Macrofauna group/order	**Treatment type**						**Summary of statistical analysis**				
	T1	T2	T3	T4	T5	T6	Total	% Total	Lsd	Sed	P-value
Oligochaeta	45	56	71	73	95	123	463	22.1	22	12	0.001
Isoptera	140	93	249	105	188	168	943	45	62	31.4	0.098
Hymenoptera	27	16	63	16	41	29	192	9.2	12	6.03	0.024
Coleoptera	59	45	85	55	56	65	365	17.4	12	6.43	0.001
Orthoptera	3	4	0	1	1	0	9	0.4	1	0.738	0.231
Blattodea	3	1	0	3	0	0	7	0.3	1	0.44	0.014
Hemiptera	0	0	0	0	0	0	0	0	1	0.314	0.161
Chilopoda	3	4	1	4	4	4	20	1	3	1.59	0.486
Diplopoda	9	8	23	16	3	9	68	3.2	7	2.51	0.009
Araneae	4	3	3	5	9	5	29	1.4	2	1.16	0.005
Mean total	293	230	495	278	397	403	2096	100	-	-	-

Key: T1= control, T2=Fertilizer, T3= Peepoo compost, T4 =Vermitech compost, T5 = Poultry manure, T6=Cow manure, Exc=Exchangeable and Extr= Extractable.

4.6.2. Effects of organic amendments on soil nematodes

Seven genera of nematodes were identified and then classified into two trophic groups, which were; plant parasitic and free-living groups as shown in table 7. Four plant parasitic nematodes genera namely; *Meloidogyne* (root-knot nematodes), *Pratylenchus* (root-lesion nematodes), *Helicotylenchus* (spiral nematodes), and *Tylenchus* were most dominant across all the treatments. The free-living nematodes included *Criconemella*, *Cephalobus and heterocephalobus* as dominants. Soils that were amended with fertilizer and the control had the highest numbers of the plant parasitic nematodes. Application of manures and composts recorded higher number of both plant parasitic and free-living nematodes. Peepoo compost recorded the highest number of free-living nematodes in the first season but had the lowest in the second season while cow manure showed an opposite trend

Addition of Peepoo compost increased the number of free-living nematodes, followed by Vermitech compost, poultry manure, and cow manure in that order. In season 2, the observed trend was Peepoo compost had the lowest number while cow manure had the highest, Vermitech compost >Peepoo compost = poultry manure < cow manure. Lower numbers were observed across all treatments in the second season as compared to season one.

Table 7: Nematode numbers/200 cm^3 of soil treated with manure and composts

a. Season one

	Treatment type						**Statistics**		
Genera	T1	T2	T3	T4	T5	T6	SED	Lsd	p-value
Meloidogyne	167	33	167	133	233	67	120.2	248	0.360
Pratylenchus	233	67	133	400	167	200	200.0	413	0.704
Tylenchus	100	100	100	67	33	33	79.3	164	0.726
Helicotylenchus	0	0	167	333	67	33	124.7	257	0.100
Criconemella	133	33	233	133	67	33	79.3	164	0.081
Cephalobus	67	67	233	133	133	67	66.7	138	0.040
Heterocephalobus	67	33	100	33	33	33	60.9	126	0.671

b. Season two

Genera	**Treatment type**						**Statistics**		
	T1	T2	T3	T4	T5	T6	SED	Lsd	p-value
Meloidogyne	133	0	233	200	67	167	101.8	210	0.241
Pratylenchus	33	67	133	0	100	400	134.7	278	0.064
Tylenchus	33	0	100	67	0	100	74.5	154	0.493
Helicotylenchus	0	100	0	33	0	100	72.0	149	0.423
Criconemella	33	0	33	67	33	67	27.1	50	0.783
Cephalobus	33	0	33	33	33	67	50.9	48	0.783
Heterocephalobus	0	0	33	33	67	67	24.0	48	0.495

Key: T1= control, T2=Fertilizer, T3= Peepoo compost, T4 =Vermitech compost, T5 = Poultry manure, T6=Cow manure, Exc=Exchangeable and Extr= Extractable

CHAPTER FIVE

5. DISCUSSION

5.1. Characteristics of composts and manures applied to maize

The higher amounts of P, K and macronutrients in Peepoo compost coincided with literature reports that have shown human excreta to be excellent in terms of providing nitrogen (N), phosphorus (P) and potassium (K) the high amounts of micronutrients such as Fe, B, and Mn (Table 2) is an added advantage of human waste over the other organic amendments and hence its potentiality is adequate to crops as reported by Heinonen-Tanski and Wijk-Sijbesma (2005). The nutrients present in human waste can be tapped and re-used in agriculture to improve crop yields. Human waste application to land will be the most effective way of utilizing this nutrient-rich resource.

5.2. Effect of manures and composts on soil chemical properties

Soils in the study area were found to be generally low in N and P as well as other exchangeable bases. This calls for application of adequate amounts of manures and fertilizers in order to support good crop yield. The organic carbon was also found to be low and due biomass removal from cultivated systems for consumption by man and livestock. Continuous use of fertilizers implies low organic matter addition into the soil thus low food availability for soil biota and low water holding capacity of the soil. Low organic matter content reduces the soil's capacity to retain nutrients and water. This low nutrient status can be overcome through integrated nutrient management that promotes proper utilization of organic and inorganic sources of crop nutrients (Bationo *et al.*, 2012). Phosphorus is also among the most limiting nutrients in the tropical soils and deficiencies are often associated with low crop yields (Sanchez *et al*., 1997). This is because most tropical soils are severely weathered, and have a high P fixation capacity due to the large concentrations of Al and Fe-oxides (Otinga *et al*., 2012). One way of alleviating P deficiency is through use of organic or inorganic fertilizer inputs (Otinga *et al*., 2012). Since high cost of purchasing inorganic fertilizer remains high to most small-scale farmers in Kenya, then they opt for organic amendments either in form of animal manures or crop residues. If available in large quantities and are of good quality, organic amendments may be an important source of nutrients as well as replenishing soils organic matter, which is important in regulation of many soil functions such as nutrient mineralization, aggregate stability, aeration, favorable water uptake and retention properties (Khan *et al*., 2010). However, the bulk of available organic materials in most subsistence cereal farmers are of low quality making it difficult to rely on them as the sole sources of crop nutrients. This therefore, calls for identification of cheaper and readily available alternative sources that can complement and/or substitute these organic amendments.

Human excreta are an important source of nutrients, such as N, P, and other cations following mineralization. (Mnkeni and Austin, 2008). Generally, the results indicated that human manure has good fertilizer value with regard to P and K status in the soil after application. Its application in the current study led to an increase in the soil N, P, and K status. This could perhaps have resulted from release of N, P, and K more readily than cow and poultry manure. This demonstrates superiority of human excreta in releasing and maintaining higher levels of available of nutrients such as P and K in the soil in the soils than other organic amendments. This agrees with a study by Mnkeni and Austin (2008), in which they observed an increase in soil P and K following the application of human manure. This demonstrates the greater ability of human manure to decompose and release available P and K into the soil. The higher P and K values could be attributed to the fact that human manure consists of less lignaceous materials than other organic manures (cow, poultry and goat manure) and is thus more susceptible to decomposition (Mnkeni *et al.,* 2006).

Plots treated with inorganic fertilizer had lower N, P and K values in comparison with peepoo compost, which agrees with an earlier study by Tadesse *et al.* (2013), who reported an increase in soil total N and available phosphorus due to application of organic manures compared to NPK fertilizer. The release of nutrients on compost treated plots could have been slow but continuous, thus higher available N values at critical stages of crop development. Commercial fertilizers readily release the nutrients into soil solution and therefore are rapidly taken up either by plants or are prone to losses such as leaching and volatilization, and therefore retention rates on the soils are quite low. An increase in carbon across all the treatments when compared to the control could be due to contribution of organic matter from the organic. The lowest increase in C on plots treated with commercial fertilizer concurs with an earlier with Khan *et al* (2010) who reported that application of inorganic fertilizers had no significant effect on this element. Peepoo compost, though it had a near neutral pH , did not significantly increase the soil pH coincided with Mnkeni and Austin (2008) who note that human waste had no effect on pH at low rates of application (less than 20 t ha^{-1}) . Rates above 21.6 t ha^{-1} however increased pH, suggesting that its regular use and at this rate, could have a liming effect in acidic soils. A reduction in pH following the application of treatments may have been as a result of nitrification which involves the oxidation of $NH_4^+$to nitrate (NO_3^-) and in the process H^+ are released and hence lowering the soil pH.

5.3. Agronomic effectiveness of organic manures on performance of maize

Application of manures and composts significantly improved maize yield. The higher yields obtained with application of peepoo compost could be partly because of its higher nutrient content .Maize under Peepoo compost, could have benefited from the high P content of human feaces. Mnkeni and Austin (2008) in their study also reported that human excreta significantly increased P and K levels in the soils compared to goat manure. An increase in soil P content leads to an increase in crop yield as reported by Otinga *et al*. (2013) that addition of 26 kg P ha^{-1} to a crop increased maize yield to 4 ton ha^{-1} compared to unamended control. Higher content of micronutrients (Mn, B, and Fe) in Peepoo compost could also give crops a competitive advantage over those in plots treated with other organic amendments and inorganic fertilizer. Though cow manure also had a higher P content, this did not increase yields as could have been expected. This could perhaps, be due to its low mineralization rate. Peepoo compost, having undergone initial decomposition, perhaps mineralized faster thus making the nutrient available to crops, and therefore the observed differences. Ghuza *et al*. (2005) also reported similar results where increased maize yield was linked to treatment of soil with human excreta. They also reported that maize grown on these plots used the least water amount per unit of grain produced, thus showing superiority of human excreta compost in not only improving yield but could also be the best alternative in rain-fed agriculture conditions. In a similar study using spinach,Kutu *et al*. (2010) showed that the application of human faeces and urine, either separately or in combination, resulted in increased fresh and dry matter yields. A study by Cofie and Adamtey (2009), also demonstrated a two -threefold increase in yields of crops (maize, sorghum and cabbage) grown on faecal sludge-treated soils as compared to untreated soils. This confirms that the material may be a good amendment for a variety of crops.

Biomass differences among treatments could be explained by N and P availability to crops and release patterns of the nutrients by the treatments. The higher biomass yields obtained in the fertilizer, peepoo and vermitech compost treatments may have been as a result of nutrients being readily available from the fertilizers.

5.4. Influence of manures and composts on soil macrofauna

Application of composts and manures led to an increase in earthworm abundance. This was in agreement with Ayuke *et al.* (2003) who reported an increase in earthworm abundance on application of plant residues and farmyard manure. Similarly, Font *et al*. (2009) reported that tomato mulch increased abundance and diversity of earthworms and Ayuke (2000), observed that *Senna* and *Tithonia* residues increased the faunal population by 100% above the control. Organic inputs such as crop residues, tree prunings and manures, are a source of nutrients for the soil organisms. In this study, Peepoo and Vermitech compost recorded the highest number of earthworm abundance. In the second season, cow and poultry manure recorded the highest abundance of earthworms and this could be because of the residual effect of the manures. Their slower rate of mineralization of the manures in the first season could have been felt on the second season. Thus, accumulation of organic matter could have led to the higher faunal population in composts and manure. The numbers for all the other macrofauna groups (Orthoptera, Blattodea, Hemiptera, Chilopoda, Diplopoda, and Araneae) doubled in the second season. This may have as a result of the combined effect of the residuals of treatments applied in the first season together with the application in the second season. This implies that continued use of composts and manures will positively influence the population and abundance of soil fauna.

These results show that organic inputs are important in the maintenance of diverse soil macrofauna as shown by Mafongoya and Sileshi (2007), the active communities of macrofauna in the soil could thus be maintained by diverse organic inputs.

5.5. Effect of organic amendments on soil nematodes

Application of organic amendments reduced plant parasitic nematodes which was also observed by Agyarko and Asante (2005) who found that the population of plant parasitic nematodes reduced upon application of neem leaves and poultry manure. The decline may have been as a result of organic soil amendments favoring the establishment of antagonistic microbes that feed on the plant-parasitic nematodes (Akhtar and Malik, 2000).Decomposition of organic matter may have resulted in the release of specific organic/inorganic compounds with nematicidal effect thus negatively affecting nematode populations (Akhtar and Malik, 2000). For instance, Kimenju *et al.* (2004) found that plots amended with organic materials reduced root knot nematodes in common beans compared to soils that were not amended. The effect of Peepoo compost on control of plant parasitic nematodes was not consistent in the two seasons and this may have been as a result of rapid mineralization of the compost.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusions

1. Peepoo compost had significantly high amount of P and K. Its incorporation into the soil led to an increase in soil nutrients that included total and available N, organic carbon, phosphorus, and pH.
2. There was an increase in soil fauna diversity and abundance while populations of plant parasitic nematodes declined and free-living nematodes increased with application of the compost.
3. High maize yields were obtained when peepoo compost was applied.

6.2. Recommendations

1) Human waste has potential as a source of plant nutrients and could be exploited for production of organic manure. The nutrients in human excreta can be tapped and re-used in agriculture to improve crop yields instead of ending up in wastewater treatment plants and water bodies.
2) Treatment by compost production to improve on safety and handling during application by farmers in their farms should be carried out.
3) There is need to revisit policies that govern human waste management and emphasize its importance as source of nutrients to enhance crop yields.
4) Further research is needed to establish the long-term beneficial effects of human feacal compost on soil health, environment, and livelihoods.

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