BELOWGROUND INFLUENCE OF FARMER-PRODUCED COMPOSTS ON SOIL BIOTA, FOLIAR PESTS AND YIELDS OF COMMON BEAN (*Phaseolus vulgaris*) IN WESTERN KENYA

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A thesis submitted in partial fulfillment for the award of Degree of Master of Science in Crop Protection of Masinde Muliro University of Science and Technology

AUGUST 2018

DECLARATION

This thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance of Masinde Muliro University of Science and Technology a thesis entitled "Belowground influence of Farmer-produced Composts on Soil Biota, Foliar Pests and Yields of Common Bean (*Phaseolus vulgaris*) in Western Kenya".

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DEDICATION

To my late dad Mr. Charles Maingi, loving mother Josephine Wayua, husband Sammy Njuguna, children Natally Nduta, Natasha Wayua and Natania Kabura, parents in-law George Nyanjui and Rose Nduta, for material and moral support during my studies.

ACKNOWLEDGEMENT

ABSTRACT

The production of common bean *Phaseolus vulgaris* in Kenya has been reducing due to declining soil fertility. The use of synthetic fertilizers has been linked to soil acidification, which constrains plant growth and interferes with beneficial rhizosphere biota. The application of composts is being encouraged, and farmers in Western Kenya are being trained on composting of locally available organic materials. However, there is need to establish the performance of such farmer-produced composts in terms of improving soil fertility and biota, for instance *Rhizobium*, rhizobacteria, fungi, micro- invertebrate, as well as mitigating infestations by foliar pests such as *Aphis fabae*, *Frankliniella occidentalis*, *Colletotrichum lindemuthianum*. A field experiment was conducted on Masinde MuliroUniversity of Science and Technology farm, to assess belowground influence of farmer-produced composts on the soil biota, the foliar pests and yields of common bean. The experiment comprised 2×7 factorial treatments, with common bean cultivar having two levels i.e. Mwezi Moja (GLP 1004) and KALRO Kakamega 8 (KK8); with seven levels of soil fertility amendments, comprising five farmer-produced composts(FC 1-5), with varying plant and animal waste ingredients , DAP fertilizer and untreated controls. Each of the resulting 14 treatment combinations comprised of twin plots (3 m $\times$ 2 m) for the two bean varieties, each having n = 40 plants per variety, spaced at 50 cm $\times$ 15 cm, replicated in 3 blocks (24 m $\times$ 14 m) in a randomized block design, over a period of 2 seasons i.e. long rains (1st April to 30th June 2014) and short (17th July to 5th October 2014). Data collected includes, root endophytic (*Rhizobium*) and rhizosphere microbes (bacteria and fungi), soil micro-invertebrates (nematodes and arthropods), the foliar pests *A. fabae, F. occidentalis* and *C. lindemuthianum*; and plant growth and yields. Statistical analysis was conducted using SAS 9.1 at p≤0.05. Apart from N and P, farmer-produced composts contained a variety of additional nutrients including, K, Ca, Mg, Fe, Cu, Mn and Zn that DAP lacks. Germination % was lowest in bean seeds grown with DAP (72.0 % b) and highest in those receiving FPC$_1$ (85 % a), FPC$_3$ (86.9 % a) and the controls (84.8 % a). Germination percentage was higher in KK8 bean variety (96 % a) than in Mwezi Moja bean variety (67 % b) (P<0.0001). Plant size and grain yields were generally better in compost-treated plots than in DAP and the control. Leaves were longest when farmer-produced compost FPC$_5$ (9.4) and shortest in those that received DAP (7.9) and the controls(7.1) (P<0.05) KK8 bean variety grown with farmer-produced compost (CF1, CF3) and Mwezi moja variety grown with (CF1, CF4) had significantly higher N and K content than those receiving DAP and the controls (P<0.05). *Rhizobium* root nodules, rhizosphere fungal and bacterial populations, were significantly higher in the compost-treatments than in DAP (P<0.05), while soil nematode populations were significantly lower, but without variations in micro-arthropod population(p>0.05). At harvest, compost-treated plots had pH 5.3 and improved nutrient concentrations than DAP and control plots. The results of this study shows that, trained farmers produced composts contained important nutrients that were utilized by common bean to promote growth and yields, while enhancing endophytic colonization by beneficial *Rhizobium* species, and promoting rhizosphere colonization by bacteria and fungi, but suppressing soil nematode populations. Farmer-produced compost CF3 was relatively better in performance. However, there was no evidence that farmer-produced composts influenced bean infestation by the foliar pests.

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ACRONYMS AND ABBREVIATIONS

ALS	Angular leaf spot
cmolc Kg^{-1}	Centimoles of positive charge per kilogram of soil
DAP	Diammonium Phosphate
FAO	Food and Agriculture Organization of the United Nations
GLP	Grain Legume Project
KALRO	Kenya Agricultural and Livestock Research organization
MMUST	Masinde Muliro University of Science and Technology
PGPM	Plant Growth Promoting Microbes
ppm	Parts per million
NA	Nutrient Agar
PDA	Potato Dextrose Agar
YMA	Yeast Mannitol Agar

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Common bean *Phaseolus vulgaris* L (Fabaceae) is a major staple food crop in Eastern Africa, which is rich in dietary protein among other nutrients (Wortmann et al., 1998). The crop has short growth cycle with considerably high adaptability to environmental conditions (Gentry, 1969), making it a suitable component for enhancing food security (Mkwambizi et al., 2011). The average bean production in Kenya is 500 Kg ha^{-1} which is below the potential of 2000 Kg ha^{-1}; with annual national production of 215,000 MT that unfortunately barely meets the 450,000 MT demand (Mungai & Karubiu, 2011). These reductions in bean production have been linked to decline in soil fertility, invertebrate pests such as the black bean aphid (*Aphis fabae,* Aphididae), thrips (*Frankliniella occidentalis,* Thripidae) and microbial pathogens such as *Colletotrichum lindemuthianum* (Naluyange et al., 2014).

Although bean farmers are advised to apply inorganic (synthetic) fertilizers especially diammonium phosphate (DAP) (Graham & Rosas, 1979), there are no indications that bean yields have improved in Western Kenya (Marenya et al., 2009), while the effects of pests and diseases have still been increasing in Kenya and around the world (Altieri & Nicholls, 2003; Naluyange et al., 2014). Besides, soil acidification has been on the rise (Kisinyo et al., 2012), which interferes with beneficial rhizosphere biota such as symbiotic *Rhizobium* species that fix nitrogen (Ortiz-Castro et al., 2011). For such reasons, the use of composts and other organic soil fertility amendments is being encouraged (Beesley et al., 2010). Organic soil fertility amendments maintain soil

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nutrient balance, thereby making bean plants more tolerant to pest-related herbivory and diseases (Naluyange et al., 2014). For some time now, there have been activities to train farmers in Western Kenya on self-production of composts from locally available organic matter (Delve & Ramisch, 2006; van Haute, 2014).

1.2 Problem statement

Use of inorganic fertilizers and insecticide has continually eroded our environment of its valuable soil biota which enriches the soil and consequently leads to low soil fertility. There have been efforts to improve soil fertility and food production on small scale farms in Western Kenya by training farmers in composting of locally available organic materials (van Haute, 2014). Composts enhance soil fertility (Diacono & Montemurro, 2010), promote soil colonization by beneficial microbes (Chen, 2006), thus improve plant tolerance to microbial pathogens and insect pests (Ghorbaniet al., 2008; Naluyange et al., 2014), and increase crop yields (Ouédraogo et al., 2001; Manivannan et al., 2009). Composts are rich in nutrients especially carbon, nitrogen, phosphorus and potassium (He et al., 2001; Naluyange et al., 2014). These nutrients enhance the colonization of plants by beneficial endophytic and rhizosphere microbes (Diacono & Montemurro, 2010). Composts release compounds that are suppressive to microbial pathogens, nematodes and arthropod pests (Nico et al., 2004; Diánez et al., 2006; Edwards et al., 2010; Kearsey, 2011). Despite these positive effects, compost can be weighty and bulky, making it expensive to transport, there are also concerns regarding potential levels of heavy metals and other possible contaminants in compost, particularly mixed municipal solid wastes which becomes an important issue when compost is used on food crops, at time the rate of nutrient release is slow so that it cannot usually meet the nutrient requirement of crops in a short time, thus

resulting in some nutrient deficiency (Sikora & Szmidt, 2001; Lekasi et al., 2003), but are rather phytotoxic constraining the growth of plants and beneficial rhizosphere biota (Wong, 1985; Selim et al., 2012). The decline in bean production due to infestation by aphid A. *fabae*, thrips F. *occidentalis* and the microbial pathogen C. *lindemuthianum* could be addressed by using locally available materials in compost preparation and also achieve agronomical benefits in Western Kenya.

1.3 Justification

Use of compost is a viable option in addressing the problem of decline in soil fertility, especially when the right materials are used. Composts are rich in nutrients like carbon, nitrogen phosphorus, potassium as well as micronutrients (Tripathi & Bhardwaj, 2004; Naluyange et al., 2014). These nutrients are known to help attract beneficial rhizosphere biota, improve plant tolerance to pests (Naluyange et al., 2014), with overall increase in bean yields (Shahza et al., 2008). For example, carbon and nitrogen promote rhizosphere colonization by beneficial microbes such as *Rhizobium* (Afzal & Bano, 2008; Raaijmakers et al., 2009), while enhancing yields in legumes (Kostov & Lynch, 1998). Moreover, maintenance of high *Rhizobium* bacterial population in the rhizosphere improves other species of plant growth promoting bacteria to thrive (Shahza et al., 2008). Such plant growth promoting microbes release siderophores that bind to iron (Fe^{3+}) in the rhizosphere, making it unavailable to phytopathogens and hence protecting plants (Mehta et al., 2013). Pests like spidermites (*Tetranychus urticae*) and aphids (*Aphis fabae*) that attack beans (Hussey & Bravenboer, 1971), can be suppressed when compost in the form of vermicompost is applied (Arancon et al., 2006). It has been established that water hyacinth-derived compost can enhance tolerance of common bean to A. *fabae* and C. *lindemuthianum* (Naluyange et al., 2014), this is achieved by stimulation of plant growth which

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influences nitrogen physiology (Johnson et al., 2012). This study points to explore area of maximization of organic compost and manures that are readily available in proper functioning subsistence or large scale farming systems, The farmer can thus, exploit organic farming that has a large local and export market, with composting locally available materials being a viable option in enhancing; soil fertility, promoting root and rhizosphere colonization by plant growth promoting microbes, increasing plant tolerance to pests and diseases, resulting in improved plant growth and yields.

1.4 Objectives

The general objective of this study was to determine belowground influence of farmer-produced composts on soil biota, foliar pests and yields of common bean *P. vulgaris* in Western Kenya.

 Specific objectives of the research were:-

1. To determine the effect of farmer-produced compost on root endophytic and rhizosphere microbes associated with beans within Western Kenya.
2. To evaluate the effect of farmer-produced compost on bean infestation by aphids *A. fabae*, thrips *F. occidentalis* and the microbial pathogen *C. lindemuthianum*.
3. To assess the effect of farmer-produced compost on growth and yields of bean cultivars in Western Kenya.

It was hypothesized that:-

1. Farmer-produced compost is rich in nutrients that will enhance the colonization of beans by beneficial endophytic and rhizosphere biota.
2. Farmer-produced compost is rich in nutrients that will help to suppress invertebrate pests such as the black bean aphid *A. fabae*, thrips *F. occidentalis* and the microbial pathogen *C. lindemuthianum*.
3. Farmer-produced compost is rich in nutrients that will be utilized by the plant to promote bean plant growth and yields.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil fertility problem in Africa

Soils in Africa have been undergoing degradation in fertility resulting in reduced crop yields (Sanchez et al., 2005; Hartemink, 2006). In the densely populated Western Kenya, over-cultivation has led to depletion of soil nutrients, especially nitrogen (N), phosphorus (P) and potassium (K) that are essential for crop production (Muchena et al., 2005). Inorganic synthetic fertilizers such as Diammonium Phosphate (DAP) are being used to address the decline in soil fertility (Kamau et al., 2014). Unfortunately, overuse of synthetic fertilizers has resulted in problems such as soil acidification that reduces land productivity (Tittonnel et al., 2008). Extreme soil pH interferes with soil carbon and inhibits nitrogen fixation by diazotrophic bacteria (Obura et al., 2010). Decline in soil fertility could lead to loss of biodiversity of fauna involved in the breakdown of vegetative material to humus (Tian, 1998). Besides, the synthetic fertilizers are expensive to most farmers in Western Kenya (Marenya & Barrett, 2009).

2.2 Soil types and bean productivity in Western Kenya

The major soil types found in bean producing areas of Kenya include Luvisols, Cambisols, Andosols, Planosomls, Nitosols, Acrisols, Ferralsols, and Vertisols (Kamoni et al., 1998; Table 2.1). The dominant soil types in Western Kenya are Nitosols, Acrisols and Ferralsols (Rota et al., 2006; ISRIC, 2014; Naluyange et al., 2014). Nitosols are characterized by a rich clay sub-soil with a good soil structure that

allows root penetration (Driessen et al., 2000; Bationo et al., 2006; Jaetzold et al., 2007). Nitosols have no specific constrain to bean production but may require fertilization for maximum yields (Kamoni, 1988; Schnier et al., 1996). Acrisols are acidic with low base cations and a compact subsoil (horizon B) that makes water penetration difficult, and thus insufficient mineral reserves, poor root penetration and low biological activity (Kisinyo et al., 2013). Acrisols are nitrogen and phosphorus deficient and thus require fertilization with the appropriate nutrients elements (Kamoni, 1988). Ferralsols are characterized by advanced weathering resulting in good soil depth and structure with improved drainage, thus allowing unlimited root penetration (Mairura et al., 2007). However, Ferralsols have relatively low water holding capacity and are deficient in calcium, manganese, potassium and molybdenum that are necessary for legume growth (Muchane et al., 2010).. In Kakamega county of Western Kenya, crop yields have been reported to be high on Nitosols, and Acrisols, but low on Ferralsols (Ngome et al., 2012).

Table 2.1: Soil fertility constraints to bean productivity in Kenya

Soil Type	Constraint to bean production	Control measure
Nitosols	None	May require fertilization for maximum yield
Acrisols	Deficient in both N and P	Require fertilization
Ferralsols	Highly deficient in both N and P	Require fertilization; good soil conservation measures
Luvisols	Deficient in N; susceptible to erosion	Supply N; good soil conservation measure
Cambisols	None	
Andosols	Highly susceptible to erosion	Soil conservation measure
Phaeozems	Deficient in both N and P	Require fertilization
Planosols	Deficient in both P and calcium and also N in some cases; poor soil drainage	Require fertilization; improve drainage
Vertisols	Poor soil drainage	Improve drainage

Source: Kamoni (1988)

2.3 Composts

Compost is the product of controlled biological decomposition of organic matter that has been sanitized through the generation of heat and stabilized to the point that it is useful for plant growth (Rao et al., 2007). Composts have the unique capacity to improve the chemical, physical, and biological characteristics of soils, although they are in principle not characterized as fertilizers (Ouédraogo et al., 2001). The type of material used in the composting process affects the quality of compost produced (Palm et al., 2001; Gardiner & Miller, 2008). Compost materials are often not sources of large amounts of available nutrients, commonly with less than 2 % of nitrogen (N), phosphorus (P) or potassium (K) (Gardiner & Miller, 2008). Foreign particles and contaminants such as heavy metals render organic materials unsuitable for composting (Brinton & Brinton, 1992). Mature composts have little physical resemblance to the raw material from which they are developed (Chefetz et al., 1996).

2.4 Types of composts

Compost can be made from plant material, animal waste, or mixtures of plant and animal wastes. Plant waste compost is generated from dry or green weeds and cultivated plants (Zendejas et al., 2015). Animal waste composts are mainly generated from animal manure (faeces) (Saeed et al., 2015). Mixed waste compost is a mixture of plant and animal waste (Nunes et al., 2015).

2.4.1 Green waste composts

A wide variety of plant materials including crops are used in the production of green waste composts. Such plant materials may be green wastes that are woody (trees and shrubs) or herbaceous (grasses and small flowering plants), sea weeds, crop residues

and wood by-products (Senesi, 1989). These materials vary significantly in chemical composition, particle size and hence decomposition rates (Cayuela et al., 2009; De Araújo et al., 2009). The use of diseased plants in composting is discouraged, although some pathogens may be eliminated by heat generated during composting (Starbuck, 2010). The following section explores some cultivated and wild plants that are being used for compost production, especially those available in Western Kenya.

2.4.1.1 Monocotyledonous plants

Both cultivated and wild monocotyledonous plants available in Western Kenya are utilized in the production of green waste compost. Such cultivated monocotyledonous plants include poaceous crops such as maize *Zea mays*, sugarcane *Saccharum officinarum* L., millet *Pennisetum glaucum*, sorghum *Sorghum bicolor*, rice *Oryza sativa*, Napier grass *Pennisetum purpureum* (Fig 2.1) and banana *Musa acuminata* (Musaceae) (Mbau et al., 2015). Non-cultivated monocotyledonous plants with the potential of producing green waste compost include the Scurvy weed *Commelina communis* (Commelinaceae), water hyacinth *Eichhornia crassipes* (Pontederiaceae) (Naluyange et al., 2014) and Sedges (Cyperaceae) (Muthini et al., 2014; Sutton, 2015).

Residues of poaceous monocot plants are known to have the potential of producing quality compost (Hassanein & Abul-Soud, 2010). For example, maize is an important crop in Western Kenya (Odendo et al., 2001), where its highly available residues are commonly used for composting (van Haute, 2012). Compost made from maize stover was found to contain 1.68 % nitrogen, 0.48 % phosphorus, 1.41 % potassium with a carbon/nitrogen (C/N) Ratio of 1:13.5 (Hassanein & Abul-Soud, 2010). The

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application of maize stover compost in a field was associated with increased maize seedling height and sufficient maturation period (Hassanein & Abul-Soud, 2010).

Fig 2.1 Napier grass *Pennisetum purpureum* (Poaceae)

Fig 2.2 *Calliandra calothyrsus* (Mimosoideae)

Fig 2.3 Mexican sunflower *Tithonia diversifolia* (Asteraceae)

Fig 2.4 *Lantana camara* (Verbenaceae)

Source: Encyclopedia of life, 2016 (Online)

Wheat and rice are other poaceous monocot plants used as compost. Hanc et al. (2008) found that composted wheat straw contained 1.29 % nitrogen, 0.15 % phosphorus and 1.20 % potassium. Wheat straw compost has been shown to improve the growth of mung bean *Vigna radiata* L. (Fabaceae) (Shen et al., 2001). Rice stalk

compost has been reported to contain 1.72 % nitrogen, 0.46 % phosphorus, 1.60 % potassium and 1:13 C/N ratio (Hassanein & Abul-Soud, 2010). Rice stalk compost improves maize growth (Hassanein & Abul-Soud, 2010), as well as significantly increasing cowpea yields when enriched with phosphate (Zyed & Abdel, 2005). Sugarcane is the main cash crop in Western Kenya whose wastes are readily available for composting (Mbau, 2015). Compost from sugarcane waste has been found to contain up to 37 % organic carbon, 1.5 % nitrogen, 3.5 % phosphorus and 0.8 % potassium (Ramaswamy, 1999). Water hyacinth *Eichhornia crassipes* is a floating aquatic weed (Gupta et al., 2007). This water weed is a source of valuable macronutrients such as nitrogen, phosphorus and potassium that are essential for plant nutrition (Sannigrahi et al., 2002; Gunnnarsson & Petersen, 2007; Naluyange et al., 2014). Compost from mixture of water hyacinth and banana waste was found to contain C/N ratio of 15:2, 3.1 % potassium and 0.81 % phosphorus (Osama, 2013). This compost made of a mixture of water hyacinth and banana wastes significantly increased cowpea height, the number of root nodules as well as the nutrient content compared to chemical fertilizer (Osama, 2013). Adesina (2012) observed that the growth and yield of Lagos spinach *Celosia argentea* was improved when water hyacinth compost was applied.

2.4.1.2 Dicotyledonous plants

Both cultivated and wild dicotyledonous plants available in Western Kenya have the potential of producing biomass for green waste compost. Cultivated dicotyledonous plants of the family Fabaceae with potential to produce green waste compost include common bean *P. vulgaris,* Sesbania *Sesbania bispinosa*, pigeon pea *Cajanus cajan* and cowpea *Vigna unguiculata* (Kulkarni & Pandey, 1988; Egde & Ali, 2010).

Compost from cowpea has been found to contain 0.78 % nitrogen, 0.17 % phosphorus and 0.46 % potassium (Adamu et al., 2015), and increased rice yield by 19.1 % (Kulkarni & Pandey, 1988). Soy bean (*Glycine max*) stover compost increases mushroom yields (Hein, 1930). Maize grown with compost made from a stover mixture of cowpea, pigeon pea, Bambara nut, soy bean and groundnut has been found to have up to 76 % higher yield than maize grown using inorganic fertilizer (Egde & Ali, 2010). *Calliandra calothyrsus* (Mimosoideae) (Fig 2.2) is a cultivated leguminous tree that has been commonly used as green manure and compost (Brewbaker & Glover, 1988; Gichuru & Kang, 1989). Leaves of *C. calothyrsus* contain high protein content with 4.09 % nitrogen, 0.36 % phosphorus and 1.63 % potassium (Mucheru et al., 2014). Brewbaker & Glover (1988) observed that the yield of rice increased significantly when *C. calothyrsus* compost was used. However, the presence of high amounts of polyphenols (tannins) in the leaves of *C. calothyrsus* slows the rate of microbial breakdown of the organic matter reducing its value as a soil amendment (Heineman et al., 1997).

Among root crops, cassava *Manihot esculenta* (Euphorbiaceae), sweet potato *Ipomoea batatas* (Convolvulaceae) and potato *Solanum tuberosum* (Solanaceae) are important sources of biomass for compost production. Cassava peel compost has been reported to enhance crop production (Ubalua, 2007) giving better growth and yield of waterleaf *Talinum triangulare* when composted with poultry manure (Iren et al., 2015). Potato peel compost contains 4.41 % phosphorus, 1.37 % potassium and 13:43 C/N ratio, while cassava peels contain 0.79 % phosphorus, 0.11 % potassium and 8:55 C/N ratio (Sánchez-Bascones et al., 2008).

Non-cultivated dicotyledonous plants with the potential of producing green waste compost include *Tithonia diversifolia* (Asteraceae) (Fig 2.3) and *Lantana camara* (Verbenaceae) (Fig 2.4) (Olabode et al., 2007; Babajide et al., 2012; Mucheru et al., 2014).*Tithonia diversifolia* is a high quality manure plant common in Western Kenya (Jama et al., 2000; Sanchez, 2002). It is a shrub that is commonly found on field boundaries and roadsides (Olabode et al., 2007; Babajide et al., 2012). This plant has been recommended for use as a major component of compost as it has been found to contain around 3.5 % nitrogen, 0.37 % phosphorus and 4.10 % potassium in dry weight (Olabode et al., 2007; Babajide et al., 2012). *Tithonia diversifolia* has the ability to extract relatively high amounts of nutrients from soil, decomposes fast and leads to a rapid increase in soil inorganic nitrogen (Jama et al., 2000; Olabode et al., 2007; Jorge-Mustonen et al., 2013). *Tithonia diversifolia* is easy to handle as it lacks thorns (Olabode et al., 2007).

Lantana camara is a noxious weed found on roadsides and farm boundaries (Shabbir & Bajwa, 2006). It is toxic to animals and exerts allelopathic effects to neighbouring vegetation (Ghisalberti, 2000). Despite these serious negative traits, *L. camara* can be used as green compost (Sharma et al., 2008). Dry *L. camara* leaves were found to contain 2.8 % nitrogen, 0.25 % phosphorus and 2.1 % potassium (Jama et al., 2000). Vermicompost from *L. camara* has been found to increase seed germination and growth of cluster bean *Cyamopsis tetragonoloba* in terms of stem diameter, shoot length, number of leaves, number of root nodules and overall yield; which was associated with total elimination of allelochemicals during vermicomposting (Karthikeyan et al., 2014).

2.4.2 Animal waste composts

Animal waste composts are mainly generated from animal manure (faeces), mostly mixed with bedding material such as straw and sawdust (Bernal et al., 2009). Each type of animal manure has got different characteristics in terms of physical, chemical and biological attributes (Senesi, 1989). In this section, emphasis is given to livestock found in Western Kenya whose wastes have potential of being utilized as animal waste composts. These include poultry droppings (e.g. chicken, geese, turkeys, and pigeons), ruminant faeces (e.g. cattle, goats, and sheep) and non-ruminant mammal faeces (e.g. pigs and rabbits) (Tittonell et al., 2005; Akanbi et al., 2007; Bryan et al., 2011).

2.4.2.1 Poultry composts

Poultry manure contains most of the essential plant nutrients, which include nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, manganese, copper, zinc, chlorine, boron, iron and molybdenum (Amanullah et al., 2010). Chicken faeces are a major source of poultry manure that can be transformed into compost, and contains the highest amount of nitrogen, phosphorus and potassium compared to wastes of other livestock (Elliots, 2005). Chicken faeces need to be composted before use to obtain low toxicity and high stability (Young et al., 2016)

2.4.2.2 Ruminant animal composts

Ruminant livestock found in Western Kenya include cattle, goats and sheep. These animals have a digestive system having four compartments namely rumen, reticulum, omasum and abomasum, with the rumen being the largest section and the main digestive center (van Soest & Peter, 1994). Ruminant manure (faeces) mixed with

bedding material such as straw and sawdust is good for composting (Bernal et al., 2009). Manure from dairy cattle may be the single most useful soil fertility builder, with cow manure being low in nutrient content, which makes it safe to use in unlimited quantities. Manure from sheep fed on hay and grain are more potent than manure from animals that live on pasture (Powell, 2014). Awodun et al. (2007) observed that the application of goat manure on pepper increased soil N, P, K, Ca, as well as tissue nutrient content, plant growth and yields.

2.4.2.3 Non-ruminant mammal compost

These are monogastric animals that digest food in one stomach, similar to humans. The main non-ruminant mammals that produce manure in Western Kenya include pigs and rabbits. Piggery wastes (urine and faeces) contain high amounts of nutrients like nitrogen and phosphorus (Imbeah, 1998). Pigs produce large amounts of manure, with daily fresh output of 6 % of body weight (Kruger et al., 1995), which is rich in organic matter and nutrients (Imbeah, 1998). Different types of pig operations have varying daily manure and nutrient outputs (Kruger et al., 1995; Table 2.2). Most pig manure is collected in liquid form containing as high as 79 % moisture and has been successfully processed into compost (Lo & Liao, 1993). Rabbit manure is rich in nitrogen and phosphorus that are important for flower and fruit formation (Lazcano et al., 2011).

Table 2.2: Fresh manure production and characteristics per 100-sow production unit types

Production unit	Total manure Kg/day	Total Solids Kg/day	Total% Nitrogen	Total% Phosphorus	Total% Potassium
Farrow to bacon	2846	429	21.7	7.3	12.1
Farrow to pork	1611	223	12	4	6.7
Farrow to weaner	951	113	6.8	2.2	3.8
Farrow to suckler	604	55	4	1.2	2.3
500 pig grower unit	1895	317	15	5.2	8.3

Source: Kruger et al. (1995)

2.5 Composting technologies

There are various types of composting technologies whose choice depends on factors such as land availability, material volumes, human population density and regulatory requirements (Goyal et al., 2005). Composting technologies include; backyard or onsite composting, vermicomposting, aerated (turned) windrow composting, aerated static pile composting, and in-vessel composting. Backyard or onsite composting is a technology whereby residents and other small-quantity generators of organic waste can use on their own property (Cooperband, 2002). The technology is suitable for converting yard trimmings and food scraps into compost that can be applied on site (Regenstein et al., 1999). Vermicomposting is a technology that utilizes red worms that are placed in bins with organic matter breaking it down into high-value compost called castings (Cooperband, 2002; Manaf et al., 2009). The composting process takes three to four months to produce harvestable castings (Cooperband, 2002). Aerated (turned) windrow composting is a technology where organic waste is formed into rows of long piles called 'windrows' and aerated by manually or mechanically turning the pile periodically (Misra et al., 2016). The ideal pile height of between four and eight feet generates sufficient heat and oxygen circulation for decomposition yielding

significant amounts of compost (Haug, 1993). Aerated static pile composting is a technology in which organic waste is mixed together in one large pile instead of rows (Haug, 1993). This method produces compost relatively quickly-within 3 to 6 months (Misra et al., 2016).In-vessel composting is a technology where organic materials are fed into a drum, silo, concrete-lined trench, or similar equipment with the environmental conditions such as temperature, moisture and aeration closely controlled (Smith, 2012). Conversion of organic material to compost takes few weeks (Cooperband, 2002), but still requires more time for stabilization of microbial activities and cooling of the pile once out of the vessel (Smith, 2012).

2.6 Influence of composts on soil biota and above ground pests

Compost application to soil affects both diversity and population of microbial communities (Bastida et al., 2008). Composts exert changes in physical, chemical, and biological properties of soil, which may influence relationships between plants, herbivorous invertebrates and microbial pathogens (Zehnder et al., 2007; Naluyange et al., 2014).

2.6.1 Influence of composts on soil biota

Compost amendments modify physico-chemical properties of soil including nutrients and biological properties especially populations of beneficial soil microbes (Schloter et al., 2003). Studies have reported increased microbial activities and biomass in soils amended with organic matter in the form of composts (Chowdhury et al., 2000; Tejada et al., 2008), which can partly be attributed to increased availability of nutrients to the rhizosphere microbes (Carrera et al., 2007; Kowaljow & Mazzarino, 2007). This increase in soil microbial activities due to organic amendments results in the suppression of plant diseases (Hoitink and Boehm, 1999). However, the presence

of toxic factors such as heavy metals, high salinity and instability of the organic matter in compost can be detrimental to soil microbes (Schloter et al., 2003; Courtney & Mullen, 2008; Stefanowicz et al., 2008). Plots treated with composts have been reported to contain high populations of nematodes and collembola (Kimpinsk et al., 2003; Jamleck et al., 2012).

2.6.2 Influence of composts on aboveground pests

In organic agriculture, it has at instances been asserted that plants supplied exclusively with nutrients from biological materials are more tolerant to insect pests than those grown using chemical fertilizers (Mochiah et al., 2011; Naluyange et al., 2014). Alyokhin & Atlihan (2005) observed that flea beetle densities were lower on collards receiving macronutrients through manure compared to those receiving similar amounts of the macronutrients from chemical fertilizers. Naluyange et al. (2014) found that *Rhizobium* inoculant was compatible with water hyacinth composts containing effective microbes and cattle manure culture, enhancing tolerance of bean plants to aboveground infestations by the aphid *A. fabae* and the anthracnose pathogen *C. lindemuthianum*.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study location

A field experiment was conducted on a piece of land measuring 26 m × 16 m at the Masinde Muliro University of Science and Technology (MMUST) farm (00° 17.104 N', 034° 45.874 E'; altitude 1561 m a.s.l.) (Fig 3.1), adjacent to the Kenya Agricultural and Livestock Research Organization (KALRO), in Kakamega County, Western Kenya.
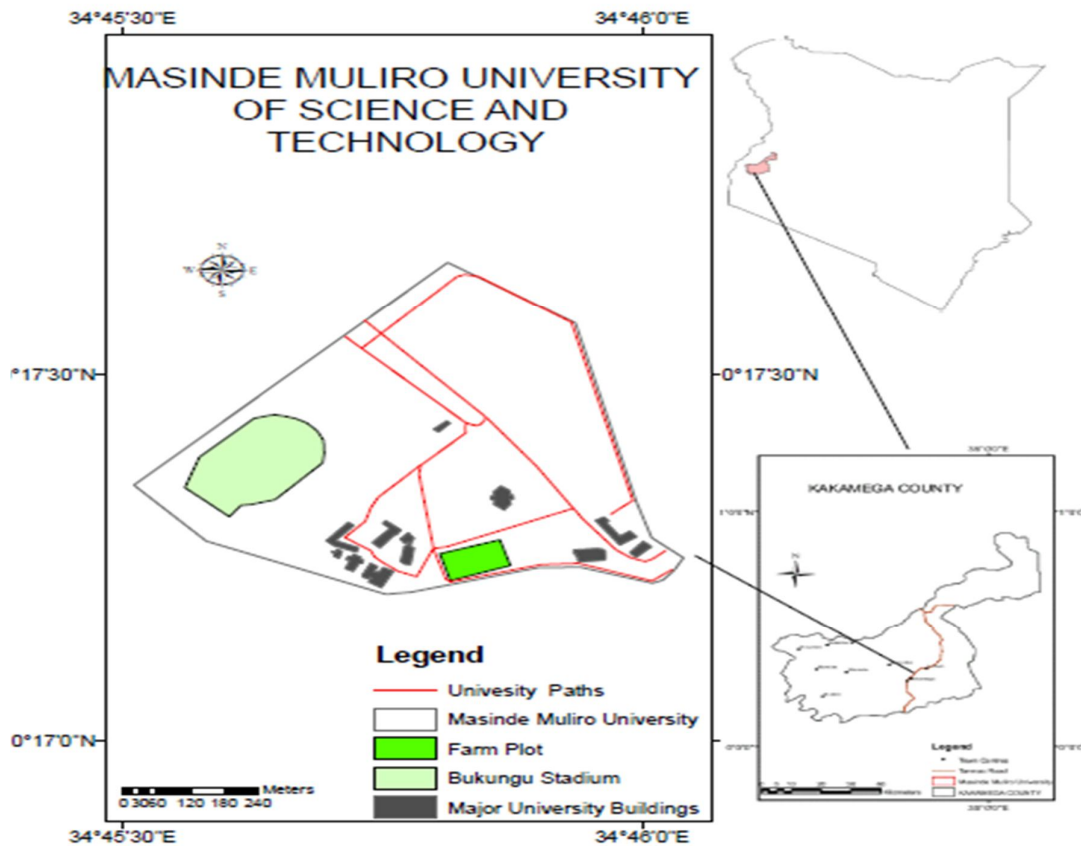
Fig 3.1 Study site at Masinde Muliro University of Science and Technology (MMUST) Farm (*Source*: own work)

Soils in this region have been classified according to FAO, (1974) as dystro-mollic Nitisols (Rota et al., 2006). Nutrient composition for the soil in the experimental field between the year 2012 and 2013 was found to have total 0.00189 % P, 0.26 %, 2.5 %, 0.41 cmolc Kg^{-1}K, 0.1 cmolc Kg^{-1} Na, 2.3 cmolc Kg^{-1}C, 0.8 cmolc Kg^{-1}Mg, 0.00019 ppm Zn and 0.000037 ppm Fe, with acidic pH of 4.2 (Naluyange et al., 2014). The region receives rainfall in two seasons, long rains ~1012 mm between March and July, and short rains ~622 mm between July and November. Average temperature in the study location ranges between 13℃ and 29.6 ℃.

3.2 Experimental design

The study was a 2×7 factorial experiment with bean cultivar factor having two levels and soil fertility amendment factor with seven levels (Table 3.1). Each of the resulting 14 treatment combinations comprised twin plots (3 m $\times$ 2 m) each having plants spaced at 50 cm $\times$ 15 cm for a total of 40 plants. This was replicated in 3 blocks (24 m $\times$ 14 m), with an interblock space of 1 m, with 0.5 m interplot spacing between the twin plots, while a 1 m wide perimeter buffer. This experiment was done over a period of two seasons in the year 2014 between 1st April and 30th June, and then repeated between 17th July and 5th October.

Table 3.1: Treatments for the field experiment: Assessing the efficacy of farmer produced compost at MMUST farm

Factor 1 (seven levels)	Factor 2 (two levels)	
Soil fertility amendments	KARI Kakamega (KK8)	MWEZI MOJA (MM)
Control (no soil amendment)	KK8	MM
Diammonium Phosphate (DAP)	KK8+DAP	MM+DAP
Compost from Farmer 1 (CF1)	KK8+CF1	MM+CF1
Compost from Farmer 2 (CF2)	KK8+CF2	MM+CF2
Compost from Farmer 3 (CF3)	KK8+CF3	MM+CF3
Compost from Farmer 4 (CF4)	KK8+CF4	MM+CF4
Compost from Farmer 5 (CF5)	KK8+CF5	MM+CF5

[*]Total treatment = 14; n =40; Replicates = 3; Trials = 2; N = 3360 ; DAP – Diammonium phosphate; CF (1 - 5) – Farmer produced composts

BLOCK A						
CF1 MM	CF3 KK	CF5 MM	NON KK	CF2 MM	CF4 KK	DAP MM
CF1 KK	CF3 MM	CF5 KK	NON MM	CF2 KK	CF4 MM	DAP KK
BLOCK B						
CF5 MM	CF4 KK	DAP MM	CF3 KK	CF1 MM	NON KK	CF2 MM
CF5 KK	CF4 MM	DAP KK	CF3 MM	CF1 KK	NON MM	CF2 KK
BLOCK C						
CF3 MM	CF1 KK	CF2 MM	CF4 KK	DAP MM	CF5 KK	NON MM
CF3 KK	CF1 MM	CF2 KK	CF4 MM	DAP KK	CF5 MM	NON KK
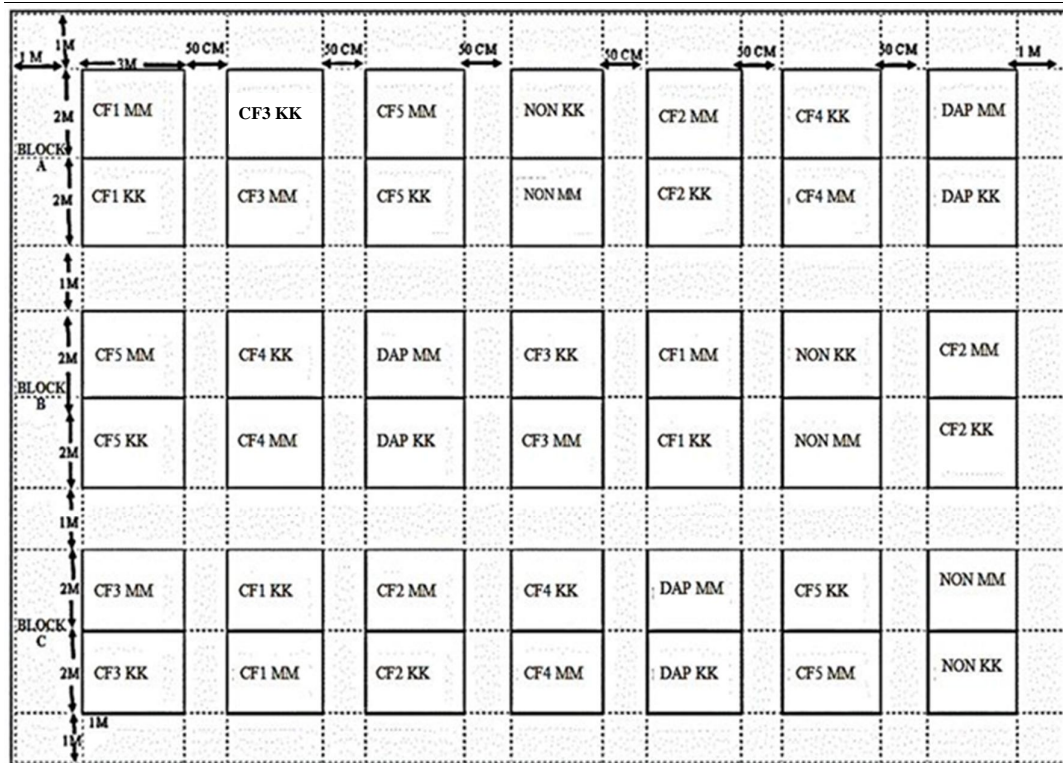
Figure 3.2 Layout for the field experiment assessing the effect of five farmer-produced composts. (CF 1-5), diammonium phosphate fertilizer (DAP) or no soil amendment (NON) on common bean varieties (KK=KK8 and MM=MWEZI MOJA) at Masinde Muliro University of Science and Technology farm in Kakamega County, Western Kenya.

3.3 Compost preparation and composting

The experiment utilized five farmer group-produced composts with organic matter sources summarized in Table 3.2. The farmers groups comprised of a model farmer and 15 general farmers. These were trained by MMUST staff in backyard composting of various available organic materials around their area (van Haute, 2014). The composting technique in the farmer training involved setting up repeated layers (8 cm thick) of plant material (dry or fresh), animal wastes, wood ashes to accelerate the composting process and soil to provide saprophytic inoculum. Water (20 L) was sprinkled over the layers of organic materials to facilitate enzymatic biodegradation. Each 8 cm thick layer was added three times, resulting in a heap approximately 4 m ×1.5 m × 1.5 m (L × W × H). The compost heaps were then protected from the sun

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under a shade made of plastic sheet to prevent overheating and drying. Each heap was mixed by turning over three times after every two weeks. Biodegradation and temperature were monitored using a stick pushed into the middle of the heap. The stick was pulled out each time the compost heap was turned and felt by hand for heat generation associated with composting. Regular turning ensured proper mixing, aeration and hence sufficient decomposition. Compost was ready for use after two months. The ready composts were packed in a 90kg sack and transported to Masinde Muliro University farm store.

Table 3.2: Materials used in farmer-made

Type of material	CF1[CF]	CF2	CF3	CF4	CF5
			Compost Ingredients		
Dry plant material	Leaves from *Spathodea campanulata* (Nandi flame) and Eucalyptus	Leaves from *Eucalyptus*, sugarcane, guava and *Lantana camara*	Leaves from *Eucalyptus*, Napier grass, finger millet and *Grevillea*	Leaves from *Eucalyptus*, sugarcane, banana, guava, Napier grass, *Grevillea*. Waste from sugarcane factory comprising lime and molasses	Leaves from *Markhamia lutea, Ficus* spp. and local tree 'Sofia*Bischofia javanica*
Green plant material	N/A	N/A	Vine tree leaves	Leaves from cassava, *Calliandra* and *Tithonia diversifolia*	Leaves of guava and *Acanthus arboreus*
Animal material	Cattle dung	Waste obtained from slaughter house, consisting of digested and undigested materials	Cattle dung and chicken droppings	Cattle dung	Cattle dung
Ratio of plant/animal	1:3	1:5	1:4	4:1	1:1

3.4 Bean cultivars

Two common bean cultivars were used in the study; KK8 and Mwezi moja. KK8 was obtained from KALRO Kakamega while Mwezi Moja was obtained from Kenya Seed Company Ltd - Kakamega town (Fig 3.3). KK8 has been reported to be moderately resistant to some races of *Phaeoisariopsis griseola* that cause angular leaf spot (ALS) (Wagara et al., 2003), and tolerant to bean root rot caused by *Fusarium solani* (Muthomi et al., 2014). Mwezi Moja has been reported to be well suited for the drier semi-arid low rainfall areas and also performs well in medium rainfall areas during short rains (Frenken et al., 1993). Mwezi Moja seeds are large beige or light brown speckled purple, tolerant to drought and bean fly (*Ophiomyia phaseoli*) (Frenken et al., 1993), but susceptible to halo-blight caused by *Pseudomonas syringae* and anthracnose caused by *C. lindemuthianum* (Mukunya & Keya, 1978).
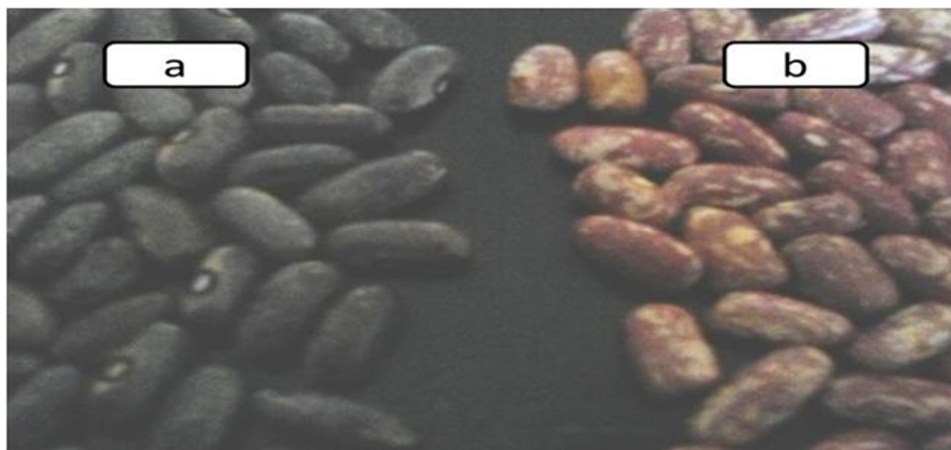
Figure 3.3 Seeds of common bean cultivars used in the experiment; (a) Mwezi Moja (*left*) and (b) KK8 (*right*).

3.5 Land preparation, soil sampling and planting

Land was prepared by hand hoeing. Soil samples (20 g) were collected for analysis before experimental set up and after harvesting the beans using a zig-zag sampling pattern as described by Sabbe & Marx (1987). Samples were mixed and air dried for two days and transported for nutrient analysis. Planting furrows accommodating 20 planting holes; (i.e. ~210 cm long × 5 cm × wide × 10 cm deep) were dug using a shovel. The composts were applied using a 250 mL cup, at a rate of 20 cups per furrow and thoroughly mixed with soil to supply nutrients at the rates stated in Table 3.2b. Soil for the non-compost treatments was mixed and spread in the furrows in a similar manner as for the compost treatments. For the DAP fertilizer that contains 20% phosphorus, one leveled teaspoon (~4.7g) was mixed with soil in the planting hole, and hence supplying 0.85 g N and 0.94 g P per plant, respectively (Naluyange et al., 2016). One bean seed was sown in every planting hole at a depth of 2 cm (Naluyange et al., 2014).

3.6 Data collection

Data was collected on parameters including plant growth and yield related parameters, populations of root endophytic and rhizosphere biota including microbes (fungi and bacteria) and macro-invertebrates (arthropods and nematodes); populations of the aboveground pests *A. fabae*, *F. occidentalis*, and the fungal pathogen *C. lindemuthianum*.

3.6.1 Bean plant growth and yields

Data from morphometric assessment and developmental duration of bean plants was recorded based on Naluyange et al. (2014). Plant height (stem base to petiole), length of the middle leaf (base to apex) and its width (widest part) was recorded when the first 3 leaves were fully formed in ~80% of the plants. Number of days for the first flower of every plant to appear was recorded. The date when the first pod in each plant formed was recorded and used to calculate the duration in number of days. Plants were harvested independently as per their full ripening dates. The number of harvested pods per plant was recorded, and the pods packed independently per plant in paper packets and sun-dried. From every packet, all pods were shelled and seed weight per plant was recorded and used to estimate yield per unit area (tons per ha^{-1}) using the formula:-

$$\text{Yield per unit area} = \Sigma \frac{y \times \alpha}{(x \times n)\beta}$$

Where y = seed weight per plant in grams, x = space occupied by one plant (0.075), n = No of plants per treatment, $\alpha = 10^{-6}$(converts grams to tons), $\beta = 10^{-4}$(converts m^2 to ha)

3.6.2 Root colonization by *Rhizobium* and density of rhizosphere microbes

During flowering, five bean plants were randomly selected from each treatment per block for estimation of the number of root nodules associated with *Rhizobium* colonization. From each plant, three nodules were selected and crushed; the resulting suspension was streaked onto yeast extract mannitol agar (YMA) containing Congo red stain (Sisco Research Lab pvt ltd, Mumbai, India) (Somasegaran & Hoben, 1985). The inoculated dishes were incubated at 28ºC for 4 days to allow the growth of microbes and sub-cultured to obtain pure cultures for morphological identification.

The density of rhizosphere microbes in terms of colony forming units (CFU) was estimated based on methods described by Loper et al. (1984), Alef & Nannipieri (1995) and Nonaka et al. (2014). Soil samples were collected from four points in each plot at a depth of 15 cm and a depth of 20 cm mixed together thoroughly and a subsample of 10 g obtained and put in Ziplock bags and transported to the of Microbiology Laboratory at (MMUST). A soil sample (1 g) was subjected to serial dilutions ($\times 10^{-2}$, $\times 10^{-4}$, and $\times 10^{-6}$) in sterile water. Aliquots of 0.5 mL from each dilution was plated onto 3 glass Petri dishes (9 cm diameter) containing two different types of media i.e. single strength Nutrient Agar (NA) (Sisco Research Lab pvt ltd, Mumbai, India) for bacterial cultures (Padmavathy et al., 2016), and single strength Potato Dextrose Agar (PDA) (Sisco Research Lab pvt ltd, Mumbai, India) for fungal cultures (Nonaka et al., 2014). The Petri dishes were incubated for 24 hours at 37°C for bacteria and 48 hours at 37°C for fungi (Masago et al., 1977; Nonaka et al., 2014). The number of microbial colony forming units was estimated using a Colony Counter (Model IMCC-02, Swastic Scientific Company, Mumbai, India); and microbial populations calculated using the formula applied by Herigstad & Heersink (2001) as follows;

$$\text{Microbe number} = \frac{\text{Colony count}}{\text{Total dilution of tube} \times \text{Amount plated}}$$

3.6.3 Rhizosphere populations of nematodes and macro-invertebrates

Two soil samples (250 g) were randomly collected at a location next to the plants from each plot; one sample was used for estimation of nematode populations, and the other for estimation of macro-invertebrate populations. Extraction and estimation of soil nematode population was based on an improvised Baermann's pan technique method (Viglierchio & Schmitt, 1983; Hooper et al., 2005; Ochieno, 2010). The 250 g soil sample was poured onto a modified Baermann's tray containing 100 mL of water and left for 48 hours to allow nematode migration. The extracts were concentrated to 10 mL by siphoning of excess water, followed by thorough mixing and counting of nematodes in 2 mL triplicate sub-samples extracted by a micropipette onto a nematode counting slide under a dissection microscope ($\times 5$ magnifications) (Ochieno, 2010). The nematode populations were expressed as counts per 100 mL of soil using the formula:-

$$\text{Number of nematodes per 100 mL volume of soil} = yx$$

Where y = Number of nematodes counted in 2 mL aliquots.
$\quad x$ = a constant (i.e. 2.4) given by

$$x = \left(\frac{a}{b} \times \frac{\beta}{\alpha} \right)$$

Where a = Standardized volume of nematode suspension, i.e. 10 mL
$\quad b$ = Pipetted volume of nematode suspension, i.e. 2 mL
$\quad \beta$ = Standard volume of soil for nematode counts, i.e. 100 mL
$\quad \alpha$ = Sampled volume of soil, i.e. 250 mL

Macro-invertebrates were extracted using a modified Berlese funnel method (Krell et al., 2005). Soil samples (250 g) were put into the funnel and subjected heat from above provided by a light bulb (40 Watts). As the heat intensified, macro-

invertebrates in the soil dropped down into the 70 % alcohol in a container (Chiarappa, 1974). The macro-invertebrates were collected after 5 days and identified under a dissecting microscope and results were expressed in 100 g.

3.6.4 Anthracnose disease incidence

Anthracnose disease incidence was scored as percentage of plants expressing symptoms of the disease (Cai et al., 2009); while severity of anthracnose disease was scored on a 1-9 disease severity scale (Singh & Saxena, 1993), based on the amount of tissue damage attributable to *C. lindemuthianum*, characterized by dark brown to black lesions on leaves (Hagedorn & Inglis, 1986; Buruchara et al., 2010). Two leaf samples were randomly collected from diseased plants in each microplot and taken to the laboratory for isolation and morphological identification of possible pathogens associated with the necrotic lesions, to confirm the presence of *C. lindemuthianum* (Kranz, 1988). Necrotic tissues were cut out of the collected leaf samples. The tissues were surface sterilized using 2 % hypochlorite solution and rinsed in sterile distilled water (Kranz, 1988). This was followed by surface sterilization in 70 % ethanol for 30 seconds then washing in three changes of sterile distilled water to remove excess ethanol (Kranz, 1988). The leaf tissues were plated in single strength PDA medium and incubated for 4 days at 20ºC for microbial growth (Kranz, 1988). Microbial colonies were sub-cultured in PDA to obtain pure colonies for morphological identification using a compound microscope (Leica Model Z45E, Leica Inc., USA). *Colletotrichum lindemuthianum* was identified by acervular conidiomata, often with setae (dark-pigmented, unbranched, thick-walled sterile hyphae usually pointed at the tip), producing elongated slimy conidia, with the presence of appressoria (thick-walled swellings at the end of a hypha or germ tube useful for attaching the fungus to the host surface before penetration of the tissue) (Cai et al., 2009).

3.6.5 Aboveground insect pest infestations

Population of the main aboveground insect pests (aphids and thrips) infesting bean plants in the study area was recorded during the vegetative and flowering stages, by the alcohol collection method (Naluyange et al., 2014), and by the sticky trap method (Brodsgaard, 1989). In the first method, collection and quantification of aphids was done by directly picking the insects from leaves into alcohol preservative (Naluyange et al., 2014). Three screw-capped containers each containing 10 mL of 70% ethanol (C_2H_5OH) were placed after every 10 plants (i.e. 2 bottles in a row). Aphids were collected into each container using a camel hair brush from leaves and stems and taken to the Laboratory of Zoology (MMUST). The collected aphids were poured onto a Petri dish; identification was done using a dissecting microscope (Model Z45E, Leica Inc., USA) at ×10 magnification and the total count done using a tally counter.

In the second method of insect collection, sticky traps were applied in the collection and quantification of both aphids and thrips; with the blue colour being attractive to thrips *Frankliniella occidentalis* (Pergande) (Brodsgaard, 1989), and the yellow colour preferred by aphids (Alverson, 1977). Sticky traps (2 blue and 2 yellow) (Bioworks,Inc., New York) were placed in each plot 30 cm above the beans plants, after three days the trapped insects were identified and counted using hand lens (A'Brook, 1973).

3.7 Statistical analysis

Data were analyzed using SAS 9.1 software (SAS Institute Inc.) at $p \leq 0.05$ confidence level. Proc Means was used in the generation of descriptive statistics such as means and standard errors for nodule counts, aphid and thrip populations, plant growth and yields. Data for nodules, aphid and thrip populations were log-

transformed prior to analysis. Germination frequencies (%) were generated using Proc Freq. For plant growth, insect populations and nodule number, Analysis of Variance (ANOVA) between treatment means (fertility $\times$ variety) was done by Proc Mixed using the three blocks as random effects and the two seasons as repeated measures. Means for plant growth, insect population and nodule number were separated using Ls-means when treatment effects were significant ($p < 0.05$). Nematode populations and microbial CFU were analyzed by Proc Genmod (χ^2 test; Poisson) while for germination percentages, Proc Genmod with binomial distribution was used.

CHAPTER FOUR

RESULTS

4.1 Physico-chemical Analysis of manure and Soil

The ready composts were sampled for nutrient analysis, and were found to contain the

physico-chemical characteristics summarized in (Table 4.1).

Table 4.1 : Nutrient composition of each farmer produced compost

Sample description	CF1 [CF]	CF2	CF3	CF4	CF 5
Nitrogen %*	1.75	0.70	1.05	0.35	1.05
Phosphorus %*	0.46	0.40	0.45	0.19	0.45
Potassium %*	0.10	0.05	0.06	0.06	0.13
Calcium %*	0.90	0.50	0.40	0.10	0.90
Magnesium %*	0.20	0.01	0.01	0.01	0.15
Iron %*	0.21	0.08	0.09	0.09	0.12
Copper %*	0.0031	0.0002	0.000517	0.0001	0.00168
Manganese %*	0.12	0.01	0.04	0.03	0.07
Zinc %*	0.02	0.0010	0.0005	0.00017	0.0073
Density (g/250mL)**	105	89	93	50	151

*Original data from soil analysis laboratory expressed data in mg/Kg
**Farmer-based application rate of composts is 250 mL cup per plant
[CF]Farmer produced compost

The soil before planting was found to have the physico-chemical characteristics

summarized in (Table 4.2a). Soil analysis was also repeated at the end of the

experiment, (Table 4.2 b).

Table 4.2 a: Physico-chemical characteristics of soil before planting

Experimental plot	CF1		CF2		CF3		CF4		CF5		Non		DAP	
Fertility results	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class
*Soil pH	4.660	Strong acid	4.687	Strong acid	4.903	Strong acid	4.670	Strong acid	4.703	Strong acid	4.650	Strong acid	4.543	Strong acid
Exch. Acidity %	0.2	Adequate	0.2	Adequate	0.167	Adequate	0.20	Adequate	0.267	Adequate	0.233	Adequate	0.36	Adequate
*Total nitrogen %	0.223	Adequate	0.217	Adequate	0.220	Adequate	0.210	Adequate	0.210	Adequate	0.187	Low	0.190	Low
*Total organic carbon %	2.177	Moderate	2.120	Moderate	2.153	Moderate	2.063	Moderate	2.060	Moderate	1.823	Moderate	1.850	Moderate
Phosphorus ppm	31.667	Adequate	23.333	Low	33.333	Adequate	23.333	Low	25.000	Low	18.333	Low	23.333	Low
Potassium%	0.220	Low	0.180	Low	0.300	Low	0.193	Low	0.247	Low	0.193	Low	0.133	Low
Calcium %	0.933	Low	1.067	Low	1.233	Low	1.2	Low	1.067	Low	0.667	Low	0.867	Low
Magnesium%	0.65	Low	0.667	Low	0.96	Low	1.13	Low	0.88	Low	0.613	Low	0.647	Low
Manganese%	0.683	Adequate	0.893	Adequate	0.913	Adequate	0.837	Adequate	0.767	Adequate	1.023	Adequate	0.900	Adequate
Copper ppm	4.683	Adequate	4.6305	Adequate	4.543	Adequate	4.5068	Adequate	4.6637	Adequate	4.973	Adequate	4.943	Adequate
Iron ppm	34.3	Adequate	34.267	Adequate	33.8	Adequate	37.467	Adequate	32.533	Adequate	33.067	Adequate	38.2	Adequate
Zinc ppm	5.863	Adequate	8.367	Adequate	7.067	Adequate	7.873	Adequate	7.083	Adequate	8.253	Adequate	6.230	Adequate
Sodium%	0.053	Adequate	0.067	Adequate	0.073	Adequate	0.093	Adequate	0.060	Adequate	0.067	Adequate	0.0467	Adequate

[1]ppm=parts per million (parts per million conversion to percentage=0.0001) ; *TotalN = Ammonium -N plus organic N

Table 4.2b Physico-chemical characteristics of soil at harvest

Experimental plot	CF1		CF2		CF3		CF4		CF5		NON		DAP	
Fertility results	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class	Value	Class
*Soil pH	5.253	medium acid	5.457	medium acid	5.313	medium acid	5.223	medium acid	5.403	medium acid	5.247	medium acid	5.077	medium acid
Exch. Acidity %	0.300	adequate	0.350	adequate	0.333	adequate	0.367	adequate	0.167	adequate	0.300	adequate	0.433	adequate
*Total Nitrogen %	0.22	adequate	0.21	adequate	0.237	adequate	0.220	adequate	0.240	adequate	0.213	adequate	0.203	adequate
* Total Org. Carbon %	2.18	moderate	2.06	moderate	2.337	moderate	2.177	moderate	2.380	moderate	2.140	moderate	1.997	moderate
Phosphorus ppm	31.667	adequate	50.00	adequate	35.00	adequate	28.33	adequate	33.333	adequate	33.333	adequate	26.667	adequate
Potassium %	0.54	adequate	0.553	adequate	0.413	adequate	0.52	adequate	0.647	adequate	0.387	adequate	0.2267	adequate
Calcium %	2.18	adequate	2.06	low	2.337	adequate	2.177	adequate	2.380	low	2.140	low	1.997	low
Magnesium %	2.923	adequate	2.4267	adequate	2.833	adequate	2.293	adequate	2.810	adequate	2.327	adequate	1.397	adequate
Manganese %	0.423	adequate	0.497	adequate	0.490	adequate	0.593	adequate	0.430	adequate	0.450	adequate	0.4267	adequate
Copper ppm	5.797	adequate	5.580	adequate	5.683	adequate	5.597	adequate	6.563	adequate	7.057	adequate	5.803	adequate
Iron ppm	56.567	adequate	85.233	adequate	58.400	adequate	55.700	adequate	42.700	adequate	66.100	adequate	56.467	adequate
Zinc ppm	10.533	adequate	11.600	adequate	12.100	adequate	11.267	adequate	11.567	adequate	11.390	adequate	8.98	adequate
Sodium %	0.153	adequate	0.273	adequate	0.113	adequate	0.153	adequate	0.180	adequate	0.1267	adequate	0.087	adequate

[1] ppm=parts per million (parts per million conversion to percentage=0.0001); *TotalN = Ammonium -N plus organic N

4.1 Germination rate and developmental time

Seed germination percentage was higher in KK8 than in Mwezi Moja bean variety; with some farmer-produced composts (CF2, CF4 and CF5) appearing to produce low germination percentage in Mwezi Moja; while both varieties having low germination percentage when grown with DAP fertilizer (χ^2=18.21, p=0.0057) (Figure 4.1). Duration in number of days to germination was shortest in KK8 bean variety, especially when seeds were grown with CF3 compost or without soil fertility amendment; but longest duration to germination occurred when in Mwezi Moja seeds grown with DAP, and KK8 seeds grown with CF2 and CF4 composts, respectively (p<0.05; Table 4.3). Mwezi Moja took shorter time to flowering than KK8 bean plants (p<0.05); but this did not vary between the soil fertility amendments (p>0.05) (Table 4.1). Number of days for bean pods to ripen was shorter in Mwezi Moja variety than in KK8 variety; with KK8 taking the shortest time to ripen when grown with CF4 compost and without soil fertility amendment, and longest time when CF3 compost was applied (p<0.05; Table 4.3).
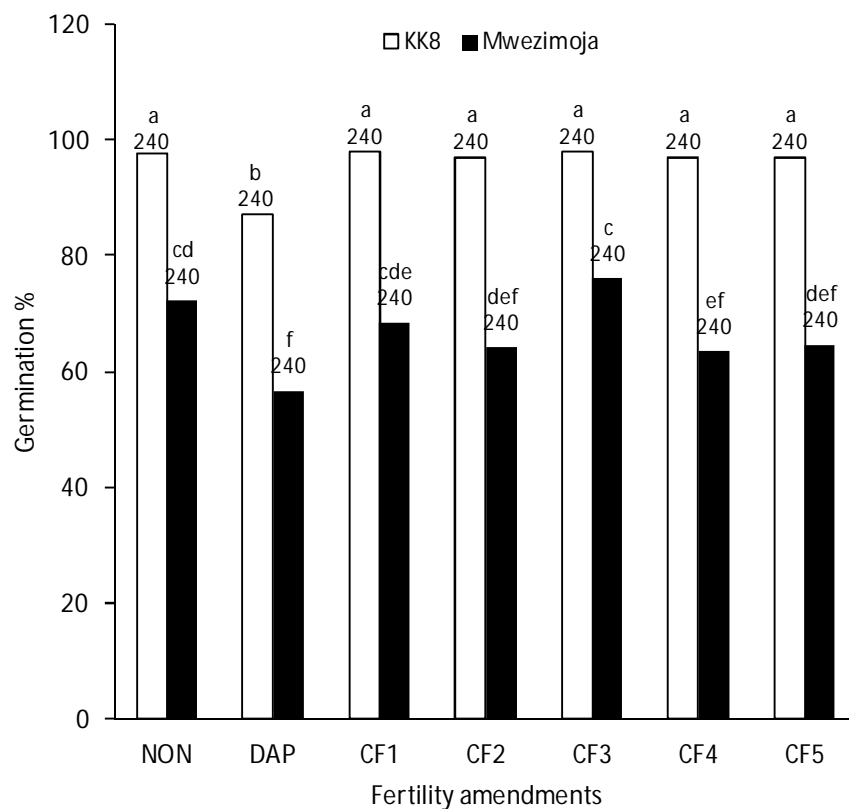
Fig 4.1: Germination percentage of KK8 and Mwezi Moja bean varieties. When grown with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON).

Table 4.3a: Effect of fertilizer treatments on bean growth of two bean

Source of variation		df	Leaf length	Leaf width	Plant height	Emergence	Flowering	Pod ripening
			F value	F value	F value	F value	F value	F value
Season		1	10.85*	18.17**	23.00**	3.42	24.49**	459.2***
Fertilizer		6	6.46***	6.98***	3.33*	4.66**	1.46	1.09
Variety		1	4.92*	9.4**	5.55*	14.33***	58.2***	69.8***
Fertilizer*variety		6	0.26	0.73	0.74	2.64*	1.54	4.05**
			means	means	means	means	means	means
Overall mean (both seasons)			8.38±0.06	5.04±0.06	5.89±0.11	8.91±0.03	41.57±0.27	74.85±0.10
Seasons	1		8.05±0.08 b	4.75±0.06 b	6.45±0.04 a	9.22±0.20	40.43±0.51 b	76.67±0.17 a
	2		8.67±0.18 a	5.38±0.14 a	5.16±0.27 b	8.72±0.17	43.08±0.04 a	71.12±0.20 b
			cm	cm	cm	days	days	days
Fertilizer	Non		7.16±0.22 c	4.21±0.14 c	5.58±0.17 b	8.62±0.34	41.06±0.92	74.07±0.35
	DAP		7.7±0.19 bc	4.63±0.18 bc	5.44±0.23 b	9.44±0.31	41.64±0.43	75.09±0.89
	CF1		9.07±0.26 a	5.45±0.21 a	6.25±0.21 a	8.34±0.1	41.12±0.57	74.87±0.67
	CF2		8.55±0.23 a	5.31±0.23 a	5.85±0.16 ab	9.52±0.31	42.2±0.63	74.87±0.83
	CF3		8.91±0.48 a	5.39±0.23 a	6.18±0.11 a	8.54±0.17	41.26±0.99	75.47±0.96
	CF4		8.27±0.21 ab	4.94±0.14 ab	5.74±0.25 ab	9.04±0.34	42.29±0.26	74.68±0.48
	CF5		9.01±0.29 a	5.36±0.2 a	6.19±0.05 a	8.85±0.2	41.38±0.69	74.89±0.87
Variety	KK8		8.62±0.2 a	5.25±0.14 a	6.05±0.1 a	8.61±0.16	42.77±0.13 a	76.12±0.33
	Mwezi moja		8.14±0.19 b	4.84±0.12 b	5.73±0.11 b	9.2±0.14	40.36±0.3 b	73.57±0.15
Fertilizer × Variety	Non KK8		7.14±0.23	4.28±0.23	5.74±0.2	8.05±0.14 e	42.91±0.39	73.79±0.63 cd
	Non Mwezi Moja		7.17±0.44	4.15±0.21	5.42±0.29	9.18±0.48 abc	39.2±0.83	74.36±0.35 d
	DAP KK8		7.86±0.18	4.85±0.12	5.77±0.33	9.09±0.25 abcd	42.48±0.38	77.01±0.38 ab
	DAP Mwezi Moja		7.54±0.34	4.42±0.32	5.11±0.21	9.79±0.54 a	40.81±0.29	73.16±0.29 d
	CF1 KK8		9.47±0.24	5.75±0.2	6.6±0.06	8.28±0.13 de	42.21±0.51	75.89±1.05 abc
	CF1 Mwezi Moja		8.66±0.34	5.15±0.29	5.89±0.31	8.41±0.16 bcde	40.02±0.4	73.84±0.24 d
	CF2 KK8		8.72±0.26	5.71±0.32	5.88±0.34	9.83±0.6 a	43.44±0.18	76.68±0.39 ab
	CF2 Mwezi Moja		8.38±0.4	4.91±0.09	5.83±0.14	9.21±0.18 ab	40.96±0.67	73.06±0.19 d
	CF3 KK8		9.25±0.41	5.51±0.22	6.32±0.14	8.22±0.11 e	42.98±0.33	77.30±1.02 a
	CF3 Mwezi Moja		8.56±0.93	5.26±0.44	6.03±0.14	8.87±0.19 bcde	39.54±1.36	73.63±0.51 d
	CF4 KK8		8.54±0.35	4.94±0.24	5.91±0.32	8.3±0.13 cde	42.63±0.33	75.52±0.57 bc
	CF4 Mwezi Moja		8.0±0.17	4.95±0.2	5.57±0.43	9.77±0.16 a	41.95±0.36	73.84±0.35 d
	CF5 KK8		9.35±0.41	5.7±0.17	6.12±0.06	8.49±0.16 bcde	42.71±0.24	76.67±0.72 ab
	CF5 Mwezi Moja		8.67±0.36	5.01±0.25	6.27±0.06	9.2±0.23 ab	40.05±0.76	73.12±0.41 d

Asterisk indicates significant effect; ***P ≤ 0.001, **P ≤ 0.01, *P ≤ 0.05; Means with the same letter(s) are not significantly different (p > 0.05); those with more than one letter are intermediate.

Table 4.3b: Effect of fertilizer treatments on bean yield of two

Source of variation		df	Pods/plot	Pods/plant	Yield/unit area	Seed weight/plant	Shoot dry weight
			F value	F value	F value	F value	F value
Season		1	338.21***	98.49***	1082.58***	341.2***	1564.23***
Fertilizer		6	9.57***	3.74***	9.19***	4.84**	4.07**
Variety		1	97.45***	2.51	58.98***	0.24	0.02
Fertilizer*variety		6	1.34	0.42	1.27	0.62	0.58
			counts	counts	means	means	means
Overall mean (both seasons)			222.9±13.06	7.02±0.37	1.31±0.05	8.55±0.19	7.44±0.12
			counts	counts	means	means	means
Seasons	1		399.09±15.62 a	8.44±0.58 a	2.46±0.06 a	10.57±0.47 a	10.97±0.16 a
	2		46.86±11.07 b	2.41±0.17 b	0.17±0.04 b	1.78±0.08 b	3.92±0.07 b
			Counts	Counts	Tons/ha	Grams/plant	Grams per plant
Fertilizer	Non		187.9±35.8 c	6.24±0.41 bc	1.14±0.18 c	8.00±0.42 bcd	5.35±0.61 c
	DAP		115.2±26.2 d	5.59±0.73 c	0.57±0.11 d	5.77±0.64 d	5.71±0.20 c
	CF1		233.2±30.2 bc	6.6±0.5 bc	1.37±0.19 bc	7.84±0.55 bcd	7.1±0.86 abc
	CF2		252.3±35.4 ab	9.2±0.5 a	1.54±0.19 ab	11.49±0.78 a	9.14±1.03 a
	CF3		307.2±44.9 a	8.07±0.99 ab	1.83±0.27 a	10.15±1.39 ab	9.2±0.92 a
	CF4		228.7±50.9 bc	6.41±0.43 bc	1.24±0.29 bc	7.24±0.64 cd	6.73±0.59 bc
	CF5		236.3±32.8 bc	7.02±0.53 bc	1.51±0.21 abc	9.32±0.98 abc	8.88±0.92 ab
Variety	KK8		294.5±18.1 a	7.4±0.38	1.69±0.12 a	8.71±0.58	7.4±0.34
	Mwezi moja		151.4±12.7 b	6.64±0.39	0.93±0.09 b	8.38±0.56	7.48±0.65
Fertilizer × Variety	Non KK8		259.9±33.7	6.78±0.73	1.45±0.22	7.81±0.80	5.6±0.22
	Mwezi Moja		116±9.2	5.69±0.1	0.81±0.03	8.19±0.47	5.09±1.31
	DAP KK8		151±40.3	6.03±1.09	0.70±0.16	5.54±0.60	5.92±0.39
	Mwezi Moja		79.3±22.8	5.15±1.12	0.45±0.13	5.99±1.29	5.51±0.11
	CF1 KK8		292.3±3.7	7.32±0.85	1.72±0.1	8.80±0.75	7.46±0.46
	Mwezi Moja		174±32.5	5.88±0.11	1.02±0.2	6.89±0.19	6.74±1.83
	CF2 KK8		323±32.1	8.78±0.76	1.92±0.17	10.64±0.77	8.39±0.78
	Mwezi Moja		181.6±15.0	9.63±0.72	1.15±0.12	12.35±1.32	9.89±2.04
	CF3 KK8		399.3±29.0	8.35±1.93	2.33±0.33	10.06±2.93	8.9±1.08
	Mwezi Moja		215±27.5	7.8±1.05	1.34±30.15	10.23±1.06	9.5±1.71
	CF4 KK8		333±26.3	6.68±0.34	1.84±0.18	7.75±0.83	7.56±0.85
	Mwezi Moja		124.3±37.1	6.14±0.86	0.64±0.21	6.74±1.05	5.9±0.57
	CF5 KK8		303±11.1	7.86±0.84	1.87±0.08	10.34±1.57	8.01±0.64
	Mwezi Moja		169.6±28.5	6.19±0.21	1.13±0.26	8.31±1.17	9.74±1.76

Asterisk indicates significant effect; ***P ≤ 0.001, **P ≤ 0.01, *P ≤ 0.05; Means with the same letter(s) are not significantly different (p > 0.05); those with more than one letter are intermediate.

Table 4.4a: KK bean variety plant tissue analysis

Nutrients	CF1	CF2	CF3	CF4	CF5	DAP	NON
Calcium (%)	3.628± 3.358	4.19±3.203	2.262±0.472	1.732±1.281	2.566±1.006	3.678±2.910	2.376±0.877
Copper (mg/kg)	14.3±2.236	18.68±2.994	16.66±3.934	16.34±3.190	16.66±2.641	17.68±3.036	16±3.877
Iron (mg/kg)	781.6±697.91	971.6±645.075	869±807.164	1014.6±717.38	948.6±779.95	1895.2±1837.547	1892±1465.487
Magnesium (%)	0.562±0.118	0.58±0.160	0.508±0.094	0.454±0.0976	0.464±0.093	0.628±0.092	0.574±0.125
Manganese (mg/kg)	172±31.377	244±82.429	176.8±9.148	203.6±74.945	412±23.216	469.6±197.276	251.4±48.366
Nitrogen (%)	3.92±0.759	3.36±0.531	3.29±0.586	3.01±0.192	2.87±0.383	3.15±0.247	3.29±0.313
Phosphorus (%)	0.448±0.023	0.468±0.060	0.466±0.036	0.446±0.023	0.464±0.034	0.47±0.061	0.406±0.064
Potassium (%)	3.408±1.398	2.48±0.414	2.94±0.240	3.002±0.470	2.684±0.540	2.728±0.240	2.85±0.316
zinc (mg/kg)	40.32±2.182	44.66±10.887	39.34±4.962	40.68±6.310	40.64±7.508	42.68±6.202	43.66±8.010

1 mg/kg= 0.0001 percent ; 1ppm= 0.0001 percent

Table 4.4b: Mwezi Moja bean variety plant tissue analysis

Nutrients	CF1	CF2	CF3	CF4	CF5	DAP	NON
Calcium %	2.64±3.238	3.290±0.537	2.135±0.884	1.740±2.249	3.155±0.163	2.835±0.318	3.175±0.969
Copper mg/kg	15.800±3.535	20.000±2.404	20.850±1.202	19.150±1.202	18.350±2.333	19.200±3.535	17.500±5.940
Iron mg/kg	1537.500±144.96	1589±185.262	1747±7162.63	1542.5±788.42	1659±560.028	3045.5±2386.49	2801±659.023
Manganese mg/kg	166±4.242	164±0.707	177.5±3.181	156±2.828	782.5±424.618	545.5±143.189	278.5±39.951
Nitrogen %	3.325±0.123	3.150±0.247	2.800±0.248	2.975±0.123	2.8±0.000	3.150±0.000	2.975±0.123
Phosphorus%	0.47±0.00	0.520±0.070	0.485±0.049	0.465±0.0212	0.475±0.063	0.445±0.035	0.450±0.028
Potassium%	2.935±0.417	2.705±0.109	3.035±0.276	2.985±0.388	2.505±0.289	2.745±0.445	2.835±0.106
Zinc mg/kg	40.8±3.535	44.15±8.273	43.35±4.735	43.350±4.737	39.150±1.202	43.350±2.333	51.650±2.333

1 mg/kg= 0.0001 percent; 1ppm= 0.0001 percent

4.1.1 Plant size and yield

Bean plants grown with farmer-produced composts, especially those with CF1 (6.6),

CF3 (6.32) and CF5 (6.12), were taller with larger leaves than those grown with DAP

(5.77) and the controls (5.74) without soil fertility amendment (p<0.05; Table 4.3a).

Mwezi Moja plants were shorter(5.73) than KK8 plants(6.05) (Table 4.3a). Shoot dry

weights for bean plants grown with farmer-produced composts, particularly

CF2(8.39), CF3(8.9) and CF5(8.01), were higher than for plants grown with DAP(5.09) and without soil fertility amendment(5.6) ($p < 0.05$; Table 4.1a). The number of pods per plant was highest in CF2(8.78) and CF3(8.35), but lowest in DAP-treated plot (6.03), CF4 (6.68), CF5 (7.86), CF1 (7.32) and NON (6.78) ($p = 0.0074$, $F = 3.74$). Number of pods per plot was high when beans were grown with farmer-produced composts, especially those with the CF2 (323.32) and CF3 (399.3) composts; but was lowest when grown with DAP (151) ($p < 0.0001$; Table 4.3b). These trends on number of pods per plot appeared to be reflected in seed weight per plant and in the form of yield per unit area ($p < 0.05$; Table 4.3b).

4.1.2 Root nodules and rhizosphere microbes

Root nodules produced cells confirmed to be *Rhizobium* species, since they exhibited the characteristic cultural features on yeast extract mannitol agar (YMA) containing Congo red (Fig 4.2a).


Figure 4.2a: Plates showing cultural characteristics of *Rhizobium*

Number of root nodules was higher on bean plants grown with the farmer-produced composts CF1(50), CF2 (55), CF3(60), CF4 (55), CF5 (30) than those that received DAP (5) and without soil fertility amendment (10), ($p < 0.05$; Figure 4.2b). Number of

bacterial colony forming units from the rhizosphere soil was high in the farmer-produced composts CF3 (1200), CF4(1250) and CF5 (1100); but the bacterial population was low in the other four treatments, especially in soil that received DAP (700) and CF2(700) compost ($p<0.05$; Figure 4.3). Number of fungal colony forming units from the rhizosphere soil was lower in the control (30) compared to the six soil fertility amendments, especially in the farmer-produced composts CF1 (280), CF3 (400), CF4 (280) and CF5(500) composts ($p<0.05$; Figure 4.4).
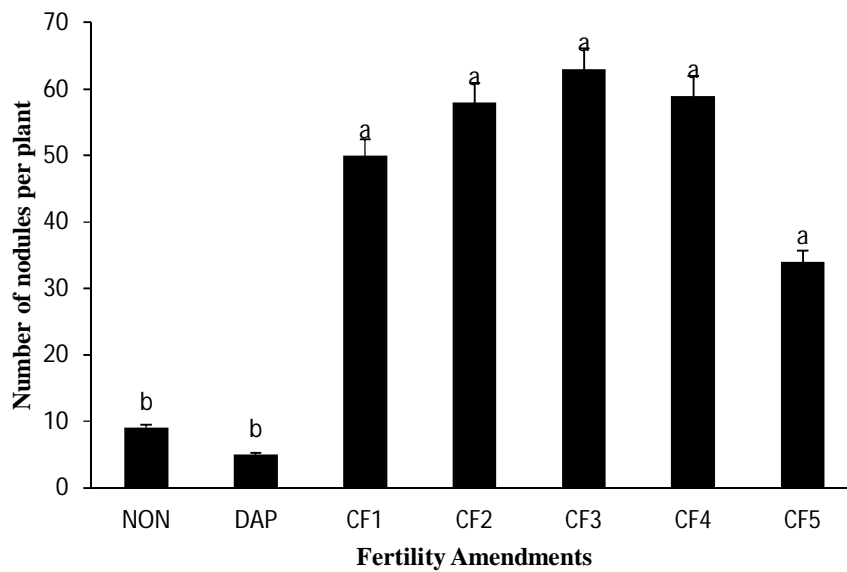
Figure 4.2b: Number of root nodules on bean roots. Grown with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (F test; $p > 0.05$).
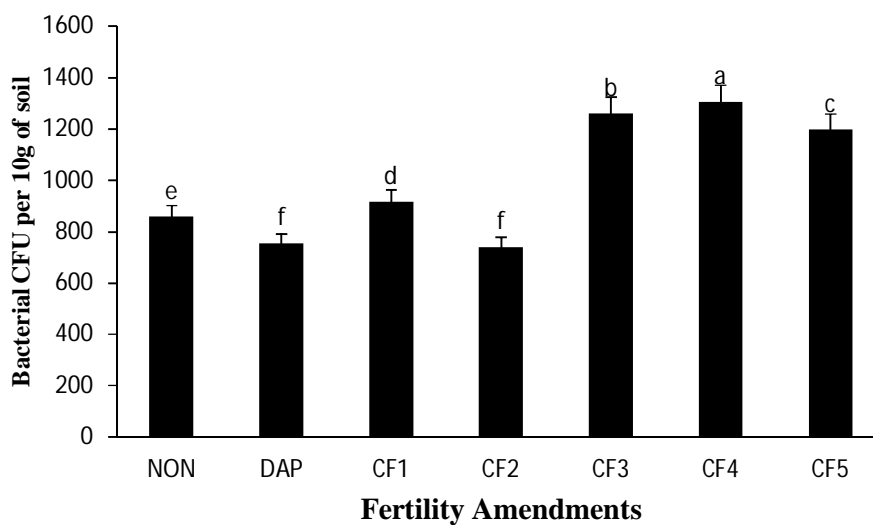
Figure 4.3: Bacterial populations (CFU) in the rhizosphere of bean plots. Treated with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (χ^2 test; p > 0.05).
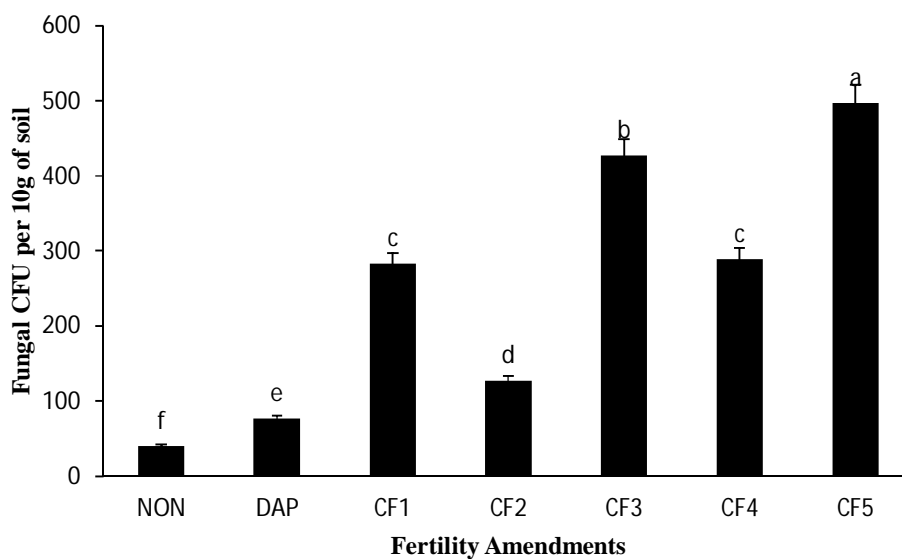
Figure 4.4: Fungal populations (CFU) in the rhizosphere of bean. Plots treated with diammonium phosphate fertilizer (DAP**),** farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (χ^2 test; p > 0.05).

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4.1.3 Rhizosphere nematodes, macro-invertebrates, foliar pests and anthracnose disease incidence

Rhizosphere nematode populations were low in plots that received the five farmer-produced composts especially in the CF2 (7) compost; but their numbers were highest in DAP-treated plots(38) ($p < 0.05$; Figure 4.5).

Figure 4.5: Nematode populations in the rhizosphere of bean. Plots treated with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (χ^2 test; $p > 0.05$).
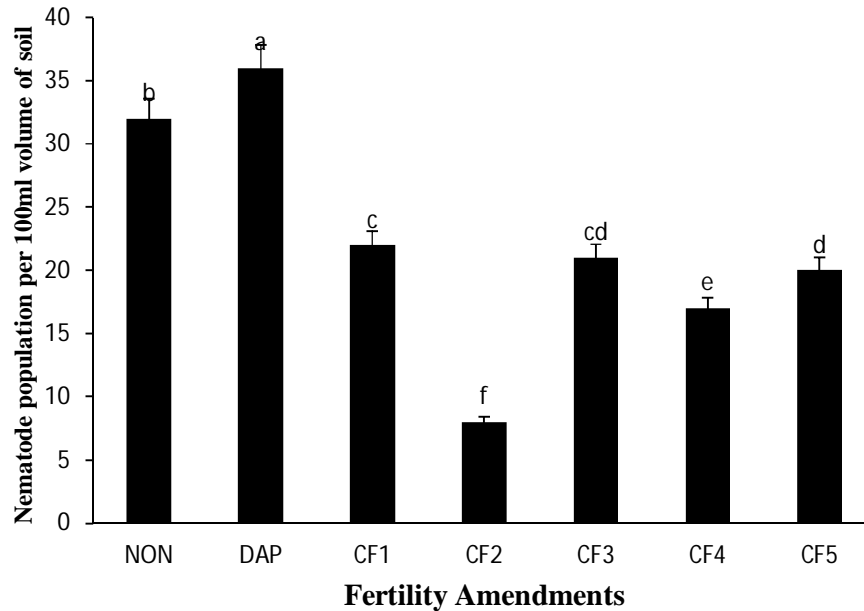
The overall population of macro-invertebrates (arthropods) was very low (1110 individuals per 100g of soil), and not statistically different between the treatments ($p > 0.05$). These soil arthropods comprised of collembola, crane fly, leaf beetles, plant bugs red ant, rove beetle and sandfly. Population aphid *A. fabae* and the black bean thrip *F. occidentalis* did not vary between the treatments ($p > 0.05$), with the aphids averaging 28 insects per plant and the thrips being 179 insects per sticky trap.

Anthracnose disease severity averaged 4.4, while the trends varied indiscernibly across the fourteen treatment combinations (p<0.05).

CHAPTER FIVE

DISCUSSION

5.1 Nutrient content of farmer-produced composts

All the farmer-produced composts contained nutrients that are necessary for bean plants. However, the composts varied in nutrient composition. For example, the farmer-produced compost with the highest nitrogen content was CF1 with 1.75% N, while CF4 had the least N content of 0.35%. The difference in N content may partly be attributed to the proportion of animal manure used in making the composts. The CF1 compost contained 75% cattle manure, while CF4 had only 20% cattle manure. Moreover, cattle manure mixes with urine that contains high N content in the form of urea (Misselbrook et al., 2005; Dijkstra et al., 2013). Nutrient content between the farmer-produced composts and the initial nutrient content of soil was evident. There was evidence that the application of some farmer-produced composts improved soil fertility at the end of the experiment. For example, nitrogen content in plot CF4 increased by ~4.8%, while phosphorus was increased by ~21.7%. The application of farmer-produced compost generally improved other important soil physico-chemical characteristics that are important for bean plants. For instance, soil pH in plots that received farmer-produced composts increased from relatively more acidic (pH 4.6) before planting to less acidic (pH 5.2), which is within the range of pH 5.2-6.8 favorable for bean plants (Wallace, 1980; Warncke et al., 2009; Fageria et al., 2010).

The bean plants appeared to have differentially utilized nutrients from some farmer-produced compost. Leaf tissues of the two bean varieties grown with farmer-produced

composts, especially CF1 and CF3, had higher concentrations of nutrients such as phosphorus (P) and potassium (K), when compared to those that were grown without any soil amendment. Composts, especially those containing chicken droppings (e.g. CF3) improve the accumulation of phosphorus and potassium in leguminous leaf tissues which is in agreement with Adeli et al. (2005). This could have been due to a higher amount of N, P and K in poultry compost compared to wastes of other livestock (Elliots, 2005).

5.2 Plant growth and yields as influenced by farmer-produced composts

Application of some farmer-produced compost was associated with improved growth and yields of bean plants. Bean plants grown with any of the five farmer-produced composts, especially those receiving CF1, CF3 and CF5, were taller with larger leaves, compared with those grown without soil fertility amendment. Shoot dry weights for bean plants grown with farmer-produced composts, especially CF2, CF3 and CF5, were higher than for plants grown without soil fertility amendment. Such an observation on enhanced growth of bean plants and other legumes due to compost application has been reported by other researchers (e.g. Abdelhamid et al., 2004; Yagoub et al., 2014). Enhanced bean growth under compost application has been linked to improved photosynthetic efficiency that increases plant biomass as expressed in shoot dry weight (Abdelhamid et al., 2004). Farmer-produced compost CF2 was strongly associated with high grain yield per unit area, with CF3 and CF5 having a similar effect but not quite strong, when compared to plots that did not receive any soil fertility amendment. The higher soil concentration of N, P and K on

these plots at harvest than at planting may partly explain the higher yields on plots receiving CF2 and CF3 (Naluyange et al., 2014; Yagoub et al., 2014).

5.3 Influence of farmer-produced composts on endophytic and rhizosphere microbes

The number of root nodules was generally high in bean plants that were grown with the five farmer-produced composts. Extracted from these bean root nodules were endophytic bacterial cells, which confirmed to be *Rhizobium* species, this was also observed in other studies by Peter et al. (1996); McInnes et al. (2004), since they exhibited the characteristic cultural features on yeast extract mannitol agar (YMA) containing Congo red (Burton, 1985; Giller, 2001; Woomer et al., 2011). This increase in bean root nodules is a desirable effect of composts (Zahran, 1999; Graham & Vance, 2000), as a high number of root nodules is associated with improved nitrogen fixation by the symbiotic diazotrophic *Rhizobium* species (Hungria et al., 2003; Remig et al., 2016). The farmer-produced composts may have promoted root nodulation by addition of nutrients, especially phosphorus and potassium (Zahran, 1999; Shahzad et al., 2014). High number of root nodules may also have been due to increase in soil pH that favours *Rhizobium* survivorship and nitrogenase activity (Marschner, 1991; Vassilera et al.,1997; Thrall et al., 2000; Ferguson et al., 2013).

In the rhizosphere, non-specific bacterial and fungal colonies were detected, with their populations being generally high in plots that received any of the five farmer-produced composts. This may partly be attributed to the increased nutrient availability and elevated soil pH, which have been associated with enhancing microbial colonization in the rhizosphere (Zhen et al., 2014). These enhancements in

rhizosphere bacterial and fungal populations tended to be more pronounced in plots that received CF1, CF3, CF4 and CF5 composts. The common factor between the previous four composts is that all of them contained cattle manure. Compost made out of cattle manure increases bacterial and fungal diversity by enhancing carbon content in soil (Wu et al., 2008; Zhen et al., 2014). In addition, microbes derived from the animal gut add up to the ones that already exist in the soil (Gupta et al., 2016; Manyi-Loh et al., 2016).

5.4 Influence of farmer-produced composts on rhizosphere nematodes and aboveground pests

The population of rhizosphere nematodes was low in plots that received any of the five farmer-produced composts, especially on plot CF2. This can partly be attributed to the action of soil microorganisms on organic material during composting that releases a wide range of nematicidal chemical compounds and enzymes (Korayem, 2003; Nahar et al., 2006; Stirling, 1991). Also, composts that have undergone advanced mineralization may not be suitable for colonization by saprophytic and plant-parasitic nematodes (Hunt et al, 1973; Nahar et al., 2006), as such species feed on relatively intact organic matter as necrotrophs or biotrophs (Lozano & Smant 2011). On the contrary, increase in microbial density in plots that received farmer-produced composts may have favored bacterivore and fungivores nematode species that feed on bacteria and fungi (Bardgett al., 1999; Blanc et al., 2006; Nahar et al., 2006). The increase in bacterial and fungal populations may also have included some antagonistic microbes that suppress nematodes (Kerry, 2000; Oka, 2010). In addition, the low nematode density may have been due high organic matter (total organic

carbon) that was relatively enhanced in some plots, which may have slowed nematode migration during extraction using the Baermann's method (McSorley & Walter, 1991). Aboveground, infestation levels of the black bean aphid *A. fabae*, the bean flower thrip *F. occidentalis* and anthracnose disease caused by *C. lindemuthianum* was low in all the plots, and did not vary between treatments. It would be expected that a higher level of root nodulation by *Rhizobium* species in compost treatments would be associated with increase in *A. fabae* populations and *C. lindemuthianum* infestations (Dean et al., 2009; Naluyange et al., 2014, 2016). This was not the case in the present study, as there was no inoculation of the seeds with additional commercial or non-native *Rhizobium*, as was the case for Dean et al. (2009) and Naluyange et al. (2014).

5.5 Performance of DAP fertilizer and bean varieties

Results from this study reveal some key differences on the effect of DAP fertilizer on soil fertility as compared to the farmer-produced composts. Bean plants grown with DAP fertilizer had smaller leaves, lower shoot dry weight and fewer pods per plot compared to those that received farmer-produced compost. Grain yields per unit area from the DAP-treated bean plants were also low. Reduced plant growth and yields in DAP-treated plots may be attributed to quicker depletion of nitrogen and phosphorus by the time of harvest; and the absence of additional nutrients such as calcium, potassium and micronutrients in DAP (Marenya et al., 2009), when compared to the farmer-produced composts. This considerably poor growth rates on DAP-treated plots, may be linked to the lower grain yields that were attained (Naluyange et al., 2014). Such negative effects of DAP on beans have been linked to phytotoxicity and

high osmotic pressure that constrains water uptake by seeds (Kabir et al., 2010; Naluyange et al., 2014). There was no evidence that the two bean varieties performed differently due to the soil amendments. However, KK8 bean variety appeared to be inherently superior to Mwezi Moja (GLP 1004) in terms of seed germination percentage, plant size (height, leaf length and width), and number of pods per plant.

DAP-treated bean plants had lower number of *Rhizobium*-associated root nodules compared to those receiving farmer-produced composts. This may partly be due to DAP fertilizer deficiency in essential soil nutrients such as potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn), which are important for root nodulation by *Rhizobium* (Foy, 1984; Brear et al., 2013). Such nutrients were present in the farmer-produced composts. DAP also tended to lower soil pH, and hence creating acidic conditions that do not favour *Rhizobium* survivorship and nitrogenase activity (Manyi-Loh et al., 2016), besides being toxic to *Rhizobium* and bean plants (Maheshwari et al., 2010; Naluyange et al., 2014). Rhizosphere bacterial and fungal colony forming units (CFU) were also low on DAP-treated plots; which could be linked to low soil pH (van Loon et al., 1998; Musyoki et al., 2016). The composts had the advantage of enhancing soil pH; creating alkaline conditions that are favorable for rhizosphere bacteria and fungi (Rousk et al., 2009; Strickland & Rousk, 2010).

5.6 Comparative analysis of nutrient contents in DAP and composts

Diammonium phosphate fertilizer (DAP) contains 18% nitrogen and 46% phosphorus pentoxide (P_2O_5), with phosphorus (P) constituting 20% of the total mass (Naluyange et al., 2016). Hence, DAP plots received approximately 0.94g phosphorus and 0.85g

nitrogen per plant when applied using a leveled teaspoon (~5g) of the fertilizer (Naluyange et al., 2016). DAP therefore was superior in supply of phosphorus per plant (0.94g) compared to the farmer-produced composts that supplied a maximum of 0.68g in CF5. However, DAP supply of nitrogen per plant (0.85g) was intermediate compared to the farmer-produced composts (0.18-1.84g N per plant). However, DAP lacked important additional nutrients such as potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn), which were present in the five farmer-produced composts. This is among benefits of composts compared to DAP and other synthetic fertilizers that have narrow range of nutrient elements (McAndrews et al., 2006; Bedad et al., 2014).

Generally, plots that received DAP fertilizer seemed to exhibit low soil fertility reserves at harvest compared to those that received the farmer-produced composts. This is because at harvest, DAP-treated plots had relatively lower amounts of macro-nutrients (e.g. potassium) and micro-nutrients (e.g. calcium, magnesium, iron, copper, manganese and zinc), when compared to plots that received the farmer-produced compost. Therefore, the composts provide multiple nutrients for better plant growth and yields (Muthaura, 2015). DAP as compared to farmer made composts has high water solubility, thus a quicker N and P uptake or depletion occurs unlike in composts (Edmeades, 2003). Moreover, leaching of N and P in plots treated with DAP could have been higher than in the compost treated plots (Nishanth & Biswas, 2008). Composts have good water holding capacity and slow rate of nutrient release that minimizes leaching (Abdou et al., 2016).

5.7 Summary and Conclusion

The present study aimed at determining the belowground influence of farmer-produced composts on soil biota, foliar pests and yields of common bean *P. vulgaris* in Western Kenya. In the first objective, farmer-produced compost contained a variety of nutrients including N, P, K, Ca, Mg, Fe, Cu, Mn and Zn, which were utilized by bean plants thus promote growth and yields. In the second objective, farmer-produced compost were associated with enhanced colonization of bean roots by beneficial endophytic bacteria like *Rhizobium* species that fixes nitrogen, as well as rhizosphere bacteria and fungi. Farmer-produced compost application was also associated with suppressed nematode populations. In the third objective, farmer-produced compost did not induce variations in bean infestation by foliar pests that included the black bean aphid *A. fabae*, the bean flower thrip *F. occidentalis*, and the fungal anthracnose pathogen *C. lindemuthianum*. Generally, DAP-fertilizer was not beneficial when compared to the controls and the composts; as the bean plants that received DAP exhibited low germination rate, plant size and yields, with lower fungal and bacterial populations including *Rhizobium* nodulation, but exhibited a higher nematode population. Though there was no consistent evidence that the two bean varieties performed differently due to the soil amendments, KK8 bean variety appeared to be inherently superior to Mwezi Moja (GLP 1004) in terms of seed germination percentage, plant size (height, leaf length and width), and number of pods per plant.

In conclusion, trained farmers produced composts that contained important nutrients that were utilized by bean plants to promote growth and yields, while enhancing

endophytic colonization by beneficial *Rhizobium* species, and promoting rhizosphere colonization by bacteria and fungi, but suppressing soil nematode populations. However, the composts did not affect the foliar pest aphids *A. fabae*, thrips *F. occidentalis* and the microbial pathogen *C. lindemuthianum.*

5.8 Knowledge gaps and recommendations for future studies

There are important issues that could not be addressed in the present study, which could form basis for further studies.

1. The present study detected and quantified endophytic and rhizosphere bacteria and fungi, as well as soil nematodes. However, the methods used could not clearly identify these organisms to specific taxa. Future studies could include more accurate organism identification methods, especially by advanced molecular techniques such as High-throughput DNA sequence that have been used in characterizing *Rhizobium* and other bacteria, fungi and nematode species (Rogers & Oldroyd, 2014; Hardoim et al., 2015).

2. Some of the microbes may have been pathogenic; hence the need for further confirmatory studies to ensure proper pathogen eradication so as to avoid the spread of diseases (Noble & Roberts, 2004).

3. The microbial populations were high in compost treatments, while nematode populations were low. Therefore further studies need to be carried out to determine the influence of composts on the relationship between the microbes and nematodes.

4. This study involved training of farmers in producing compost using the conventional backyard composting technique. Although this is quite promising, there are new technologies that could be included in the future farmer trainings, especially

vermicomposting that utilizes various species of worms to break down organic matter

(Fernández et al., 2015; Guo et al., 2015).

REFERENCES

Abdelhamid, M. T., Horiuchi, T., & Oba, S. (2004). Composting of rice straw with oilseed rape cake and poultry manure and its effects on faba bean (*Vicia faba* L.) growth and soil properties.*Bioresource technology*, 93(2), 183-189.

Abdou, G., Ewusi-Mensah, N., Nouri, M., Tetteh, F. M., Safo, E. Y., & Abaidoo, R. C. (2016). Nutrient release patterns of compost and its implication on crop yield under Sahelian conditions of Niger. *Nutrient cycling in agroecosystems*, 105(2), 117-128.

A'brook, J. O. H. N. (1973). The effect of plant spacing on the number of aphids trapped over cocksfoot and kale crops. *Annals of applied biology*, 74(3), 279-285.

Adamu, U. K., Almu, H., Adam, I. A., & Sani, S. A. (2015). Evaluation of nutrient composition of some cereals and legumes crops residues as compost materials. *Bayero Journal of Pure and Applied Sciences*, 7(2), 52-54.

Adeli, A., Sistani, K. R., Rowe, D. E., & Tewolde, H. (2005). Effects of broiler litter on soybean production and soil nitrogen and phosphorus concentrations. *Agronomy Journal*, 97(1), 314-321.

Adesina, G. O., & Akintoye, O. (2011). Effect of water hyacinth and neem based composts on growth, fruit yield and quality of cucumber *(Cucumis sativus). African Journal of Agricultural Research*, 6(31), 6477-6484.

Afzal, A., & Bano, A. (2008). *Rhizobium* and phosphate solubilizing bacteria improve the yield and phosphorus uptake in wheat (*Triticum aestivum*). *International Journal of Agricicultural Biology*, 10(1), 85-88.

Akanbi, W. B., Adebayo, T. A., Togun, O. A., Adeyeye, A. S., & Olaniran, O. A. (2007). The use of compost extract as foliar spray nutrient source and botanical

insecticide in *Telfairia occidentalis*. *World Journal of Agricultural Sciences*, 3(5), 642-652.

Alef, K., & Nannipieri, P. (1995). Methods in applied soil microbiology and biochemistry.Academic Press. London, U.K.

Altieri, M. A., & Nicholls, C. I. (2003). Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. *Soil and Tillage Research*, 72(2), 203-211.

Alverson, D. R., All, J. N., & Matthews, R. W. (1977). Response of leafhoppers and aphids to variously colored sticky traps. *Journal of the Georgia Entomological Society*, *12*(4), 336-341.

Alyokhin, A., & Atlihan, R. (2005). Reduced fitness of the Colorado potato beetle (Coleoptera: Chrysomelidae) on potato plants grown in manure-amended soil. *Environmental entomology*, *34*(4), 963-968.

Amanullah, M. M., Sekar, S., & Muthukrishnan, P. (2010). Prospects and potential of poultry manure. *Asian Journal of Plant Sciences*, 9(4), 172.

Arancon, N. Q., Edwards C. A., Bierman, P. (2006). Influences of vermicomposts on field strawberries; *Bioresource Technology,* 97(6), 831-840.

Awodun, M. A., Omonijo, L. I., & Ojeniyi, S. O. (2007). Effect of goat dung and NPK fertilizer on soil and leaf nutrient content, growth and yield of pepper. *International Journal of Soil Science*, 2(2), 142-147.

Babajide, P. A., Fagbola, O., & Alamu, L. O. (2012). Influence of biofertilizer-fortified oranic and inorganic nitrogenous fertilizers on performance of sesame (*Sesamum indicum* L.) and soil properties under savanna ecoregion. *International Journal of Applied Agriculture & Apiculture Research*, 8(1), 108-116.

Bardgett, R. D., & Chan, K. F. (1999). Experimental evidence that soil fauna enhance nutrient mineralization and plant nutrient uptake in montane grassland ecosystems. *Soil Biology & Biochemistry*, 31(7), 1007-1014.

Bastida, F., Kandeler, E., Moreno, J. L., Ros, M., García, C., & Hernández, T. (2008). Application of fresh and composted organic wastes modifies structure, size and activity of soil microbial community under semiarid climate. *Applied Soil Ecology*, 40(2), 318-329.

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E., & Thiombiano, L. (2006). African soils: their productivity and profitability of fertilizer use. *Proceedings of the African Fertilizer Summit 9th June, 2006*.

Beesley, L., Moreno-Jiménez, E., & Gomez-Eyles, J. L. (2010). Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. *Environmental Pollution*, 158(6), 2282-2287.

Bedada, W., Karltun, E., Lemenih, M., & Tolera, M. (2014). Long-term addition of compost and NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. *Agriculture, Ecosystems & Environment*, 195, 193-201.

Blanc, C., Sy, M., Djigal, D., Brauman, A., Normand, P., & Villenave, C. (2006). Nutrition on bacteria by bacterial-feeding nematodes and consequences on the structure of soil bacterial community. *European Journal of Soil Biology,* 42, S70-S78.

Bernal, M. P., Alburquerque, J. A., & Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. A Review. *Bioresource technology*, 100(22), 5444-5453.

Brear, E. M., Day, D. A., & Smith, P. M. C. (2013). Iron: an essential micronutrient for the legume-*Rhizobium* symbiosis. *Frontiers in plant science*, 4, 359.

Brewbaker, J. L., & Glover, N. (1988). Woody species as green manure crops in rice-based cropping systems. *Sustainable Agriculture; Green Manure in Rice Farming*, 29-44.

Bardgett, R. D., Cook, R., Yeates, G. W., & Denton, C. S. (1999). The influence of nematodes on below-ground processes in grassland ecosystems. *Plant & Soil,* 212(1), 23-33.

Brinton W.F., and Brinton, R.B., (1992). MSW Composting: Old history, new challenges, MSW composting report REV 2.0, *Woods End Research*, Mt Vernon, USA.

Brødsgaard, H. F. (1989). Coloured sticky traps for *Frankliniella occidentalis* (Pergande) (Thysanoptera, Thripidae) in glasshouses. *Journal of Applied Entomology*, 107(1) 136-140.

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., & Herrero, M. (2011). Adapting agriculture to climate change in Kenya: Household and community strategies and determinants. *ILRI report to the World Bank for the Project Adaptation of Smallholder Agriculture to Climate Change in Kenya*. https://www.gwu.edu/~iiep/signatureinitiatives/adaptation/docs/Bryan,%20Adapting%20Agriculture%20to%20Climate%20Change%20in%20Kenya%20Household%20and%20Community.pdf.

Burton, J.C.1985: Legume inoculant production manual. NifTAL Project, Hawaii.

Buruchara, R., Mukankusi, C., & Ampofo, K. (2010). *Bean Disease & Pest Identification & Management: Handbooks for small-scale seed producers* no.04. International Center for Tropical Agriculture (CIAT); Pan-Africa Bean Research Alliance (PABRA), 67 pp

Cai, L., Hyde, K. D., Taylor, P. W. J., Weir, B., Waller, J., Abang, M. M., & Prihastuti, H. (2009). A polyphasic approach for studying *Colletotrichum. Fungal Diversity*, 39(183), 204.

Carrera, L. M., Buyer, J. S., Vinyard, B., Abdul-Baki, A. A., Sikora, L. J., & Teasdale, J. R. (2007). Effects of cover crops, compost, and manure amendments on soil microbial community structure in tomato production systems. *Applied Soil Ecology*, 37(3), 247-255.

Cayuela, M. L., Mondini, C., Insam, H., Sinicco, T., & Franke-Whittle, I. (2009). Plant and animal wastes composting: Effects of the N source on process performance. *Bioresource Technology*, 100(12), 3097-3106.

Chefetz, B., Hatcher, P. G., Hadar, Y., & Chen, Y. (1996). Chemical and biological characterization of organic matter during composting of municipal solid waste. *Journal of Environmental Quality*, 25(4), 776-785.

Chen, J. H. (2006, October). The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. In *International workshop on sustained management of the soil-rhizosphere system for efficient crop production and fertilizer use* (Vol. 16, p. 20). Land Development Department Bangkok, Thailand.

Chiarappa, L. (1974). Possibility of supervised plant disease control in pest management systems. *FAO Plant Protection Bulletin*. http://pdf.usaid.gov/pdf_docs/PNABG722.pdf.

Chowdhury, M. A. H., Kouno, K., Ando, T., & Nagaoka, T. (2000). Microbial biomass, S mineralization and S uptake by African millet from soil amended with various composts. *Soil Biology & Biochemistry*, 32(6), 845-852.

Cooperband, L. (2002). The art and science of composting. *Center for Integrated Agricultural Systems*. http://webcache.googleusercontent.com/search?q= cache:XwKMXMbnQqoJ:www.cias.wisc.edu/wpcontent/uploads/2008/07/artofc ompost.pdf+&cd=1&hl=en&ct=clnk

Courtney, R. G., & Mullen, G. J. (2008). Soil quality and barley growth as influenced by the land application of two compost types. *Bioresource Technology*, 99(8), 2913-2918.

de Araújo, A. S. F., de Melo, W. J., & Singh, R. P. (2009). Municipal solid waste compost amendment in agricultural soil: changes in soil microbial biomass. *Reviews in Environmental Science and Bio/Technology*, 9(1), 41-49.

Dean, J. M., Mescher, M. C., & De Moraes, C. M. (2009). Plant–rhizobia mutualism influences aphid abundance on soybean. Plant and Soil, 323(1-2), 187-196.

Delve, R. & Ramisch, J. (2006). Land Management options in Western Kenya and Eastern Uganda. *Strategies for sustainable land management in the East African Highlands*, 2(7), 319-331.

Diacono, M., & Montemurro, F. (2010).Long-term effects of organic amendments on soil fertility. A review.*Agronomy for Sustainable Development*, 30(2), 401-422.

Diánez, F., Santos, M., Boix, A., De Cara, M., Trillas, I., Avilés, M., & Tello, J. C. (2006). Grape marc compost tea suppressiveness to plant pathogenic fungi: role of siderophores. *Compost Science & Utilization*, *14*(1), 48-53.

Dijkstra, J., Oenema, O., Van Groenigen, J. W., Spek, J. W., Van Vuuren, A. M., & Bannink, A. (2013). Diet effects on urine composition of cattle and N_2O emissions. *Animal*, 7(2), 292-302.

Driessen, P., Deckers, J., Spaargaren, O., & Nachtergaele, F. (2000).*Lecture notes on the major soils of the world* (No. 94). Food and Agriculture Organization (FAO). http://www.fao.org/3/a-y1899e.pdf

Edwards, C. A., Arancon, N. Q., Vasko-Bennett, M., Askar, A., Keeney, G., & Little, B. (2010). Suppression of green peach aphid (*Myzus persicae*)(Sulz.), citrus mealybug (*Planococcus citri*)(Risso), and two spotted spider mite (*Tetranychus urticae*)(Koch.) attacks on tomatoes and cucumbers by aqueous extracts from vermicomposts. *Crop Protection*, 29(1), 80-93.

Edmeades, D. C. (2003). The long-term effects of manures and fertilizers on soil productivity and quality: a review. *Nutrient cycling in Agroecosystems*, 66(2), 165-180.

Egbe, O. M., & Ali, A. (2010). Influence of soil incorporation of common food legume stover on the yield of maize in sandy soils of Moist Savanna Woodland of Nigeria. *Agriculture and Biology Journal of North America*, *1*(2), 156-162.

Elliott, H. A., Brandt, R. C., & O'Connor, G. A. (2005).Runoff phosphorus losses from surface-applied biosolids. *Journal of Environmental Quality*, 34(5), 1632-1639.

Fageria, N. K., Baligar, V. C., & Jones, C. A. (2010). *Growth and mineral nutrition of field crops*. CRC Press.

FAO.(1974). Soil Map of the World 1: 5000000, Vol I, Legend.

Ferguson, B., Lin, M. H., & Gresshoff, P. M. (2013). Regulation of legume nodulation by acidic growth conditions. *Plant signaling & behavior*, 8(3),

Fernández-Gómez, M. J., Nogales, R., Plante, A., Plaza, C., & Fernández, J. M. (2015). Application of a set of complementary techniques to understand how varying the proportion of two wastes affects humic acids produced by vermicomposting. *Waste Management*, 35(1), 81-88.

Foy, C. D. (1984). Physiological effects of hydrogen, aluminum, and manganese toxicities in acid soil. *Soil acidity and liming. American Society of Agronomy*,Inc.,Madison.WI. 57-97.

Frenken, G., Hometz, B., Jaetzold, R., & Willems, W. (1993). Actual landuse advice in marginal areas of SE-Kenya by atmosphere-ocean-teleconnection.*Journal of Agriculture in the Tropics & Subtropics*, 94(1), 3-12.

Gardiner, D. T., & Miller, R. W. (2008). *Soils in our environment*. Upper saddle river, new jersey: Pearson/Prentice Hall.

Gentry, H. S. (1969).Origin of the common bean, *Phaseolus vulgaris. Economic Botany*, 23(1), 55-69.

Ghisalberti, E. L. (2000). *Lantana camara* L.(verbenaceae). *Fitoterapia*, 71(5), 467-486.

Ghorbani, R., Koocheki, A., Jahan, M., & Asadi, G. A. (2008). Impact of organic amendments and compost extracts on tomato production and storability in agroecological systems. *Agronomy for Sustainable Development*, 28(2), 307-311.

Gichuru, M. P., & Kang, B. T. (1989).*Calliandra calothyrsus* (Meissn.) in an alley cropping system with sequentially cropped maize and cowpea in southwestern Nigeria. *Agroforestry Systems*, 9(3), 191-203.

Giller, K. E. (2001).Nitrogen fixation in tropical cropping systems. CABI.

Goyal, S., Dhull, S. K., & Kapoor, K. K. (2005).Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. *Bioresource Technology*, 96(14), 1584-1591.

Graham, P. H., & Rosas, J. C. (1979). Phosphorus fertilization and symbiotic nitrogen fixation in common bean. *Agronomy Journal*, 71(6), 925-926.

Graham, P. H., & Vance, C. P. (2000). Nitrogen fixation in perspective: an overview of research and extension needs. Field Crops Research, 65(2), 93-106.

Gunnarsson, C. C., & Petersen, C. M. (2007). Water hyacinths as a resource in agriculture and energy production: A literature review. *Waste Management*, 27(1), 117-129.

Guo, L., Wu, G., Li, C., Liu, W., Yu, X., Cheng, D., & Jiang, G. (2015). Vermicomposting with maize increases agricultural benefits by 304%. *Agronomy for sustainable development*, 35(3), 1149-1155.

Gupta, P., Roy, S., & Mahindrakar, A. B. (2012). Treatment of water using water hyacinth, water lettuce and vetiver Grass-A review. *Resources and Environment*, *2*(5), 202-215.

Gupta, K. K., Aneja, K. R., & Rana, D. (2016). Current status of cow dung as a bioresource for sustainable development. *Bioresources & Bioprocessing,* 3(1), 28.

Hagedorn, D. J., & Inglis, D. A. (1986). *Handbook of Bean Diseases* (p. 24). University Wisconsin-Madison Extension Bulletin A3374.

Hanč, A., Tlustoš, P., Száková, J., & Balík, J. (2008).The influence of organic fertilizers application on phosphorus and potassium bioavailability.*Plant Soil & Environment*, *54*(6), 247.

Hardoim, P. R., Van Overbeek, L. S., Berg, G., Pirttilä, A. M., Compant, S., Campisano, A., & Sessitsch, A. (2015). The hidden world within plants: ecological and evolutionary considerations for defining functioning of microbial endophytes. *Microbiology and Molecular Biology Reviews*, 79(3), 293-320.

Hartemink, A. E. (2006). Assessing soil fertility decline in the tropics using soil chemical data. *Advances in Agronomy*, 89(1), 179-225.

Hassanein, M. K., & Abul-Soud, M. (2010). Effect of different compost types and application methods on growth and yield of three maize hybrids. *Journal of Applied Sciences Research*, 6(9), 1387-1399.

Haug, R.T., 1993. *The Principal Handbook of Compost Engineering*. Lewis Publishers, Boca Raton, FL, USA.

He, Z., Yang, X., Kahn, B. A., Stoffella, P. J., & Calvert, D. V. (2001). Plant nutrition benefits of phosphorus, potassium, calcium, magnesium, and micronutrients from compost utilization. *Compost utilization in horticultural cropping systems. Boca Raton (FL): CRC Press LLC. p*, 307-320.

Hein, I. (1930). Soy-bean stover compost for mushroom culture. *Mycologia*, 22(5), 227-231.

Heineman, A. M., Otieno, H. J. O., Mengich, E. K., & Amadalo, B. A. (1997). Growth and yield of eight agroforestry tree species in line plantings in Western Kenya and their effect on maize yields and soil properties. *Forest Ecology & Management*, 91(1), 103-135.

Herigstad, B., Hamilton, M., & Heersink, J. (2001).How to optimize the drop plate method for enumerating bacteria. *Journal of Microbiological Methods*, *44*(2), 121-129.

Hoitink, H. & Boehm, M. (1999). Biocontrol within the context of soil microbial communities: asubstrate-dependent phenomenon. *Annual Review of Phytopathology,* 37(1), 427-446.

Hooper, D. J., Hallmann, J., & Subbotin, S. A. (2005). Methods for extraction, processing and detection of plant and soil nematodes. *Plant Parasitic Nematodes in Subtropical and Tropical Agriculture*, (3)*2*, 53-86.

Hungria, M., Campo, R. J., & Mendes, I. C. (2003).Benefits of inoculation of the common bean (Phaseolus vulgaris) crop with efficient and competitive *Rhizobium tropici* strains. *Biology & Fertility of Soils,* 39(2), 88-93.

Hunt, P. G., Hortenstine, C. C., & Smart, G. C. (1973). Responses of plant parasitic and saprophytic nematode populations to composted municipal refuse. *Journal of Environmental Quality*, 2(2), 264-266.

Hussey, N. T., & Bravenboer, L. (1971). Control of pests in glasshouse culture by the introduction of natural enemies. In *Biological control* (pp. 195-216). Springer, Boston, MA.

Imbeah, M. (1998).Composting piggery waste: a review. *Bioresource Technology*, 63(3), 197-203.

Iren, O. B., Akpan, J. F., Ediene, V. F., & Asanga, E. E. (2015). Influence of cassava peels and poultry manure-based compost on soil properties, growth and yield of waterleaf (*Talinum triangulare* Jacq) in an ultisol of south-eastern Nigeria. *Journal of Soil Science & Environmental Management*, 6(7), 187-194.

ISRIC. (2014). http://www.isric.org/projects/soter-kenya-kensoter. Consulted on May 28th 2016.

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C. (2007). Farm management handbook of Kenya-Natural conditions and farm management information-Part A Western Kenya Subpart A1 western province, edn. *Ministry of Agriculture, Kenya, in cooperation with the German Agricultural Team (GAT) of the German Agency for technical Cooperation (GTZ), Nairobi, Kenya*.

Jama, B., Palm, C. A., Buresh, R. J., Niang, A., Gachengo, C., Nziguheba, G., & Amadalo, B. (2000).*Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: a review. *Agroforestry Systems*, 49(2), 201-221.

Jamleck, M., John, M., John, M., Lagerlöf, J., & JK, M. A. (2012). Effect of Integrated Soil Fertility Management Interventions on the abundance and diversity of soil collembola in Embu and Taita Districts, Kenya.

Jorge-Mustonen, P. S., Oelbermann, M., & Kass, D. C. (2013). Production of Phaseolus vulgaris L. Genotypes with Tithonia diversifolia (Hemsl.) Gray and Cajanus cajan (L.) Millsp. *Agronomy*, *3*(1), 232-247.

Kabir, E., Bell, R.W. and Johansen, C. 2010. Triple superphosphate placement affects early growth of chickpea. *19th World Congress of Soil Science, Soil Solutions fora Changing World*. Brisbane, Australia. pp. 276-279.

Kamau, M., Smale, M., & Mutua, M. (2014). Farmer demand for soil fertility management practices in Kenya's grain basket. *Food Security*, 6(6), 793-806.

Kamoni, P. T. (1988). Nature and importance of soil-related constraints to bean production in Kenya. In *PROCEEDINGS OF A WORKSHOP ON* (p. 183).

Karthikeyan, M., Hussain, N., Gajalakshmi, S., & Abbasi, S. A. (2014). Effect of vermicast generated from an allelopathic weed lantana (*Lantana camara*) on seed germination, plant growth, and yield of cluster bean (*Cyamopsis tetragonoloba*). *Environmental Science & Pollution Research*, 21(21), 12539-12548.

Kearsey, A. J. (2011). Impact of management practices on soil microflora: implications for subsequent effects on plants and insects.Thesis, New Castle University, UK.https: // theses.ncl.ac.uk/dspace/ bitstream/ 10443/1362/1/ Kearsey%2011%20(12% 20mths).

Kerry, B. R. (2000). Rhizosphere interactions and the exploitation of microbial agents for the biological control of plant-parasitic nematodes. *Annual Review of phytopathology,* 38(1), 423-441.

Kimpinski, J., Gallant, C. E., Henry, R., Macleod, J. A., Sanderson, J. B., & Sturz, A. V. (2003). Effect of compost and manure soil amendments on nematodes and on yields of potato and barley: A 7-year study. *Journal of Nematology*, 35(3), 289-293.

Kisinyo, P. O., Gudu, S. O., Othieno, C. O., Okalebo, J. R., Opala, P. A., Maghanga, J. K., & Nekesa, A. O. (2012). Effects of lime, phosphorus and rhizobia on *Sesbania sesban* performance in a Western Kenyan acid soil. *African Journal of Agricultural Research*, 7(18), 2800-2809.

Kisinyo, P. O., Othieno, C. O., Gudu, S. O., Okalebo, J. R., Opala, P. A., Maghanga, J. K.,& Ogola, B. O. (2013). Phosphorus sorption and lime requirements of maize growing acid soils of Kenya. *Sustainable Agriculture Research*, 2(2), 116.

Korayem, A.M., 2003, Effect of some organic wastes on *Meloidogyneincognita* development and tomato tolerance to the nematode. Egypt. Journal of Phytopathology 31(2), 119-127.

Kostov, O., & Lynch J., M. (1998). Composted sawdust as a carrier for BradyRhizobium, *Rhizobium Azospirillum* in crop inoculation. *World Journal of Microbiology Biotechnology,* 14(3), 389-397.

Kowaljow, E., & Mazzarino, M. J. (2007). Soil restoration in semiarid Patagonia: Chemical and biological response to different compost quality. *Soil Biology & Biochemistry*, 39(7), 1580-1588.

Kranz, J. (1988). Measuring plant disease. *Experimental techniques in plant disease epidemiology* (pp. 35-50). Springer Berlin Heidelberg.

Krell, F. T., Chung, A. Y., DeBoise, E., Eggleton, P., Giusti, A., Inward, K., & Krell-Westerwalbesloh, S. (2005). Quantitative extraction of macro-invertebrates from temperate and tropical leaf litter and soil: efficiency and time-dependent taxonomic biases of the Winkler extraction. *Pedobiologia*, 49(2), 175-186.

Kruger, I., Taylor, G., & Ferrier, M. (1995). Australian pig housing series: effluent at work. *NSW Agriculture: Tamworth*.

Kulkarni, K. R., & Pandey, R. K. (1988).Annual legumes for food and as green manure in a rice-based cropping system. *Sustainable Agriculture: Green Manure in Rice Farming*, 289-299.

Lazcano, C., Revilla, P., Malvar, R. A., & Domínguez, J. (2011). Yield and fruit quality of four sweet corn hybrids (*Zea mays*) under conventional and integrated fertilization with vermicompost. *Journal of the Science of Food and Agriculture*, 91(7), 1244-1253.

Lekasi, J. K., Tanner, J. C., Kimani, S. K., & Harris, P. J. C. (2003). Cattle manure quality in Maragua District, Central Kenya: effect of management practices and development of simple methods of assessment. *Agriculture, Ecosystems & Environment*, 94(3), 289-298.

Loper, J. E., Suslow, T. V., & Schroth, M. N. (1984).Lognormal distribution of bacterial populations in the rhizosphere. *Phytopathology,* 74(12), 1454-1460.

Lo, K. V., Lau, A. K., & Liao, P. H. (1993). Composting of separated solid swine wastes.*Journal of Agricultural Engineering Research*, *54*(4), 307-317.

Lozano, J. O. S. E., & Smant, G. E. E. R. T. (2011). Survival of plant-parasitic nematodes inside the host. *Molecular & Physiological Basis of Nematode Survival. Oxfordshire: CABI*, 28-62.

ltieri, M. A., & Nicholls, C. I. (2003). Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. *Soil & Tillage Research*, *72*(2), 203-211.

Maheshwari, D. K., Kumar, S., Kumar, B., & Pandey, P. (2010). Co-inoculation of urea and DAP tolerant *Sinorhizobium meliloti* and *Pseudomonas aeruginosa* as integrated approach for growth enhancement of *Brassica juncea. Indian journal of microbiology*, 50(4), 425-431.

Manaf, L. A., Jusoh, M. L. C., Yusoff, M. K., Ismail, T. H. T., Harun, R., Juahir, H., & Jusoff, K. (2009). Influences of bedding material in vermicomposting process. *International Journal of Biology*, 1(1), 81.

Manyi-Loh, C. E., Mamphweli, S. N., Meyer, E. L., Makaka, G., Simon, M., & Okoh, A. I. (2016). An Overview of the Control of Bacterial Pathogens in Cattle Manure. *International Journal of environmental research & public health*, 13(9), 843.

Manivannan, S., Balamurugan, M., Parthasarathi, K., Gunasekaran, G., & Ranganathan, L. S. (2009).Effect of vermicompost on soil fertility and crop productivity-beans (*Phaseolus vulgaris*). *Journal of Environmental Biology*, 30(20), 275-281.

Marenya, P. P., & Barrett, C. B. (2009). Soil quality and fertilizer use rates among smallholder farmers in western Kenya. *Agricultural Economics*, 40(5), 561-572.

Marschner, H. (1991). Mechanisms of adaptation of plants to acid soils. In *Plant-Soil interactions at low pH* (pp. 683-702). Springer Netherlands.

Masago, H., Yoshikawa, M., Fukada, M., & Nakanishi, N. (1977).Selective inhibition of *Pythium* spp. on a medium for direct isolation of *Phytophthora* spp. from soils and plants. *Phytopathology*, 67(3), 425-428.

Mbau, S. K., Karanja, N., & Ayuke, F. (2015). Short-term influence of compost application on maize yield, soil macrofauna diversity and abundance in nutrient deficient soils of Kakamega County, Kenya. *Plant & Soil*, 387(1), 379-394.

McAndrews, G. M., Liebman, M., Cambardella, C. A., & Richard, T. L. (2006). Residual Effects of Composted and Fresh Solid Swine (L.) Manure on Soybean [(L.) Merr.] Growth and Yield. *Agronomy journal*, 98(4), 873-882.

McInnes, A., Thies, J. E., Abbott, L. K., & Howieson, J. G. (2004). Structure and diversity among rhizobial strains, populations and communities–a review. *Soil Biology & Biochemistry,* 36(8), 1295-1308.

McSorley, R., & Walter, D. E. (1991). Comparison of soil extraction methods for nematodes and microarthropods. *Agriculture, Ecosystems & Environment,* 34(1-4), 201-207.

Mehta, P., Walia, A., Chauhan, A., & Shirkot, C. K. (2013). Plant growth promoting traits of phosphate-solubilizing rhizobacteria isolated from apple trees in trans Himalayan region of Himachal Pradesh. *Archives of microbiology*, 195(5), 357-369.

Misselbrook, T. H., Powell, J. M., Broderick, G. A., & Grabber, J. H. (2005). Dietary manipulation in dairy cattle: Laboratory experiments to assess the influence on ammonia emissions. *Journal of dairy science,* 88(5), 1765-1777.

Misra, R. V., Roy, R. N., & Hiraoka, H. (2016). *On-farm composting methods*. Rome, Italy: UN-FAO.

Mkwambizi, D. D., Fraser, E. D., & Dougill, A. J. (2011). Urban agriculture and poverty reduction: evaluating how food production in cities contributes to food security, employment and income in Malawi. *Journal of International Development*, 23(2), 181-203.

Mochiah, M. B., Baidoo, P. K., & Owusu-Akyaw, M. (2011). Influence of different nutrient applications on insect populations and damage to cabbage. *Journal of Applied Biosciences*, 38(1), 2564-2572.

Muchane, M. N., Jama, B., Othieno, C., Okalebo, R., Odee, D., Machua, J., & Jansa, J. (2010). Influence of improved fallow systems and phosphorus application on

arbuscular mycorrhizal fungi symbiosis in maize grown in western Kenya. *Agroforestry Systems*, 78(2), 139-150.

Muchena, F. N., Onduru, D. D., Gachini, G. N., & De Jager, A. (2005). Turning the tides of soil degradation in Africa: capturing the reality and exploring opportunities. *Land Use Policy*, 22(1), 23-31.

Mucheru-Muna, M., Mugendi, D., Pypers, P., Mugwe, J., Kung'u, J., Vanlauwe, B., & Merckx, R. (2014).Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in central Kenya small-hold farms. *Experimental Agriculture*, 50(2), 250-269.

Mukunya, D. M., & Keya, S. O. (1978). Yield Performance and selection for resistance in beans (*Phaseolus vulgaris* L.) to common diseases in Kenya. *East African Agricultural & Forestry Journal*, 43(4), 390-396.

Mungai, N. W., & N. M. Karubiu. (2011). Effectiveness of rhizobia isolates from Njoro soils (Kenya) and commercial inoculants in nodulation of common beans (*Phaseolus vulgaris*). *Journal of Agriculture, Science &Technology,* 12(1), 32-45.

Musyoki, M. K., Cadisch, G., Zimmermann, J., Wainwright, H., Beed, F., & Rasche, F. (2016). Soil properties, seasonality and crop growth stage exert a stronger effect on rhizosphere prokaryotes than the fungal biocontrol agent *Fusarium oxysporum* f. sp. *strigae. Applied Soil Ecology*, 105, 126-136.

Muthaura, C. (2015). *Effects of selected limiting nutrients on growth and yield of maize and their variability in smallholder farms of Kandara, Murang'a County* (Doctoral dissertation, Kenyatta University).

Muthini, M., Maingi, J. M., Muoma, J. O., Amoding, A., Mukaminega, D., Osoro, N., & Ombori, O. (2014). Morphological assessment and effectiveness of indigenous rhizobia isolates that nodulate *Phaseolus vulgaris* in water hyacinth compost testing field in Lake Victoria Basin. *British Journal of Applied Science & Technology*, 4(5), 718.

Muthomi, J. W., I. K. Mugambi, J. Ojiem, G. N. Chemining'wa, & J. H. Nderitu. (2014). Effect of incorporating lablab biomass in soils on root rot disease complex and yield of beans intercropped with maize. *International Journal of AgriScience* 4 (12), 515-524.

Nahar, M. S., Grewal, P. S., Miller, S. A., Stinner, D., Stinner, B. R., Kleinhenz, M. D., ... & Doohan, D. (2006). Differential effects of raw and composted manure on nematode community, and its indicative value for soil microbial, physical and chemical properties. *Applied Soil Ecology,* 34(2), 140-151.

Naluyange, V., Ochieno, D. M., Maingi, J. M., Ombori, O., Mukaminega, D., Amoding, A., & Muoma, J. V. (2014). Compatibility of *Rhizobium* inoculant and water hyacinth compost formulations in Rosecoco bean and consequences on *Aphis fabae* and *Colletotrichum lindemuthianum* infestations. *Applied Soil Ecology*, *76*, 68-77.

Naluyange, V., Ochieno, D. M., Wandahwa, P., Odendo, M., Maingi, J. M., Amoding, A., & Muoma, J. (2016). Belowground influence of Rhizobium inoculant and water hyacinth composts on yellow bean infested by *Aphis fabae* and *Colletotrichum lindemuthianum* under field conditions. *Journal of Plant Studies*, *5*(2), 32.

Ngome, A. F. E., Becker, M., & Mtei, K. M. (2012). Leguminous cover crops differentially affect maize yields in three contrasting soil types of Kakamega, Western Kenya. *Journal of Agriculture and Rural Development in the Tropics &Subtropics*, 112(1), 1-10.

Nico, A. I., Jiménez-Dí az, R. M., & Castillo, P. (2004). Control of root-knot nematodes by composted agro-industrial wastes in potting mixtures. *Crop Protection*, *23*(7), 581-587.

Nishanth, D., & Biswas, D. R. (2008). Kinetics of phosphorus and potassium release from rock phosphate and waste mica enriched compost and their effect on yield and nutrient uptake by wheat (*Triticum aestivum*). *Bioresource technology*, 99(9), 3342-3353.

Noble, R., & Roberts, S. J. (2004). Eradication of plant pathogens and nematodes during composting: a review. *Plant pathology*, 53(5), 548-568.

Nonaka, K., Todaka, N., Ōmura, S., & Masuma, R. (2014). Combination cellulose plate (non-agar solid support) and agar plate method improves isolation of fungi from soil. *The Journal of Antibiotics*, 67(11), 755-761.

Nunes, W. A. G. D. A., Menezes, J. F. S., Benites, V. D. M., Lima Junior, S. A. D., & Oliveira, A. D. S. (2015). Use of organic compost produced from slaughterhouse waste as fertilizer in soybean and corn crops. *Scientia Agricola*, 72(4), 343-350.

Obura, P., Schulze, D., Okalebo, J., Othieno, C., Johnston, C., & Gilkes, R. J. (2010, August). Characterization of selected Kenyan acid soils. In *2010 19th World congress of soil science, soil solutions for a changing world* (pp. 1-6).

Ochieno, D. M. (2010).Endophytic control of *Cosmopolites sordidus* and *Radopholus similis* using *Fusarium oxysporum* V5w2 in tissue culture banana. Doctoral thesis and propositions, Wageningen University and Research Centre, The Netherlands.

Odendo, M., De Groote, H., & Odongo, O. M. (2001).Assessment of farmers' preferences and constraints to maize production in moist midaltitude zone of Western Kenya.In *5th International Conference of the African Crop Science Society, Lagos, Nigeria October* (Vol. 2126, p. 2001).

Oka, Y. (2010). Mechanisms of nematode suppression by organic soil amendments-a review. *Applied Soil Ecology,* 44(2), 101-115.

Olabode, O. S., Ogunyemi, S., Akanbi, W. B., Adesina, G. O., & Babajide, P. A. (2007). Evaluation of *Tithonia diversifolia* (Hemsl.): A gray for soil improvement. *World Journal of Agricultural Sciences*, 3(4), 503-507.

Ortiz-Castro, R., Díaz-Pérez, C., Martínez-Trujillo, M., Rosa, E., Campos-García, J., & López-Bucio, J. (2011). Transkingdom signaling based on bacterial cyclodipeptides with auxin activity in plants. *Proceedings of the National Academy of Sciences*, 108(17), 7253-7258.

Osama, T.S., (2013). Utilization of water hyacinth and banana wastes compost in reclamation of sandy soils for increasing growth, yield of cowpea. *Journal of Advanced Laboratory Research in Biology*, 4(1), 36-45.

Ouédraogo, E., Mando, A., & Zombré, N. P. (2001).Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa.*Agriculture, Ecosystems & Environment*, 84(3), 259-266.

Padmavathy N & Vijayaraghavan R (2008) Enhanced bioactivity of ZnO nanoparticles-an antimicrobial study. *Science & Technology of Advanced Materials* 9(3), 1–7.

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G., & Giller, K. E. (2001). Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems & Environment*, 83(1), 27-42.

Peter, J., Young, W., & Haukka, K., E. (1996). Diversity and phylogeny of rhizobia. *New Phytologist,* 133(1), 87-94.

Powell, J. M. (2014). Feed and manure use in low-N-input and high-N-input dairy cattle production systems. *Environmental Research Letters*, 9(11), 115004.

Raaijmakers, J. M., Paulitz, T. C., Steinberg, C., Alabouvette, C., & Moënne-Loccoz, Y. (2009). The rhizosphere: a playground and battlefield for soilborne pathogens and beneficial microorganisms. *Plant & Soil*, 321(1-2), 341-361.

Ramaswamy, P. P. (1999). Recycling of agricultural and agro-industry waste for sustainable agricultural production. *Jounal of Indian Society in Soil Sci*ence, 47(4), 661-665.

Rao, J. R., Watabe, M., Stewart, T. A., Millar, B. C., & Moore, J. E. (2007). Pelleted organo-mineral fertilizers from composted pig slurry solids, animal wastes and spent mushroom compost for amenity grasslands. *Waste Management*, 27(9), 1117-1128.

Remigi, P., Zhu, J., Young, J. P. W., & Masson-Boivin, C. (2016). Symbiosis within symbiosis: evolving nitrogen-fixing legume symbionts. *Trends in microbiology,* 24(1), 63-75.

Regenstein, J. M., Kay, D., Turci, P., & Outerbridge, T. (1999). Small to medium scale composting of food wastes in New York City. *Cornell University, Ithica, NY, USA*.http://compost.css.cornell.edu/NYCComposting.pdf.

Rogers, C., & Oldroyd, G. E. (2014). Synthetic biology approaches to engineering the nitrogen symbiosis in cereals. *Journal of experimental botany*, 65(8),1939-1946.

Rota, J. A., Wandahwa, P., & Sigunga, D. O. (2006). Land evaluation for soybean (*Glycine max* L. Merrill) production based on kriging soil and climate parameters for the Kakamega district, Kenya. *Journal of Agronomy,* 5, 142-150. http://dx.doi.org/10.3923/ja.2006.142.150.

Rousk, J., Brookes, P. C., & Bååth, E. (2009). Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Applied & Environmental Microbiology*, 75(6), 1589-1596.

Sabbe, W. E., & Marx, D. B. (1987). Soil sampling: spatial and temporal variability. Soil testing: Sampling, correlation, calibration, and interpretation, (soil testing sampl),

114.https://dl.sciencesocieties.org/publications/books/abstracts/sssaspecialpubl/soiltestingsamp/1.

Saeed, A., Sayyed, A. H., Safdar, S., & Manzoor, S. (2015). Reduction in animal waste.*The Role of Biotechnology in Improvement of Livestock* (pp. 111-134). Springer Berlin Heidelberg.

Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science*, 295(5562), 2019-2020.

Sanchez, P. A., & Swaminathan, M. S. (2005). Hunger in Africa: the link between unhealthy people and unhealthy soils. *The Lancet*, 365(9457), 442-444.

Sánchez-Bascones, M., Díez-Gutiérrez, M. A., Hernández-Navarro, S., Corrêa-Guimarães, A., Navas-Gracia, L. M., & Martín-Gil, J. (2008) Use of potato peelings in composting techniques: A high-priority and low-cost alternative for environmental remediation., Thesis. University of Valladolid, Avenida de Madrid 44, 34004 - Palencia, Spain.

Schloter, M., Dilly, O., & Munch, J. C. (2003).Indicators for evaluating soil quality.*Agriculture, Ecosystems & Environment*, 98(1), 255-262.

Schnier, H. F., Recke, H., Muchena, F. N., & Muriuki, A. W. (1996). Towards a practical approach to fertilizer recommendations for food crop production in smallholder farms in Kenya. *Nutrient Cycling in Agroecosystems*, *47*(3), 213-226.

Selim, S., Zayed, M. S., & Atta, H. M. (2012).Evaluation of phytotoxicity of compost during composting process.*Nature and Science*, *10*(2), 69-77.

Senesi, N. (1989). Composted materials as organic fertilizers. *Science of the Total Environment*, 81(1), 521-542.

Shabbir, A., & Bajwa, R. (2006).Distribution of parthenium weed (*Parthenium hysterophorus* L.), an alien invasive weed species threatening the biodiversity of Islamabad.*Weed Biology & Management*, 6(2), 89-95.

Shahzad, S. M., Khalid, A., Arif, M. S., Riaz, M., Ashraf, M., Iqbal, Z., & Yasmeen, T. (2014). Co-inoculation integrated with P-enriched compost improved nodulation and growth of Chickpea (*Cicer arietinum* L.) under irrigated and rainfed farming systems. *Biology & fertility of soils,* 50(1), 1-12.

Shahzad, S. M., Khalid, A., Arshad, M., Khalid, M., & Mehboob, I. (2008).Integrated use of plant growth promoting bacteria and P-enriched compost for improving growth, yield and nodulation of chickpea. *Pakistan Journal of Botany*, 40(4), 1735-1741.

Sannigrahi, A. K., Chakrabortty, S., & Borah, B. C. (2002). Large scale utilization of water hyacinth (Eichhornia crassipes) as raw material for vermi composting and surface mulching in vegetable cultivation. *Ecology Environment and Conservation*, *8*, 269-271.

Sharma, V., Pandher, J. K., & Kanwar, K. (2008). Biomanagement of lantana (*Lantana camara* L.) and congress grass (*Parthenium hysterophorus* L.) through vermicomposting and its response on soil fertility. *Indian Journal of Agricultural Research*, 42(4), 283-287.

Shen, Q. R., & Shen, Z. G. (2001).Effects of pig manure and wheat straw on growth of mung bean seedlings grown in aluminium toxicity soil. *Bioresource Technology*, 76(3), 235-240.

Sikora, L. J., & Szmidt, R. A. (2001). Nitrogen sources, mineralization rates, and nitrogen nutrition benefits to plants from composts. *Compost utilization in horticultural cropping systems. CRC Press, Boca Raton, FL*, 287-305.

Singh, K. B., & Saxena, M. C. (Eds.). (1993). *Breeding for stress tolerance in cool-season food legumes* (p. 474). Chichester, UK: Wiley.

Smith, D. B. (2012).*A 2012 survey and economic assessment of composting and anaerobic digestion options for Miami University* (Doctoral dissertation, Miami University). USA.

Somasegaran, P., & Hoben, H. J. (1985). *Methods in legume-Rhizobium technology* (p. 365). Paia, Maui: University of Hawaii NifTAL Project and MIRCEN, Department of Agronomy and Soil Science, Hawaii Institute of Tropical Agriculture and Human Resources, College of Tropical Agriculture and Human Resources.

Starbuck, C. J., & Ornamentals, W. (2010).Making and Using Compost.University of Wisconsin-Extension. USA.https://counties.uwex.edu/kenosha/files/2010 /07/2D-Compost.pdf.

Stefanowicz, A. M., Niklińska, M., & Laskowski, R. (2008). Metals affect soil bacterial and fungal functional diversity differently. *Environmental Toxicology & Chemistry*, 27(3), 591-598.

Stirling, C.R., 1991, Biological control of plant parasitic nematodes. Progress, Problems and Prospects. CAB International, Wallingford, Oxon, UK., pp: 282.

Strickland, M. S., & Rousk, J. (2010). Considering fungal: bacterial dominance in soils–methods, controls, and ecosystem implications. *Soil Biology & Biochemistry*, *42*(9), 1385-1395.

Sutton, C. (2015). *Impact of Management on Soil Fertility and Rice Yields in Smallholder Farms in Tanzania* (Doctoral dissertation, The Ohio State University).

Tejada, M., Gonzalez, J. L., García-Martínez, A. M., & Parrado, J. (2008).Effects of different green manures on soil biological properties and maize yield. *Bioresource Technology*, 99(6), 1758-1767.

Thrall, P. H., Burdon, J. J., & Woods, M. J. (2000). Variation in the effectiveness of symbiotic associations between native rhizobia and temperate Australian

legumes: interactions within and between genera. *Journal of Applied Ecology,* 37(1), 52-65.

Tian, G. (1998). Effect of soil degradation on leaf decomposition and nutrient release under humid tropical conditions. *Soil Science*, 163(11), 897-906.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. & Havlin, J. L. (1985). Soil fertility (5th ed.). Macmillan Publishing Company. USA.

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Shepherd, K. D., & Giller, K. E. (2005).Exploring diversity in soil fertility management of smallholder farms in western Kenya: II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture, Ecosystems & Environment*, 110(3), 166-184.

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Shepherd, K. D., & Giller, K. E. (2005).Exploring diversity in soil fertility management of smallholder farms in western Kenya: II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture, Ecosystems & Environment*, *110*(3), 166-184.

Tittonell, P., Shepherd, K. D., Vanlauwe, B., & Giller, K. E. (2008). Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya-An application of classification and regression tree analysis. *Agriculture, ecosystems & environment*, 123(1), 137-150.

Tripathi, G., & Bhardwaj. P. (2004). Comparative studies on biomass production, life cycles composting effi ciency of *Eisenia fetida* (Savigny) *Lampito mauritii* (Kinberg). *Bioresource technology, 92*(3) 275-28.

Ubalua, A. O. (2007). Cassava wastes: treatment options and value addition alternatives. *African Journal of Biotechnology*, 6(18), 2065-2073.

van Haute, J. (2014). Evaluation of the effects of compost on soil properties, performance and yield of maize and beans in Kenya (*MSc. Thesis* Gent University) Belgium.http://lib.ugent.be/fulltxt/RUG01/002/166/414/RUG01-002166414_2014_0001_AC.pdf.

van Loon, L. C., Bakker, P. A. H. M., & Pieterse, C. M. J. (1998). Systemic resistance induced by rhizosphere bacteria. *Annual Review of phytopathology*, 36(1), 453-483.

van Soest, P. J. (1994). *Nutritional ecology of the ruminant.* Cornell University Press.

Vassileva, V., Milanov, G., Ignatov, G., & Nikolov, B. (1997). Effect of low pH on nitrogen fixation of common bean grown at various calcium and nitrate levels. *Journal of Plant Nutrition*, 20(2-3), 279-294.

Viglierchio, D. R., & Schmitt, R. V. (1983). On the methodology of nematode extraction from field samples: Baermann funnel modifications. *Journal of Nematology*, 15(3), 438.

Wagara, N., Mwang'ombe, A. W., Kimenju, J. W., Buruchara, R. A., & Kimani, P. M. (2003). Pathogenic variability in *Phaeoisariopsis griseola* and response of bean germplasm to different races of the pathogen. *African Crop Science Journal Society*, 6(1), 352-357.

Wallace, A. (1980). Effect of excess chelating agent on micronutrient concentrations in bush beans grown in solution culture. *Journal of Plant Nutrition,* 2(1-2), 163-170.

Warncke, D. D., Dahl, J., Jacobs, L., & Laboski, C. (2009). *Nutrient recommendations for field crops in Michigan*. Michigan State University Extension.

Wong, M. H. (1985). Phytotoxicity of refuse compost during the process of maturation. *Environmental Pollution Series A, Ecological & Biological*, 37(2), 159-174.

Woomer P. L., Karanja N., Kisamuli S. M., Murwira M., Bala A. (2011). A Revised Manual for Rhizobium Methods and Standard Protocols. Available at: www.N2Africa.org [accessed April 18 2015]

Wortmann, C. S., Kirkby, R. A., Aledu, C. A. & Allen, J. D. (1998). Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa, CIAT Cali, Colombia.

Wu, T., Chellemi, D. O., Graham, J. H., Martin, K. J., & Rosskopf, E. N. (2008). Comparison of soil bacterial communities under diverse agricultural land management and crop production practices. *Microbial Ecology,* 55(2), 293-310.

Yagoub, S. O., Ahmed, W. M. A., & Mariod, A. A. (2012). Effect of urea, NPK and compost on growth and yield of soybean (*Glycine max* L.), in semi-arid region of Sudan. ISRN Agronomy, 2012.

Young, B. J., Rizzo, P. F., Riera, N. I., Della Torre, V., López, V. A., Molina, C. D., & Sánchez, A. (2016). Development of phytotoxicity indexes and their correlation with ecotoxicological, stability and physicochemical parameters during passive composting of poultry manure. *Waste Management*.54(1), 101-109

Zahran, H. H. (1999). Rhizobium-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. *Microbiology & molecular biology Reviews,* 63(4), 968-989.

Zayed, G., & Abdel-Motaal, H. (2005). Bio-active composts from rice straw enriched with rock phosphate and their effect on the phosphorus nutrition and microbial community in rhizosphere of cowpea. *Bioresource Technology*, 96(8), 929-935.

Zehnder, G., G. M. Gurr, S. Kühne, M. R. Wade, S. D. Wratten, & E. Wyss. (2007). Arthropod management in organic crops. *Annual Review of Entomology,* 5 (2), 57–80.

Zendejas, H. S. L., Oba, M. S., Oba, A. S., Gallegos, E. G., & Estrada, J. L. G. (2015). A bioeconomic approach for the production of biofertilizers and their influence on faba bean (*Vicia faba* L) productivity. *Journal of Natural Sciences*, 3(2), 75-91.

Zhen, Z., Liu, H., Wang, N., Guo, L., Meng, J., Ding, N., & Jiang, G. (2014). Effects of manure compost application on soil microbial community diversity and soil microenvironments in a temperate cropland in China. *PloS one, 9(10),* e108555.