TOWARDS OPTIMIZING COFFEE-BANANA AGRO-FORESTRY CROPPING SYSTEMS FOR MANAGEMENT OF BIOTIC STRESSES IN MID-EASTERN COFFEE GROWING REGION OF UGANDA.

A POSTGRADUATE DISSERTATION PRESENTED TO THE FACULTY OF AGRICULTURE IN PARTIAL FULFILLMENT OF THE AWARD OF MASTER OF SCIENCE IN AGROECOLOGY.

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DEDICATION

I dedicate this report to my mum Miss TUSIIME GERTRUDE who has been by my side throughout my studies. She has always been with me through thick and thin and has never deserted me.

May the almighty God bless her and the works of her hands.

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ACRONYMS

Mg- Milligrams

Ha- Hectare

Yr- Year

FW- Fresh Weight

Kg- Kilogram

NARO- National Agricultural Research Organization

UCDA- Uganda Coffee Development Authority

IITA- International Institute for Tropical Agriculture

CIAT- International Center for Tropical Agriculture

ABSTRACT

This study aimed at (i) assessing farmers' knowledge and their coping mechanisms in managing the biotic constraints, (ii) identifying the biotic constraints within coffee-banana agro-forestry systems in the Mid-eastern region of Uganda, and (iii) determining the key biotic factors most related to coffee and banana yield losses. This information will provide a basis for recommendations for managing the major biotic factors in coffee-banana agro-forestry systems in Mid-eastern region of Uganda. A survey employing a questionnaire and biological data collection tool was conducted on 70 randomly selected farmers in the Mid-eastern coffee-banana agro-forestry systems of Uganda. Respondents acknowledged that the black coffee twig borer (BCTB) and coffee wilt disease (CWD) were the most important coffee pest (46%) and disease (72%) respectively. On the other hand, the banana weevils and banana bacterial wilt (BBW) were the major pest (21%) and disease (84%) respectively. Overall, the majority of the respondents (80%) were not managing the biotic stresses. However, 50 and 79% of the respondents reported that they were using phyto-sanitary measures to manage BCTB and CWD respectively. For bananas, 45 and 71% of the respondents were employing phyto-sanitary measures to manage banana weevil and BBW respectively. Skeletonizers, tailed caterpillars and black coffee twig borers were the most important pests of coffee with 50% of the coffee plants infested with these pests; whereas, coffee leaf rust was the most observed coffee disease (18%). On the other hand, the most observed pest and disease of bananas were the banana weevils (4%) and black sigatoka (40%) respectively. Further, boundary line analysis results showed that the key biotic factors most related to yield losses in coffee were leaf eating beetles (R^2=0.8967), BCTB (R^2=0.8656), skeletionizers (R^2=0.8585) and for bananas, banana weevils (R^2=0.8749) and Sigatoka (R^2=0.7895). In conclusion, respondents generally had limited knowledge on pests and diseases of both crops as well as their management, apart from BCTB, CWD, banana weevil and BBW. These same biotic stresses have been identified as the key biotic factors most related to coffee and banana yield losses. Research should therefore aim at developing management strategies for them.

Keywords: Biotic constraints, coping strategies, coffee-banana agro-forestry

CHAPTER ONE
INTRODUCTION

1.0 Introduction

This chapter covers the background of the study, problem statement, objectives of the study and research questions. The scope of the study, significance of the study and conceptual framework are also presented in this chapter.

1.1 Background of the study

Coffee is Uganda's largest export product generating approximately 20% of the foreign exchange earnings. For example, in year 2011/12, coffee exports generated US$446 million (UCDA, 2012). More than 10 million Ugandans depend on coffee related activities of which 85% of them are smallholder farmers who contribute 90% of Uganda's coffee (Ssempijja Vincent, pers. comm.). They own fields ranging from 0.5 to 2.5 hectares (UCDA, 2012). For smallholder farmers, coffee is of great importance as the major economic source that delivers a cash boom once or twice a year (Jassogne, 2011). However, there was general decline in coffee production in the last decade. For example, from a peak of 4 to 2.7 million 60 kg bags in 1996/1997 and 2006/2007 respectively (Anonymous, 1997; Anonymous, 2007) mainly due to pests and diseases (Musoli *et al*., 2001). Coffee Wilt Disease (CWD) which broke out in the early 90's and wiped out more than 50% of the country's Robusta coffee has been the main cause of this decline (Adipala-Ekwamu *et al.,* 2001). In addition, coffee is infected by other diseases including Coffee Leaf Rust (CLR), Coffee Berry Disease (CBD), red blister, Fusarium root disease, damping off disease, bacterial blight, and Armillaria root rot (Musoli *et al.,* 2001). However, as the country is trying to manage CWD through improved management practices and release of the 7 CWD resistant Robusta clones (Musoli *et al*., Unpublished data), there is another threat, the black coffee twig borer (*Xylosandrus compactus*) (Egonyu *et al*., 2009; Kucel *et al*., 2011; Kagezi *et al.,* 2012, 2013). The other major coffee pests include coffee berry borer, soft green scale, coffee berry moth, white coffee borer, leaf minors, leaf skeletonizer, giant looper and the root mealy bug (Waller *et al.,* 2007).

Banana on the other hand is a key crop in Uganda, supporting both rural and urban populations as a basic staple food in Ugandan diets. The crop is grown by over 75% of the country's farmers on 1.5 million hectares, an equivalent of 38% of the total land under crops (Rojas, 1998). Production is done mainly by smallholder farming communities on land holdings of less than 0.5 ha (Karamura *et al*., 1999). The annual consumption of bananas in Uganda is the highest in the world at 0.70 kg daily per person (Charlie, 2011). A hectare of a well managed banana plantation can generate up to 1500 dollars a year (Mkitavi, 2013). However, production is still far below the attainable yields mainly due to pests and diseases and declining soil fertility. The Banana Xanthomonas Wilt (BXW) which broke out in 2000 is currently the most important disease affecting banana production in Uganda (Tushemereirwe *et al*., 2001; Kubiriba *et al*., 2012). In 2005 it was estimated that BXW caused yield loss of about US$ 34 million at a time when it was well established in only about 30% of the banana producing areas (Tushemereirwe *et al.,* 2006). Other major diseases of bananas include Fusarium wilt, black and yellow sigatoka, Banana Steak Virus (BSV) among others (Tushemereirwe *et al*., 1993, 1996a; Rutherford and Kangire, 1998). On the other hand, the major pests include banana weevils (Gold, 2000; Gold *et al*., 2001) and plant parasitic nematodes (Kashaija *et al*., 1994; Talwana *et al*., 2008)

Both crops are often grown as monocultures. However, coffee-banana intercropping is common, particularly in densely populated areas (van Asten *et al.,* 2011). But sometimes bananas are grown alongside with trees (Mpiira *et al.,* 2013). Coffee yields are higher when grown under shade and the banana trees help shelter the coffee from various climate conditions such as storms (van Asten *et al.,* 2011). Furthermore, the combination of these two crops allows the farmers to tend to the banana production in the first three years of cultivation, whilst the coffee plants are still maturing (Jackson and Mesiku, 2012). The variety of trees deliberately retained, managed and planted in the system help the farmers to maximize production by supplying timber and other non-timber products such as fruits, fuelwood, fodder, food, medicinal among others (Okia *et al*., 2009; Mpiira *et al.,* 2013; Kagezi *et al.,* Unpublished data). The shade systems also improve soil fertility through mulching and nitrogen fixation by leguminous shade trees (Verchot *et al*., 2007). They can suppress weeds, some pests and diseases and harbor natural enemies for controlling pests (Beer, 1987). They also reduce solar radiations and damage to plants by frost and intercept rainfall; increase carbon sequestration therefore reducing climatic change and improving on the coffee quality (Beer *et al*., 1998). Despite these perceived benefits, coffee-banana agro-forestry systems are yet to be fully quantified and there exists limited information that can provide a basis for recommendations for managing the major biotic factors in coffee-banana agro-forestry cropping systems of Mid-eastern, Uganda.

1.2 Problem statement

Productivity of coffee and bananas is still below attainable yields due to biotic stresses. This has led to low incomes and food security, thus poor livelihoods. The actual banana yields on many smallholder banana farms are 5−20 Mg ha^{-1} yr^{-1} FW which are far below the estimated potential yield of 100 Mg ha^{-1} yr^{-1} FW. Farmers report soil fertility decline, moisture stress, pests (banana weevils and nematodes) and diseases (coffee wilt disease and coffee berry disease) as the major factors responsible for yield decline (Nyombi, 2013).). Studies have also reported on pests such as banana weevils (Gold *et al.,* 2000), parasitic nematodes (Speijer *et al*., 1999) and diseases such as banana bacterial wilt and fusarium wilt (Tushemereirwe *et al.,* 2006) to be the cause of the low banana production. On the other hand, the actual clean (green) Robusta coffee yields average at 550 Kg ha^{-1} which is almost four times the attainable yields of 2.2 t ha^{-1} (Café Africa, 2008). Pests and diseases have been identified as the primary constraints such as black coffee twig borer, coffee berry disease and coffee leaf rust (UCDA, 2013). Currently, farmers have limited management options for these biotic stresses. However, research and extension have identified the integration of shade trees as an entry point for re-establishing the productivity of both crops. The shade system has many other added advantages such as conservation of biodiversity, mitigation of extreme climatic conditions, suppression of weeds as well as pests and diseases, carbon sequestration and prevention of soil erosion (Vandermeer and Perfecto 1997; Castro *et al.,* 2003). However, the key biotic factors most related to coffee and banana yield losses as well as farmers' coping mechanism for the biotic stresses within the coffee-banana agro-forestry systems are yet to be identified and there exists limited information that can provide a basis for recommendations for managing the major biotic factors in coffee-banana agro-forestry systems

1.3 Objectives of the study

1.3.1 General objective

To generate information that will provide a basis for recommendations for managing the major biotic factors in the coffee-banana agro-forestry systems of the Mid-eastern region of Uganda in order to increase coffee and banana yields.

1.3.2 Specific objectives

- To assess farmers' knowledge on the biotic stresses of coffee and banana and their coping mechanisms in managing them in the coffee-banana agro-forestry systems of the Mid-eastern region of Uganda.
- To identify the biotic factors within the coffee-banana agro-forestry systems of the Mid-eastern region of Uganda.
- To determine the key biotic factors most related to the coffee and banana yield losses within the coffee-banana agro-forestry systems of the Mid-eastern region of Uganda.

1.4 Research questions

- What information do farmers possess on the biotic stresses limiting coffee and banana production and how do they cope with them?
- What are the biotic factors within the coffee-banana agro-forestry systems of the Mid-eastern region of Uganda?
- What are the key biotic factors most related to the coffee and banana yield losses within the coffee-banana agro-forestry systems?

1.5 Scope of study

The study was conducted in the Mid-eastern coffee growing agroecological zone of Uganda in 2014-2016. This region was chosen firstly because it grows coffee and banana together with trees. Secondly, because this region is likely to be faced with poverty and food insecurity as most of their land has been converted into sugar cane growing (Waluube, 2013).

1.6 Significance of the study

Intercropping has been reported to be one of the methods to improve productivity of both annual and perennial crops through management of pests and diseases (Schroth *et al.,* 2000). However, limited studies have been carried out to identify the most limiting biotic constraints in the coffee-banana agro-forestry systems. Agro-forestry systems are cheap, ecologically and environmentally-friendly and they minimize the use of synthetic chemicals (SAFE, 2004). Therefore, this study aims at identifying the major pests and diseases and farmers' coping strategies as well as determining the key biotic factors most related to coffee and banana yield losses. This information will be used to provide a basis for recommendations for managing the major biotic factors in the Mid-eastern coffee-banana agro-forestry systems. Better management of pests and diseases will lead to increased productivity of banana and coffee. This will result into increased income and food security at both household and national level leading to improved livelihoods in the long run.

1.7 Justification of the study

Coffee and bananas are constrained with many biotic stresses particularly diseases and pests (van Asten *et al*., 2011) which leads to the production of both crops to be far below the attainable yield (Café Africa, 2008; Nyombi, 2013). Modern research has identified that integrating shade trees in the coffee-banana systems as the entry point for re-establishing productivity of both crops (For example Schroth *et al.,* 2000). An agro-forestry system has numerous advantages including the production of higher returns per unit land compared to coffee or banana monocrop due to the ability to suppress pests and diseases (van Asten *et al*., 2011). However, the key biotic factors most related to the coffee and banana yield losses within the coffee-banana agro-forestry systems of the Mid-eastern region are yet to be identified. This study therefore determined farmers' knowledge on biotic stresses and their coping mechanisms as well as key biotic factors most related to the coffee and banana yield losses. This information will be used to provide a basis for recommendations for managing the major biotic factors in the Mid-eastern coffee-banana agro-forestry systems. Better management of the pests and diseases will lead to increased incomes at household and national levels through increased sales from coffee, banana and trees. This will also improve food security through directly utilizing bananas but also by farmers utilizing incomes obtained from coffee sales to cater for their domestic needs such as food, shelter, medical care and school fees instead of buying food. All this will result in improved livelihoods.

1.8 Definition of key terms

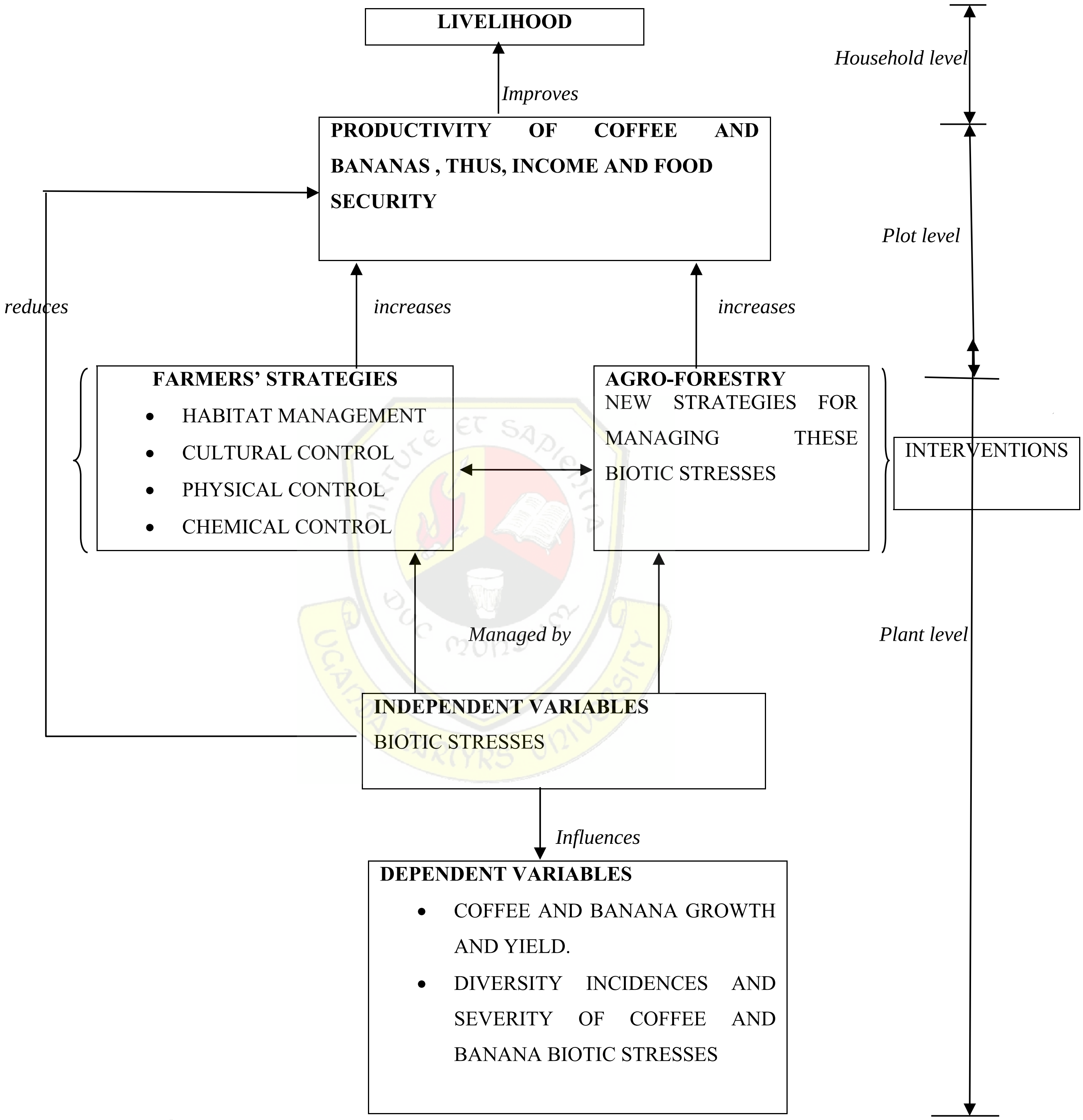
Biotic factors are the living components of an ecosystem, for example, the animals, plants and microorganisms (Christopherson, 1997).

Agro-forestry is a land-use management system in which trees or shrubs are grown around or among crops or pastureland (Sanchez, 1995).

Coping strategies refer to as the person's constantly changing cognitive and behavioral efforts to manage specific external or internal demands that are appraised as taxing or exceeding the person's resources (Redhwan *et al.*, 2009).

1.9 Conceptual framework

Production of coffee and bananas in the Mid-eastern region of Uganda is still below the attainable yields. Farmers are using some strategies such as habitat management, cultural control, physical control and chemical control to mention a few in order to manage these stresses. Nevertheless, agro-forestry is a new strategy being recommended by modern research for managing the biotic stresses of both crops. Management of biotic constraints will lead to increased productivity of coffee and banana, thus increased incomes and food security. This will result into improved livelihoods. However, this study looked at only plant level interactions (Fig. 1)



Source: Researcher (2014)

Figure 1: Management of biotic stresses of coffee and banana using agro-forestry system to increase productivity of both crops

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

Agriculture contributes 23.9% to Gross Domestic Products (GDP) of Uganda (Rusoke *et al.,* 2000). Coffee is the main cash crop harvested once or twice a year while banana is a primary food and cash crop produced throughout the year (van Asten *et al.,* 2011). In 2012, Uganda was the 24th largest coffee producer in the world, and the 47th largest banana producers (FAO, 2012). The estimated area under coffee and banana in Uganda was 310000 ha and 130000 ha with production of 6004 Hg/Ha and 43846 Hg/Ha respectively (FAO, 2012). In Uganda Arabica (*Coffea arabica*) and Robusta (*C. canephora*) are the two main types of coffee grown and estimated to comprise 20% and 80% of the total production respectively (Musoli *et al*., 2001; Masiga and Ruhweza, 2007). The East African highland banana (*Musa spp*. AAA-EA) is the major and most important banana genome grown in Uganda (Gold *et al.,* 2002).

Bananas are commonly cultivated together with coffee by small scale farmers with the motivation of enhancing land-use sufficiency, providing shading to coffee, supplying mulch materials and reducing soil erosion (van Asten *et al.,* 2010; Bongers *et al.,* 2012; Jassogne *et al*., 2013). In addition, intercropping coffee with banana also contributes to enhancing food security at household level, and to reducing farmers' risks associated with pest and disease damage as well as fluctuations in coffee beans price (van Asten *et al*., 2011). This is especially important due to recent outbreaks or resurgence of pests and diseases. For example, the Coffee Wilt Disease (CWD) and Black Coffee Twig Borer (BCTB) for coffee (Egonyu *et al*., 2009; Kagezi *et al*., 2015) and Banana Xanthomonas Wilt (BXW) and banana weevils in bananas (Tushemereirwe *et al*., 2001; Gold *et al*., 2002). Although intercropping coffee and banana has various benefits, the productivity from this system is still low due to biotic stresses among others.

Modern research has identified integrating shade trees in the coffee-banana system as the entry point for re-establishing productivity of both crops (for example Schroth *et al.,* 2001). However, the information on farmers' knowledge on biotic stresses and their coping mechanisms as well as the key biotic factors most related to the coffee and banana yield losses within the coffee-banana agro-forestry systems of the Mid-eastern region is limited. Thus, a need to determine farmers' knowledge on the biotic stresses and their coping mechanisms as well as the key biotic factors most related to the coffee and banana yield losses. This will contribute to improving household and national income and food security and eventually livelihoods.

2.1 Biotic constraints of both coffee and bananas in Uganda

In Uganda productivity of both coffee and bananas are still below the attainable yield amount mainly due to pest and diseases among others. The actual banana yields on many smallholder banana farms are 5−20 Mg ha^{-1} yr^{-1} FW which are far below the estimated potential yield of 100 Mg ha^{-1} yr^{-1} FW (Nyombi, 2013).). Also, the actual clean (green) Robusta coffee yields average at 550 Kg ha^{-1} which is almost four times below the attainable yields of 2.2 t ha^{-1} (Café Africa, 2008).The biotic constraints of coffee and bananas are outlined below;.

2.1.1 Biotic constraints of coffee in Uganda

Coffee farmers are continuously threatened by a range of pest and disease problems. Many of these are minor in terms of the damage they cause and their effect on yield and quality. However some, such as coffee berry disease, coffee leaf rust, coffee wilt disease (tracheomycosis) (Adipala-Ekwamu *et al.,* 2001; Musoli *et al.,* 2001; Rutherford and Phiri, 2006) and black coffee twig borer (Egonyu *et al.,* 2009; Kagezi *et al.,* 2015) can be very serious indeed These can have a major impact not only at household level but also on the economy of countries or regions which heavily rely on coffee for foreign exchange earnings (Rutherford and Phiri, 2006)

2.1.1.1 Coffee diseases

There are various diseases affecting coffee in Uganda which include:

2.1.1.1.1 Coffee wilt disease (CWD)

CWD is caused by a fungus *Gibberella xylarioides.* It's a soil inhibiting fungus that is spread by water, wind and human activity. It penetrates the host through the wounds caused by weeding and pruning (Rutherford, 2006). The disease has been the major threat to Robusta coffee since

1993 and it wiped out more than 50% of Robusta coffee by 2002 (Adipala-Ekwamu *et al.*, 2001; Kangire, 2014). It led to an economic loss of US dollars 80-270 million annually between 1996 and 2007 (Musoli *et al.,* 2008). The incubation period between first symptoms and death are 2-3 months. It causes wilting of leaves and the whole plant, numerous vertical and spiral cracks in the bark of the trunk, chlorosis and defoliation of the aerial parts of the crop (Rutherford, 2006). It can be controlled by planting materials from approved wilt free sources, cleaning of tools with fire, uprooting and burning of affected plants and avoiding wounding trees during weeding (Rutherford and Phiri, 2006). CWD-resistant Robusta clones have also been recommended as they are the most appropriate and sustainable method (Musoli *et al.,* 2001). Currently, 7 CWD-resistant lines are being promoted country-wide by NARO and UCDA (Kangire, 2014). Host resistance is considered to be a long term and stable solution to the problem as chemical pesticides are ineffective due to the vascular nature of the pathogen (Rutherford, 2006).

2.1.1.1.2 Coffee Berry Disease (CBD)

CBD is caused by a fungus *Colletorichum kahawae* that attracts Arabica coffee (Mouen Bedino *et al.,* 2007). It is spread by rain splash, coffee pickers, birds and movement of infected seedlings. The disease develops faster during the wet seasons. (Musoke *et al*., 2012). It leads to 60-80% yield losses under conditions conducive to the development of the fungus such as high humidity and high altitudes (> 1600m) (Mouen Bedino *et al*., 2012). It normally attacks coffee berries at any point in their maturation however, only symptoms detected on young berries can be clearly diagnosed (Wintgens, 2009). The disease appears as dark-colored indented spots on the coffee beans that are followed by a pale pink crust as the spores develop. The berry is destroyed in a matter of days and reduced to an empty, blackened and dried out pouch (Rutherford and Phiri, 2006). It doesn't kill the whole tree but moves within the stem (Musoke *et al*., 2012). CBD can be controlled by providing wider spacing and ensuring that trees are pruned appropriately to prevent prolonged wetness and high humidity (Mouen Bedino *et al.,* 2007). Planting of shade trees can also help reduce the incidences of CBD. CBD can also be controlled by the use of Copper Oxychloride or Dithianon or by planting resistant varieties such as Ruiru 11 (Rutherford and Phiri, 2006).

2.1.1.1.3 Coffee Leaf Rust (CLR)

This disease is caused by a fungus *Hemileia vastatrix*. The fungus produces thousands of tiny spores that travel in water, rain, air and remain viable for long distances (Gouveia *et al.,* 2005). It attacks more of Arabica coffee compared to Robusta coffee (Arneson, 2000). The disease gained significance in Uganda in the 1940's when its effect led to the replacement of Arabica coffee in low land areas of Buganda with indigenous Robusta varieties (Musoli *et al*., 2001). It is the second most devasting disease of Arabica coffee after coffee berry disease (Thurston, 1998). It causes an estimated yield loss of 40% on farmers' fields especially where no control measures have been undertaken (Silver *et al*., 2006). The fungus attacks coffee leaves causing a color range from yellow to orange. The spores set on the underside of leaves and can cause severe defoliation, impaired photosynthesis, and a decrease in crop production (Kubota, 2013). It can also be managed by use of entomopatogenes and mycoparasitic fungus *Lecanicillium lecanii* (Jackson *et al*., 2012). High light intensity also helps to slow the fungus growth (Muller *et al*., 2009). Copper-based chemicals such as Triadimefon, Cyproconazole and Hexaconazole have been somehow effective in combating coffee leaf rust (Kimani *et al.,* 2002).

2.1.1.1.4 Red Blister Disease (RBD)

RBD is caused by a fungus *Cercospora coffelcola*. It causes a small red and slightly raised spots that appear on both green and ripening berries that enlarge and join forming unslightly red blisters. The centres of the lesions dries up and turn black. Use of fungicides is not economical for controlling the disease (Bwana, 2009). However, for controlling the disease some cultural practices are recommended such as good field management such as proper pruning of the fields (Café Africa, 2014). It is also advised to improve the nitrogen and potassium in the soil and the use of resistant coffee varieties especially elite coffee seedlings can help combat the disease (Bwana, 2009).

2.1.1.1.5 Brown Eye Spots Disease

Brown eye spot disease is caused by a fungus *Cercospora coffeicola* that attacks both the leaves and the coffee berries. It is associated with lack of nitrogen. Water and wind are responsible for disseminating the pathogen and the disease is most common in Arabica coffee (Rodrigues *et al*., 2014). *Cercospora* causes defoliation as well as damage to the coffee fruit. The infected leaves show tan spots with grayish-white centers. On green berries, the lesions are sunken and are brown in color with an ashy center. They are sometimes encircled by a purple "halo," or tissue that has ripened prematurely due to the infection. In red coffee fruit, the lesions are larger, black in color, and can sometimes penetrate all the way to the seed, causing the pulp to adhere to the parchment (Nelson, 2008).. Brown eye leaf spot can be controlled by provision of adequate shade and nutrition. Spraying with copper based fungicides can help reduce the incidences (Rutherford and Phiri, 2006).

2.1.1.1.6 Armillaria root rot

It is caused by a fungus *Armillaria mellea* which lives as parasites on living host tissue or as saprophytes on dead woody materials. The hosts include hundreds of species of trees (for example *Pinus, Eucalyptus, Acacia, Grevillea*, coffee and cocoa), shrubs, vines and forbs growing in forests, along road sides and in cultivated areas (Williams *et al.,* 1989; Shaw and Kile, 1991). It is more common in Arabica coffee (Eshetu *et al.,* 2000). It causes wilting and yellowing of tree tops, resin exudation, as well as the occurrence of white mycelial fans under the bark of infected trees (Morrison *et al.,* 1991). The root system of affected trees shows a white growth (mycelial) of the fungus beneath the bark. In advanced stage of the disease the wood of the affected tree is decomposed into a white, wet mass with characteristic black zone lines running through the wood tissue. Infection in coffee plantings usually can be traced to shade trees or woody debris (stumps or old roots of shade trees) left in the ground when land is cleared before coffee planting (Eshetu *et al.,* 2000). If coffee is to be planted in newly cleared forest land, it is recommended that ring-barking of the forest trees be done 2 to 3 years earlier. It is also advised to remove forest trees stumps, forest trees roots and drenching the root area with a copper fungicide. However, it is not possible to save a coffee tree once infected. The infected tree should be uprooted and replanting should be delayed for 2 years (Gezahgne *et al.,* 2004). Other minor diseases of coffee but can be economically include damping off disease and bacterial blight (Trujillo *et al*., 1995; Musoli *et al*., 2001).

2.1.2 Coffee pests

Coffee in Uganda is faced with numerous pests which involves:

2.1.2.1 Black Coffee Twig Borer (*Xylosandrus compactus*)

The Black Coffee Twig Borer (BCTB) is the most recent serious pest of Robusta coffee (Egonyu *et al*., 2009), but it attacks Arabica coffee as well (Kagezi *et al*., 2012; 2014). The pest was first detected in Uganda in 1993 in the Bundibugyo district (Adipala-Ekwamu *et al.,* 2001). Females bore into the primary branches and suckers, leaving a pin-hole sized entry. The damage causes wilting and dying of twigs, primary branches, drooping of leaves. Severe infestation causes loss of considerable number of productive branches (Nelson and Davis 1972; Hara and Sewake, 1990). In Uganda, 48 plant species have been reported to be alternative hosts of BCTB including among others *Mangifera indica, Senna occidentalis, Albizia coriaria, A. chinensis, Artocarpus heterophyllus, Eucalyptus spp., Grevillea robusta and Camellia sinensis*. It causes a yield loss amounting to US$ 40 million per year (International Coffee Organisation, 2014). BCTB can be controlled by maintaining good tree care (fertilizer application and water management) to promote tree vigor and health which helps in resisting infestation (Smith, 2003). Destruction of beetle infested plant materials by burning can also help reduce the infestation (Hara and Tenbrink, 1994). Shade reduction can also help reduce the infestation (Kagezi *et al*., 2014). The entopathogenic fungus, *Beauveria bassiana* has been reported to cause some mortality in BCTB (Balakrisman *et al.,* 1994). Ethanol and (-)-α-pinene baited traps have been demonstrated to effectively attract the adult beetles (Dudley *et al.,* 2008) while verbenone and limonene repel the pest (Elsie *et al*., 2006; Dudley *et al*., 2008). A mixture of chemical such as Imax (Imidacloprid) and Orius (Tebucozanole) at a rate of 4mls per litre and 6mls per litre have also been reported to control the pest (Kagezi *et al*., 2014). Nevertheless, the decision to use chemical control is influenced by environmental and human health concerns (Pimentel, 2005). In addition, it is also difficult to apply chemicals to the concealed habitats in which BCTB lives. Also, chemicals could be unaffordable by many smallholder farmers who happen to produce more than 90% of the coffee in Uganda (Musoli *et al.,* 2001).

2.1.2.2 Coffee Borer Beetle (*Hypothenemus hampei*)

The Coffee Borer Beetle (CBB) is a small black beetle that bores into the lower portion of the coffee fruit and lays eggs in the seed endosperm (Harrington, 2010). As the larva develops they start feeding on the berries causing yield loss and lowering of the coffee quality (Vegas *et al*., 2009). It can cause up to 60% damage (Million, 2001). In Uganda CBB is a serious pest of Robusta but may also attack Arabica at low altitudes (Musoli *et al*., 2001). It thrives in humid conditions and dense crop spacing. The best means to limit infestations are through proper plant pruning and ensuring that all coffee is harvested and no coffee fruit is left in the fields between harvests (Messing, 2012). . Manual control (handpicking of berries) is laborious and expensive (Kimani *et al.,* 2002). It is also advisable to reduce on the amount of shade in the fields (Messing, 2011). Brocap traps have also been used to control the pest (Messing, 2012). Biocontrol agents such as *Heterospilos coffeicola, Beauveria bassiana and Metarhizium anisopliae* are also considered to be a critical component for effective control of CBB (Kucel, 1998). However the pest is difficult to control by spraying because much of its life cycle occurs deep inside the berry (Mathieu *et al*., 1997)

2.1.2.3 Coffee Mealybug

Planococcus ireneus, Planococcus eitri and Planococcus lilacinus are the predominant species (Shajia *et al.,* 2014). The young mealybugs can be spread over long distances by wind and the adults can be carried by ants that travel from affected to unaffected plants (Magina and Kiwelu, 2012). They secrete a sticky honeydew that both attracts ants and leads to the formation of a black sooty mold which covers the leaves and may affect photosynthesis. Infestations are sporadic. Mealybugs damage coffee plants by sucking sap from roots, leaves, petioles and berries (Baptists, 2014). They multiply rapidly during dry seasons (Magina and Kiwelu, 2012). Mealybugs can be controlled by maintaining shade at 30% for Arabica and 20-25% for Robusta (Wintgens, 2009). Affected trees and dead trees should be uprooted and burnt to reduce on the continued spread of the mealybugs (Café Africa, 2014). Removal of suckers and branches that touch the grounds can help prevent the ants from climbing the coffee (Magina and Kiwelu, 2012). Use of parasitic wasps such as *Anagyrus kivuensis* that feed on the mealybugs can help to reduce the incidences. Chemicals such as Dimethoate, Diazinon and Ethion can also be used to control the ant populations (Magina and Kiwelu, 2012). Trees showing early signs of the attack and surrounding ones should be treated with Dursban or Actara mixed into the soil around the tree (Café Africa, 2014).

2.1.2.4 Coffee White Stem Borer (*Xylotrechus quadripes*)

Arabica coffee is the preferred and principal host of this pest (Wiryadiputra and Mawandi, 2012). The larvae of the coffee white stem borer bores into the stem of coffee plants causing fragility in the plant. Younger plants usually die within one season of the infestation while older plants can survive for several seasons, however, with decreased yields. Affected plants show externally visible ridges around the stem. They may also exhibit signs like wilting and yellowing (Rajbhandari, 2013). The pest causes substantial economic loss every year because infested plants have to be uprooted (Venkatesha and Dinesh, 2012). Well-maintained coffee trees are less likely to be attacked by white stem borer. It is therefore wise to keep trees healthy and vigorous by adequate nutrition. Shade helps in reducing the infestation as the adults prefer coffee plant exposed to sunlight for egg laying (Rutherford and Phiri, 2006). A species of the insect parasitoid such as *Allorhogas pallidiceps* and *A. sahyadrica* can parasitize the eggs and the pupae of the borer (Giddegowda and Dinesh, 2012). Insecticides such as Fipronil or lime can also be used (Rutherford and Phiri, 2006). Cotton wool or paper soaked with Dursban or Super Sumithion can be used to stuff the insect hole in order to kill the larvae (Café Africa, 2014).

2.1.2.5 Green Scale (*Coccus viridis*)

Green Scales are members of the soft scale family Coccidae that secrete a honeydew that creates a film on the plant leaves (Poole *et al.,* 2005). This attracts ants and other insects, and can lead to the growth of a sooty mold that decreases photosynthesis and depreciates the value of the coffee. The ants harvest the honey dew for food and protect the scales from their natural enemies (Mau and Kessing, 2007). Scales infestation kills young trees, weaken and stunt mature trees reducing bean size and yield. Biologically they can be controlled by use of a white halo fungus

(*Vertcillium lecanii*) that infects green scales (Kawate *et al*., 2007) and parasitic wasps *Encarsia spp* (Poole *et al.,* 2005). They can also be controlled by use of Imidacloprid and Pyrethrins (Kawate *et al*., 2007).

2.1.2.6 Coffee Leaf Miner (*Leucoptera coffeela)*

The coffee leaf miner is a silvery white moth whose larvae penetrate the leaves of coffee plants and feed on the tissues between the epidermis, leaving a hollow area that dries out and results in brown spots. If not controlled, the coffee leaf miner may cause intense defoliation and loss of production (Scalon *et al.,* 2011) amounting to 50% of the total production (Reis and Sauza, 1996). Infestations are usually greater during hotter and drier periods of the year. It is associated with management practices such as shade reduction and increased use of pesticides (Guharay *et al.,* 2001). The pest can be controlled by species of predatory thrips, mites and lacewings (Kimani *et al.,* 2002). Sexual pheromones such as 5, 9-dimethylpentadecane can also be used to capture the male leaf miners (Lima, 2001). Chemical such as Chlorprifos, Disulfoton, Ethion and Methyl parathion can be used to control the leaf miners (Fragoso *et al.,* 2002). Even though chemical control is the most used method to prevent the attack, they lead to environmental pollution, higher production costs and insecticide resistance (Guedes and Oliveira, 2002)

2.1.2.7 Nematodes

Nematodes are worm-like organisms that attack the root system of plants, feeding on the sap. They can form knots in the roots that inhibit the plant from properly feeding (Kawate *et al.,* 2007). Yield losses caused by nematodes has been estimated up to 45% in Brazil (Barbosa *et al.,* 2004). Symptoms of a nematode infestation are galls, splits, scales and decreased mass in the root system, and chlorosis and defoliation in the upper plant. C. *canephora* is more resistant to nematode infestations, and thus using seedlings engrafted in C. *canephora* rootstock is a means of limiting outbreaks (Kawate *et al.,* 2007). Weed control, nutrition and water management as well as organic soil amendments can help in managing nematodes. Growing coffee under shade can also help reduce nematode infestation (Nelson *et al.,* 2002).

2.1.2.8 Coffee Antestia bug (*Antastiopsis lineaticolis)*

Antestia bugs affect Arabica coffee only (Café Africa, 2014).The adult and nymphs feeds on immature, green berries from which they suck the sap causing the fruit to shrink. It also causes berry abortion, cracking, rotting of beans, multiple branching and shortening of the internodes (Café Africa, 2014; Kimani *et al.,* 2002). The presence of 2-3 bugs per tree in the field can cause about 45% crop loss (Anonyme, 1997). Natural enemies such as beauveria bassiana can be used to control antestia bugs (Nahayo and Bayisenga, 2012). Parasitic wasps can also be used to control these bugs for example *Aridelus* spp and Ascolus wasps (Kimani *et al.,* 2002). Others minor coffee pests include; aphids, termites, coffee thrips, lace bug, capsid bug, leaf skeletonizer, gaint looper (Waller *et al.,* 2007).

2.1.3 Biotic constraints of bananas

Banana plants are susceptible to a wide range of diseases and pests. Some diseases are highly aggressive, very contagious and easily spread (Nelson *et al.,* 2006). These challenges can dramatically reduce the yield and have therefore a deep impact on food availability and economical balance in many developing country (Teycherey *et al.,* 2007; Heslop-Harrison and Schwarzacher, 2007).

2.1.3.1 Banana diseases

Banana yield can be reduced up to 100% due to disease infections then, threatening the livelihoods of smallholder farmer. The most important banana diseases in Uganda include:

2.1.3.1.1 Banana Bacterial Wilt Disease

Banana bacterial wilt disease is caused by *Xanthomonas campestris pv. musacearum.* In Uganda, it was first reported in 2001 and has since spread rapidly with incidences of up to 70% in both local landraces and exotic bananas (Tushemereirwe *et al.,* 2002). The losses could result into 500 USD/year/farmer (Eden-Green, 2004). The pathogen is transmitted by insect vectors visiting the inflorescence to collect nectar and pollen, and also by tools used for farm operations. Soil borne *Xanthomonas* can be enhanced by injuries caused mechanically or nematodes and weevils

(Mwangi *et al.,* 2006). Injured or decaying infected tissues can provide inoculum that is released into the soil and spread through soil water (Tushemereiwe *et al.,* 2003). All bananas cultivars grown in east Africa have been found to be susceptible (Eden-Green, 2005) but it is more prevalent on pisang awak locally known as kayinja (Tushemereiwe *et al.,* 2003). The bacterium causes symptoms such as dull yellow wilting leaves, fruits ripen unevenly when bunch is still young, yellow puss oozes from stems and fruits showing brown stains when cut (Tushemereiwe *et al.,* 2002). Ratoons crops arising from infected mats often wilt before even producing bunches or produce bunches with rotten fruits (Eden-Green, 2004). It can be controlled by removal of male bud with a forked stick immediately the last cluster has formed, use of clean planting materials, disinfecting tools with fire or jik and cutting and heaping or burying infested plants (Tushemereiwe *et al.,* 2003). In general, bacterial disease of plants once established are difficult to control due to the lack of effective chemicals or other curative treatments. Thus, early detection and destruction of the diseased plants is a key step in preventing disease spread (Karamura *et al.,* 2005). Movement of banana plant materials from infected areas to other areas can be controlled through restrictive quarantine thereby reducing the spread of the disease (Eden-Green, 2004). The most attractive strategy for bacterial control is to improve plant defense mechanism against the pathogens (Agrios, 2005). Development of resistant banana varieties is the most appropriate and realistic approach for controlling banana bacterial wilt. However, this remains a difficult endeavor because of the long generation times, various levels of ploidy and sterility of most edible cultivars (Tripathi *et al*., 2005)

2.1.3.1.2 Foliar diseases

In Uganda there are three dominate leaf diseases: black sigatoka caused by *Mycosphaerella fijiensis*, yellow sigatoka caused by *Mycosphaerella musicola* and *Cladosporium* leaf freckle (Tushemereirwe *et al.,* 1993). Theses foliar diseases are spread by air (Mortensen *et al.,* 2013), planting materials and by banana leaves used as packing materials during transport (Mourichon *et al.,* 1997). *Cladosporium* infections cause orange discolouration of the leaf tissues (Tushemereirwe *et al.,* 1993). Yellow sigatoka appear on the upper leaf surface as pale yellow streaks while black sigatoka appears as dark brown streaks on the lower leaf surface (Mourichon *et al*., 1997). They causes a bunch weigh reduction of 37% (Tushemereirwe *et al.,* 2000). Both East African highland bananas (AAA-EA) and plantains (AAB) are susceptible. Black sigatoka is the most important foliar disease as it even appears on the young leaves affecting the photosynthetic tissue (Mourichon *et al*., 1997). More so, this balck sigatoka causes a yield loss of 30 to 50% on bananas and plantains (Tushemereirwe, 1996). Foliar diseases can be controlled by increasing plant spacing to improve air circulation and reduce humidity. Removal of leaves with mature spots can help to reduce the propagation. Also ensuring proper plant nutrition to maintain a good rate of leaf emergence helps the plant to outgrow the disease (Mourichon *et al*., 1997). Chemicals such as Dithiocarbamates, Ethylenebisdithiocaramate and Triazole can also be used to control these foliar diseases (Henderson, 2006).

2.1.3.1.3 Fusarium wilt

Fusarium wilt caused by *Fusarium oxysporum f.sp.Cubense* is regarded as one of the most destructive banana disease (Moore *et al.,* 1995; Heslop-Harrison and Schwarzacher, 2007). Currently, in Uganda, it is found all over the country wherever susceptible banana clones are cultivated. It exclusively attacks introduced (exotic) cultivars such as gros michel (Musa AAA), kisubi (Musa AB), sukali ndizi (Musa AAB) and has not been observed on the dominant highland banana (EA-AAA) (Kangire *et al.,* 2001). It is spread through planting materials, soil and water (Daly and Walduck, 2005). The symptoms include gradual yellowing, wilting and drying of the leaves. The petioles of affected leaves may snap, resulting in the leaves drooping downwards. Internally, infestation by the fungi result in black/purple discolouration of vascular system of the corm and/or pseudstem (Kangire, 1998). When it has established in an area, it cannot be controlled by chemical fungicides, soil fumigants or by cultural practices. Use of disease free seedling and resistant varieties such as Cavendish, FHIA 21 and FHIA 25 is recommended (Hwang and Ko, 2004; Tushemereirwe *et al*., 2004).

2.1.3.1.4 Banana Streak Virus (BSV)

BSV is caused by a collection of banana streak virus species (genus *Badnavirus* family Caulimoviridae). They are propagated by infested planting materials (Lassoudiere, 2007) and vectors such as mealybugs for example *Planococcus citri, Sacharococcus sacchari and Dymicoccus brevipes* (Kubiriba *et al.,* 2001). It can cause up to 100% yield loss in severely infected areas (Tushemereirwe *et al.,* 1999b). The symptoms of streak disease are influenced by the cultivar and environmental conditions. The most common symptoms include narrow, discontinuous chlorotic and/ or necrotic streaks which run parallel to the veins of the leaf lamina (Lockhart and Jones, 2000). It can cause reduced plant growth and vigor and a reduction in bunch size and yield (Lassoudiere, 2007). BSV can be controlled by phytosanitary measures such as use of virus free planting materials and roguing infected materials. Spread of BSV into new fields from the surrounding can be reduced by separation of new fields from the old ones (Kubiriba, 2005). Other diseases include anthracnose, banana bunchy top virus and banana bract masaic virus (Anthony, 2011).

2.1.3.2 Banana pests

Pests infesting banana production include banana weevils (*Cosmopolites sordidus*), Hawaiian flower thrips (*Thrips hawaiiensis*), nematodes and banana aphids.

2.1.3.2.1 Banana weevils

Banana weevils is one of the major constraints to banana production especially in small scale farming systems (Gold *et al.,* 2001). The yield loss due to the weevils has been reported to be up to 50% in on-station trials (Rukazambuga, 1998; Gold *et al.,* 2004). Symptoms of banana weevil damage include; yellowing of the leaves, weakness, reduced bunch formation and development or presence of defective bunches. Weevil larvae cause damage by boring in the corm which results in reduced nutrient uptake of the plant (Abero *et al*., 1999; Gold *et al*., 2001). In addition, damage reduces plant vigor and predisposes the crop to snapping and sucker mortality (Gold *et al*., 2001). The weevils also cause prolonged bunch maturation period and shortened plantation life (Gold *et al.,* 2004). Cultural control involves crop sanitation (removal or destruction of plant residues), use of clean planting materials, improved crop husbandry practices to promote crop vigor (Gold *et al*., 2003) and intercropping (Rukazambuga *et al.,* 1994). Traps baited with pheromones can be used to control the weevils (Tinzaara *et al.,* 2002). Entomopathogenes such as *Beauveria bassiana* have also showed 50-100% weevil mortality (Nankinga, 1999). They can also be controlled by spreading Dieldrin dust around infested stool (Nyombi, 2003).

2.1.3.2.2 Nematodes

In Uganda there are three types of nematodes; the burrowing nematodes *Rodopholus similis*, the root lesion nematodes *Pratylenclus goodeyi* and *Helicotylenchus multicincus* (Nyombi, 2013). The root lesion nematode (*Pratylenchus goodeyi*) is the most destructive of them all (Namaganda *et al*., 2000). They are disseminated by runoff water to uninfected plots (Risede *et al.,* 2010). Nematodes are microscopic round worms that attack the root systems of the plants and impair water and nutrient uptake. In extreme infection, root systems are so weakened that the banana plants cannot support the heavy bunch in that in periods of high winds these infected plants are uprooted (Lassoudie`re, 2007). They cause a yield reduction as high as 51% on highland banana (Speijer and Gold, 1996b). The highland bananas appear to be more susceptible to nematodes than the more recently introduced cultivar Pisang Awak (*Musa* ABB) (Speijer and Bosch, 1996a). However, due to their microscopic size, farmers rarely appreciate their economic importance. Systemic pesticides such as Carbofuran are effective against nematodes, but are rarely used because of their high costs (Nyombi, 2013).

2.1.3.2.3 Aphids

Aphids (*Pentalonia nigronervosa*) are serious pests for bananas as they acts as a vector for banana bunchy top virus. It causes symptoms such as deformation of the plants with curled, shriveled leaves and galls. Plants infected with bunch top virus should be removed and destroyed to prevent the spread (Constantinides and McHugh, 2003).

2.2 Coffee-bananas intercropping

The coffee-banana intercropping system has been described as a traditional system in Uganda; both in Robusta and Arabica growing regions (Oduol and Aluma 1990).When the colonial powers introduced coffee at a large scale in the first half of the 20th century, farmers traditionally intercropped bananas at planting, but found it was challenging to keep both crops productive over time (Thomas 1940a,b). Later, Mitchell (1963) observed negative effects of banana intercropping on coffee yields in a trial in Bukoba, Tanzania. After 4 years, coffee yield decreased by 35% when intercropped. He concluded that intercropping could not be recommended. However, he based this conclusion solely on coffee revenue, without including the banana revenue generated from the same plot. Despite the doubts raised on the productivity and sustainability of coffee/banana intercrop systems, recent studies suggest that intercropping potentially provides numerous advantages to the smallholder farmer (Chipungahelo *et al.,* 2004). First, it offers higher returns per unit land compared with coffee that is monocropped, even if coffee yields decrease (van Asten *et al*., 2011). Ouma (2009) suggested that farmers increasingly revert to intercropping due to declining farm sizes in an effort to reduce risks related to income and food security. If one crop is attacked, there will be the harvest from the other crop for food or cash. This is especially important in production of both crops in case of pests and disease out breaks. For example, the black coffee twig borer (Egonyu *et al*., 2009; Kagezi *et al.,* 2012, 2013), coffee wilt disease (Adipala-Ekwamu *et al.,* 2001) and banana bacterial wilt (Tushemereirwe *et al.,* 2001).

In addition, coffee yields are higher when grown under some shade and banana trees help shelter coffee from various climatic conditions such as storms when still young. The banana leaves can also be used as mulches for the coffee (Jackson and Mesiku, 2012). More so, planting banana trees in coffee fields also helps to mitigate climate change by capturing CO_2 from the air and through the mulch, hence, enriching the soil's carbon stocks. Planting coffee in the shade of banana trees may also improve the quality of the beans. In addition, coffee planted with banana has been found to have a 50% lower incidence of leaf rust than unshaded plants coffee which is important as pests and disease risks are rising with increasing temperatures (Njuguna *et al.,* 2012). The farmer also benefits because banana and coffee intercropping is much more profitable than either banana or coffee monocropping. For example, in the Arabica coffee growing region around Mt. Elgon, annual returns per hectare averaged US$4,441 for intercrop, $1,728 for banana monocrop, and $2,364 for coffee monocrop. On the other hand, in Robusta-growing areas in south and southwest Uganda, annual returns per hectare averaged $1,827 (intercropping), $1,177 (banana monocrop), and $1,286 (coffee monocrop) (van Asten *et al.,* 2012).

Both crops are often grown as monocultures although there is increased intercropping in densely populated areas (Ssennyonga *et al.,* 1999; van Asten *et al.,* 2012). These crops are sometimes grown together alongside with trees to form an agro-forestry system (Albertin *et al.,* 2004;

Mpiira *et al*., 2013). The aim of most agro-forestry systems is to optimize the positive outcomes in order to obtain higher, more diversified and more sustainable production systems from the limited resources than is possible with other systems of land use (Huxley, 1984). Agro-forestry also give land-use a multipurpose approach towards sustained agricultural production. It aims at input substitution, food security, improved stability against short-term changes (reduced risk), and income generation (Mawanda, 2004). A study carried in Mayuge district Mid-eastern region of Uganda revealed that farmers preferred exotic trees to indigenous ones. Among the trees grown in the region included; Silk tree (*Albizia spp*), Bark-cloth fig *(Ficus natalensis)*, Bell bean tree (*Markhamia lutea)*, Mango (*Mangifera indica*), Jackfruit (*Artocarpus heterophyllus*), Umbrella tree (*Maesopsis eminii*), Calliandra (*Calliandra calothyrsus*), Silky oak (*Gravellia robusta*), Guava (*Psidium guajava*), Eucalyptus (*Eucalyptus grandis),* avocado (*Persea amiricana)* and Acacia (*Acaccia spp)* (Isabirye, 2009). The trees help in carbon sequestration through increased litter and tree pruning inputs, nitrogen fixation by leguminous tree species, improve soil fertility through mulching materials and also microclimatic extremes mitigation (Verchot *et al*., 2007). In addition to the ecological benefits, they provide wood fuel and fruits which increases the food security as the households can collect, process and consume the fruits (Isabirye, 2009). Besides that the fruits can be sold which increases the possibility to buy food and other household goods. Some trees are also used for building materials and when the timber is sold this can generate higher incomes (Hillbur, 2014). Food insecurity, and particularly the inability of the smallholder sector to maintain or increase levels of food output, has been attributed to serious shortages of arable land, the low levels of technology practiced by most smallholders (World Bank, 1995; MPED, 2003)

The intercrop system however, removes larger quantities of nutrients from the soil and in the long term, coffee can eventually out compete bananas (van Asten *et al.,* 2011; Njuguna *et al.,* 2012). This system also requires large inputs of labour and capital of the outset. Therefore, the success of intercrop system will require identification of major production constraints and the development of site specific recommendations to address them (van Asten *et al.,* 2011).

2.3 Coffee-banana agro-forestry systems in Uganda

Agro-forestry is recognized in Uganda's national strategic and operational framework for poverty eradication as one of the options for improving farm productivity and thereby eliminating poverty through increased household incomes (MFPED, 2004). Agro-forestry is emerging as the promising land use option to sustain agricultural productivity and livelihoods of the farmers (Syampunani *et al.,* 2010). It has many advantages for the farmers such as longer cropping period, more intensive cropping and higher yields (Mosango, 1999). Predominantly, Uganda's smallholder farming systems involve various tree species such as *Albizia cinesis, Ficus natalensis* among others (Albertin *et al.,* 2004). In addition, subsistence crops such as bananas are often combined in these systems (Djimde and Hoestra, 1988).

In bananas, agro-forestry system provides microclimatic conditions that are favorable for crop production (Verchot *et al.,* 2007; Jassogne *et al.,* 2013). The tree canopy also acts as a wind barrier, provides shade and hence reduces evapotranspiration from underlying soil and plants (Schroeder, 1995). Also the morphology of the banana plant with its large leaves and heavy bunches on a tall stem in combination with a very shallow root system make the crop especially susceptible to uprooting due to strong winds (Sastry, 1988). The degree of shading determines whether the above ground effect of trees on the banana yield and infestation are facilitating, complementary or competing (Dold *et al*., 2008). However, this is true for the tropics, but cannot be applied to the sub tropics where shading of bananas decreases yield. Furthermore, banana leaves showed increased radiation use efficiency under shade treatment (Norgrove, 1998). Also banana grown under shade trees shows a delay in the infection speed of black sigatoka and reduced water stress (Christian *et al*., 2008). However, if the light availability for banana is too low the positive effect of shading may turn into negative ones (Oluka *et al*., 2011) such as reduced bunch size and prolonged crop cycle (Christian *et al*., 2008).

In Uganda, majority of coffee fields are covered by shade trees with diverse shading intensity (van Asten *et al.,* 2012). It is also recommended to plant shade trees in young coffee plantation to protect them from sunburn (UCDA, 2012). Shade trees help to modify the microclimate and soil quality in coffee plantations. These modifications can alter pest and disease development through direct effects on their life cycle, or indirect effects via coffee defense mechanisms and stimulation of trophic chains (Avelino, 2010). It has been suggested that shade trees reduce coffee berry disease (*Colletotrichum kahawae*) incidence by intercepting rainfall and reducing the intensity of raindrop impacts on coffee trees, thereby limiting the splash dispersal of propagules (Mouen Bedimo *et al.,* 2008). Shade also affects the susceptibility of plants for diseases by altering their physiological state for example, stressed plants are more susceptible to diseases (Schroth *et al.,* 2000). Shade trees also favors the presence of biological control agents *Beauveria bassiana,* an entompathogenic fungus and *Cephalonomia stephanoderis*, a parasitic wasp (Medina, 1997). In addition, moderate shading can benefit slow ripening of coffee beans and promote coffee beans' quality (Läderach *et al.,* 2011). The canopy of trees also helps in reducing the amount of light reaching weeds on the ground. Generally, this results in a dramatic change in the weed flora into less aggressive ones (Muschler, 1997). Increased shade however, promotes the incidence of some commercially important pests and diseases and decrease the incidences of others for example the coffee berry borer is reported to be favored by dense shade (Messing, 2011). Excessive shading levels can also be harmful to coffee growth and production (DaMatta, 2004), for example excessive shade increases the incidence of *Mycena citricolor* (ICAFE, 1989) and the Black coffee twig borer (Kagezi *et al.,* 2013). Therefore proper shade tree selection and management are potentially important tools for integrated pest management (Wrigley, 1988).

There are numerous benefits from banana-coffee agro-forestry systems such as increased soil fertility in terms of soil organic matter and nitrogen (Zake, 2015c). There is also increased household food security among smallholder farmer practicing coffee-banana agro-forestry systems (Zake, 2015a). However, beneficial effect of intercropping only work well when the plant densities are well designed, mulching and fertilizing practices are well managed (van Asten *et al.,* 2011). Nevertheless, limited scientific data are available in Uganda on farmers' knowledge on biotic stresses and their coping mechanisms as well as the key biotic factors most related to coffee and banana yield losses within coffee-banana agro-forestry systems to ensure optimum management of these biotic stresses.

2.4 Agro-forestry as an adaptation strategy to climate change

The climate is already changing, the droughts are becoming longer, rainfall is becoming more erratic, and the rainy seasons are becoming shorter (Ministry of Water and Environment, 2015). The average temperatures in Uganda are expected to increase by 2^0C in the coming decades, with more erratic rainfall. Uganda is one of the most unprepared and vulnerable countries in the world in respect to the impacts of climate variability disasters (Zake, 2015c). This could have a considerable effect on coffee and banana production. Using climate models and analogues, the IITA-CIAT study found that the areas suitable for growing coffee will drastically decrease in the future (Jassogne *et al.,* 2013). Estimates from the study indicate that losses in the region may exceed US$100 million annually, threatening not only foreign revenue for the country by also the livelihoods of millions of smallholder farmers who depend on the crop. The coffee production areas between 1300-1700 meters will no longer be suitable for coffee production. It is therefore important for farmers to change their current practices that use traditional varieties and make use of water conservation and shade technologies (Läderach *et al.,* 2011; Consortium, 2013; Jassogne *et al.,* 2013). A temperature increase of 1^0C would lead to a yield loss of almost 100kg/ha representing 20% of the current yields amounting to US$ 100 million annually (Njuguna *et al.,* 2012). More so, coffee is mostly disadvantaged due to its sensitivity to temperature variation and its shallow feeder roots (Wrigley, 1988).

As the climate changes the major processes of agriculture that are to be directly influenced are development and incidences of weeds, pests and diseases. The soils, water, carbon and nitrogen cycles, crop growth are also likely to be affected (Rosenzwerg and Hillel 1998; Mendelsohn and Neumann, 1999; Reilly *et al*., 2001; Das, 2003). The incidence and severity of some coffee pests and diseases such as the coffee berry borer *(Hypothenemus hampei*) and coffee leaf rust (*Hemileia vastatrix*) are projected to increase. This will reduce yield and quality and increasing production costs (Muller *et al*., 2009; Filho *et al*., 2012; López-Bravo *et al*., 2012). In Uganda climate change has already affected production in most traditional production areas which has rendered the production targets unrealistic. For example coffee berry borer was previously non-existent at above 1600masl (Lepelley, 1968) but now it is found at 1864masl (Kyamanywa *et al.,* 2009). Also the intensification of coffee lace bug, stem borer and root mealybugs in eastern Uganda has already been observed (UCDA, 2008). In addition, the coffee leaf rust has increased and has spread to higher altitude (NARO, 2008; UCDA, 2008). Climate variability disasters will also cause destruction of the banana plantations increasing the risk of food shortages (Zake, 2015b). It will also have an influence on the population dynamics of black leaf streak and possibly other major diseases of banana, such as Fusarium wilt and banana bunchy top disease (Ramirez *et al*., 2011). However, agro-forestry has been identified to have some obvious advantages for maintaining production of both crops during wetter and drier years (Verchot *et al.,* 2007). Agro-forestry systems with appropriate shade trees offers a promising option to moderate the effects of heat stress locally. Trees on farm bring about favorable changes in the microclimatic conditions by influencing radiation flux, air temperature, wind speed, saturation deficit of under storey crops (Monteith *et al*., 1991). According to Beer *et al* (1998) shade trees buffer high and low temperatures extremes by as much as 5ºC. Also, Steffan-Dewnter *et al* (2007) states that the removal of shade trees increases soil surface temperature by about 4ºC and reduces relative air humidity at 2m above ground by about 12%. In fact, in most parts of the world, coffee is traditionally grown in shaded agro-forestry particularly where temperature and rainfall are not favorable (DaMatta *et al*., 2007). Also Verchot *et al.,* (2007) states that agro-forestry systems are better positioned to withstand dry periods much better mainly because their deep root systems are able to explore a larger soil volume for water and nutrients. However, farmers practice agro-forestry to provide shade, arrest degradation and for maintenance of soil fertility (Verchot, 2007). Combined yields of trees and crops from well planned and well managed agro-forestry systems tend to be higher than those from sole systems due to increased and efficient use of scarce resources especially moisture (Rao *et al*., 2007).

In addition, the Soil carbon sequestration potential of agro-forestry systems will have significant relevance in climate change adaptation and mitigation (Haile *et al.,* 2008). Actually, these systems store more carbon in the soil (14t/ha), 2 times greater than banana monoculture farming systems (Zake, 2015a). Also they reduce solar radiations and damage to plants by frost and intercept rainfall therefore improving on the coffee quality (Beer *et al*., 1998) through slow ripening of coffee beans (Läderach *et al.,* 2011).

Intercropping coffee with shade trees has also been perceived as an efficient approach to adapt to climate change and achieve sustainable production socially, environmentally and economically (DaMatta, 2004; DaMatta *et al.,* 2007; Wingtens, 2009; UCDA, 2012; van Asten *et al.,* 2012;

Jassagne *et al.,* 2013 (a, b)). Therefore, there is need to assess the tree species attributes to predict their potential compatibility with other crops (Jassogne *et al.,* 2013). Also, to evaluate different ways of their integration and their management in agro-forestry systems to provide information essential for the design of systems which may not only be ecologically sustainable but also economically attractive (Beer *et al.,* 1987). This could also be important in a production environment of increasing pressure on land resources and unstable prices (van Asten *et al.,* 2011). The characterization of compatibility-relevant attributes of tree species should allow for identification from among the wide spectrum of available timber, fruit and service tree species. In addition, the tree species should be adopted to specific environmental conditions, crop requirements and production goals (Beer *et al.,* 1987). Zake (2015a) actually states that banana, coffee and other agro-forestry tree species can coexist mutually. Therefore, a compatible match between trees and crops will ultimately help to avoid ecosystem degradation and sustain production, while at the same time produce increasingly needed timber and fruits for local or regional markets (Beer *et al*., 1987).

CHAPTER THREE
RESEARCH METHODOLOGY

3.0 Introduction

This chapter contains information about the research design, study area, study population, sampling procedures, data collection methods and instruments, quality control methods, data management and processing, data analysis and ethical considerations.

3.1 Research design

A survey research design was used to collect quantitative data. Questionnaires and biological assessment tools were used to collect the data. The questionnaire elicited socio-economic data, farm size, coffee and banana clones grown, tree species grown, other intercrops, management practices for the biotic stresses and tree species. The coffee and banana yields in 2014 were obtained by farmers' recall. The biological assessment tool was used to assess for the coffee and banana biotic constraints. A survey helped to assess the preferences, attitudes, peoples' opinions, judgment on the different tree species and knowledge of the different biotic stresses. A participatory approach was also used to collect data in that an in-depth focus interview was conducted with the randomly sampled farmers. A survey also helped in obtaining original information about the pests and diseases of coffee and banana, farmers' coping mechanisms. The independent variables in this study were the biotic constraints whereas the dependent variables were yields of both coffee and bananas.

3.2 Study area

The study was conducted in Mid-eastern region of Uganda. The region is situated in eastern Uganda immediately north of the equator at latitude 00° 45' 00" N and longitude 33° 30' 00" E. It is located at an elevation of 1,148 meters above sea level. Mid-eastern region is 3,443 square miles (8,920 square kilometers) in area, with a length of about 100 miles (160 kilometers) and a width of a little over 50 miles (80 kilometers) with a population of 3,527,000 people. Mid-eastern region is bounded by Lake Kyoga to the north, the Victoria Nile to the west, the Mpologoma River to the east, and Lake Victoria to the south. The climate and vegetation of the southern zone are influenced by Lake Victoria, where the average rainfall is 60 inches (152 centimeters) a year. This heavy rainfall produces a luxuriant growth of vegetation. The northern zone is large and flat as the land drops to Lake Kyoga. The lake affects the climate and vegetation in that area. Around the basin of Lake Kyoga, the grass is short and there are papyrus swamps. In an area with an annual rainfall of 40 inches (100 centimeters), the natural vegetation is mainly savanna interspersed with deciduous trees. The Basoga are the third largest ethnic group in Uganda. . The study was conducted in this region mainly because it is likely to be faced with poverty and food insecurity as most of the areas are being transformed into sugar cane plantations (Waluube, 2013). This study will help the farmers as coffee provides revenue twice a year and the bananas provide food throughout the year (van Asten *et al.*, 2011). The study ran from 2014 to 2016.

3.3 Study population

The study was conducted with farmers who already had existing coffee-banana agro-forestry systems in the Mid-eastern region of Uganda. Mid-eastern has a population of 3,527,000 people.

3.4 Sampling procedures

3.4.1 Sample size

70 households with already existing coffee-banana agro-forestry were selected randomly within the whole of Mid-eastern region. The 70 were considered because they fit within the planned timescale, budget and are statistically viable.

3.4.2 Sampling technique

Simple random sampling was used to select the districts to be studied within the region. Then purposive sampling technique was used to obtain the farms with already existing coffee-banana agro-forestry as these provided the necessary information that was used to achieve the objectives.

Then a simple random sample was selected from these existing coffee-banana agro-forestry**.** Simple random sampling helped to reduce error brought about by bias. Districts sampled included; Jinja, Kamuli, Luuka, Buyende, Bugiri, Kaliro and Namutuba. 10 households were sampled from each district

3.5 Data collection methods and instruments

3.5.1 Objective 1 (farmers' knowledge on the biotic stresses of coffee and banana and their coping mechanisms in managing these biotic stresses)

Questionnaire collection tools was used to collect this data (appendix 1). The questionnaire was first pre-tested to ensure that all the research objectives were being met. Questionnaires helped in obtaining large amount of information from a large number of people therefore finishing the research within the specified time. The questionnaire also helped to ensure objectivity of the data and uniformity of the questions. A pretested well-structured questionnaire with both closed and open ended questions was administered to the farmers to obtain their socio-economic characteristics (farm size, coffee and banana yield, indigenous knowledge on the field regarding biotic constraints and their coping strategies).

3.5.2 Objective 2 (biotic stresses of coffee and banana within the coffee-banana agro-forestry systems)

Biological data collection tool was used to achieve this objective. The biological field assessment helped in having an overview of the fields in this case; pests and diseases within the fields.

3.5.3 Objective 3 (the key biotic factors most related to the coffee and banana yield losses)

Biological data collection tool and farmer recall was used to achieve this objective. Farmers' recall was used to obtain the yield data for coffee and banana for the year 2014. Biological field assessment help to obtain data of the incidences of pests and diseases.

3.6 Quality control methods

Specific data collection specifications and procedures were developed and the samples were selected randomly to reduce on the errors. Also a simple language was used in structuring the questionnaire and then interpreted into the local language for the illiterate. The questionnaire and biological assessment tool were validated by the supervisors to ensure that they were suited to measure what the study intended to achieve. An open ended questions was used not to limit the farmers to specific answers. To ensure reliability the questionnaire and biological assessment tool were pre-tested with a population with similar characteristics as the target population. Then corrections were made in the collection tools to ensure a reliable set of data.

3.7 Data management and processing

Data was entered into the computer in the SPSS version 16.0 package for storing and was coded for easy entering and analysis. The annual coffee (Kiboko) and banana yields were obtained through dividing the cumulative annual production by plot size (Ha) and expressed as kg $ha^{-1}year^{-1}$ and bunches $ha^{-1}year^{-1}$ respectively. The pests and disease percentage infestations were obtained from presence and absence of the pest and disease on the sampled plants. Those with pests or disease were expressed as percentages.

3.8 Data analysis

3.8.1 Objective 1 (farmers' knowledge on the biotic stresses of coffee and banana and their coping mechanisms in managing these biotic stresses)

The data was analyzed using SPSS version 16.0. For example, socioeconomic data, farmers' knowledge and their coping mechanisms to generate means, frequencies and standard deviations. The Pearson chi-square was used to determine the significance difference between the different parameters such as sex, age and education levels. It was also used to determine the significance difference between farmers' that grew East African Highland Bananas and other banana clones. The significance difference between farmers growing Robusta and other coffee varieties was also determined using a Pearson chi-square. The chi-square was used because it can analyse frequencies. Then Microsoft excel windows 8 was used to draw the graphs and tables. In addition, the relationship of certain surrogates of indigenous knowledge (number of biotic constraints and coping strategies as mentioned by farmers) to sex, education and age of respondents were determined with simple logistic regression analysis in SAS v. 9.1 for

Windows. The nominal variables (sex, age and education) were the dependent variables and the counts were the independent variable. SPSS, SAS and Microsoft excel windows 8 were chosen as they are the ones the researcher knew and would provide the required results. The results were presented in tables and figures.

3.8.2 Objective 2 (biotic stresses with coffee-banana agro-forestry systems in Mid-eastern region of Uganda)

Percentage biotic incidences were generated using SPSS. Pearson chi-square was also used to determine the significant difference between the biotic constraints. Microsoft excel windows 8 was used to draw graphs.

3.8.3 Objective 3 (the key biotic factors most related to the coffee and banana yield losses)

The boundary line analysis was used to determine the key biotic factors most related to the coffee and banana yield losses. Boundary line analysis is a technique that helps to interpret and predict plant responses to fluctuations in several major environment factors. Boundary line analysis was originally identified by Webb (1972) and has been adapted to study the response of plants to environmental factors (Chambers *et al.*, 1985; Elliott and Dejong, 1993; Schmidt *et al.*, 1996; Webb, 1972). Recently, it has been widely applied to understand yield reduction factors and to estimate yield improvement potential (Casanova *et al.*, 1999; Fermont *et al.*, 2009; Wairegi *et al.*, 2010).

Steps involved in boundary line analysis;

1. Scatter chats were plotted in excel for the different biotic constraint and yield
2. Fitting of the boundary line. Boundary points were developed using BOLIDES (Boundary Line Development System) proposed by Schnug *et al.* (1996). The lines of the boundary points were fitted attempting to achieve the highest co-efficient of determination (R^2)
3. The key biotic factors were identified according to the factors with the highest co-efficient of determination (R^2)

3. 9 Ethical Considerations

A rapport was established with the farmers firstly by greeting them and then conducting a brief introduction about the study (for example where the researcher was from, what kind of information was required and how the research was to help the farmers), this helped in making the farmers to feel confident with the researcher. Farmers were allowed to participate voluntarily. The information collected from them was held with so much confidentiality. Their consent was obtained before going to collect data in their farms. Within their farms care was taken to ensure that no harm was caused to their crops. At the end of the study the results were shared among all stakeholders including the farmers.

3.10 Limitations of the study.

- There was a limitation of language barrier as the questionnaire had to be translated to the local language so the researcher had to get a local extension worker to help with the translation.
- The study also had a limitation of a short timeframe given by the university to finish the research and yet the research required quite a long time to finish; some objectives had to be left out and just given as recommendations for further research.
- It was also a problem to get yield information from the farmers since it was based on farmer recall so much time had to be sent on each farmer and local extension workers had to be used to make the farmers feel comfortable.

CHAPTER FOUR

PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

4.0 Introduction

This chapter contains the results and the discussion of the results.

4.1 Results

4.1.1 Socio-demographic characteristics of the interviewed respondents in Mid-eastern coffee-banana agro-forestry systems of Uganda

The socio-demographic characteristics of the farmers interviewed are summarized in table 1 below. More males (55.2%) than females (44.8%) were interviewed but not significantly (P=0.2983) different. The mean age of the respondents was 43.2 with most (41%) of the respondents belonging to the age range 37-55 years. This age range was significantly (P<.0001) different from others. The educational level of the respondents was generally low, with 60% of the respondents having not studied beyond primary level of education. A significant (P<.0001) difference amongst the education levels was observed, with most of the respondents (43%) having attained primary level of education. The mean land owned by the respondents was 2.0 hectares. Respondents in the various categories differed significantly (P=0.0225) with most of them (46%) being in category of less than 1 hectare.

Table 1: Socio-demographic characteristics of the respondents of Mid-eastern coffee-banana agro-forestry systems of Uganda.

Parameter	Respondents (%)	Chi-square (X^2)	P value	Df
Sex				
Females	44.8	1.0816	0.2983	1
Males	55.2			
Age (years)				
≤18	2.9	36.1904	<.0001	3
19-36	35.3			
37-55	41.2			
>55	19.1			
Mean±SD	43.2±15.4			
Education level				
None	17.6	32.303	<.0001	3
Primary	42.6			
Secondary	33.8			
Tertiary	5.9			
Farm size (Hectares)				
<1.0	45.6	7.5926	0.0225	2
1.0-2.0	30.9			
>2.0	23.5			
Mean±SD	2.1±3.2			

Source: Field data (2014)

4.1.2 Coffee and banana clones grown in Mid-eastern coffee-banana agro-forestry systems of Uganda

4.1.2.1 Coffee varieties

Almost all respondents (99%) reported that they were growing Robusta coffee and were significantly (P<.0001) different from those growing lowland Arabica coffee (Table 2).

Table 2: Coffee varieties grown as reported by respondents in Mid-eastern coffee-banana agro-forestry systems of Uganda

Coffee variety	Respondents (%)
Robusta	98.6
Lowland Arabica (Catimors)	1.4
Chi-square (X^2)	94.4784
Df	1
P value	<.0001

Source: Field data (2014)

4.1.2.2 Banana clones

Respondents reported to be growing 10 banana clones. The East African Highland Bananas (EAHB's) were the most (28%) grown banana clone. The number of respondents who reported this was significantly ($P<.0001$) different from other clones (Table 3).

Table 3: Banana clones grown as reported by respondents in Mid-eastern coffee-banana agro-forestry systems of Uganda

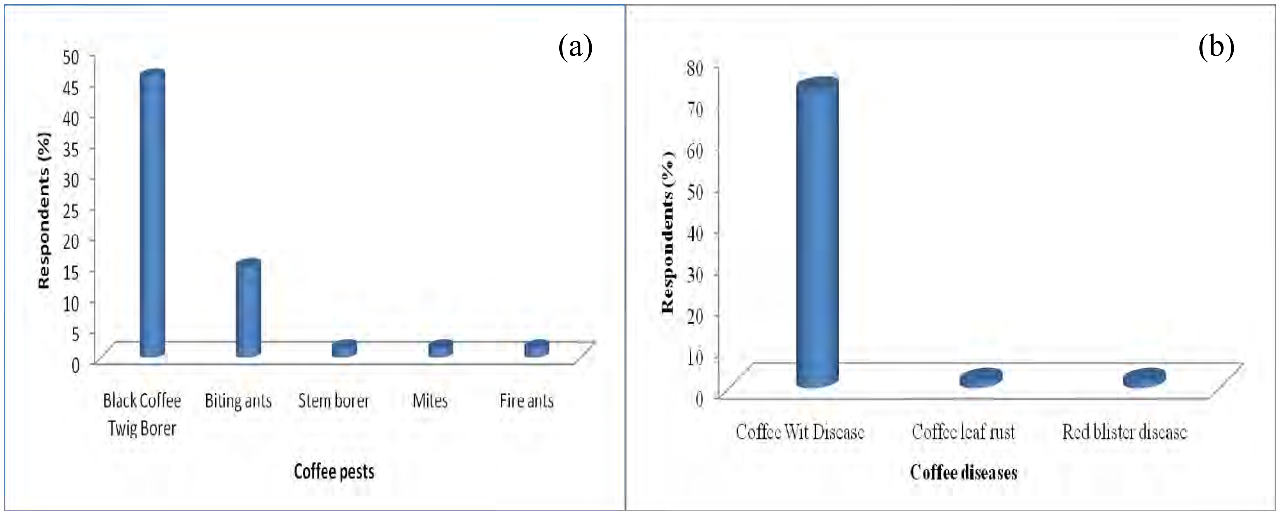
Banana clones	Use group	Respondents (%)
East African Highland bananas (EAHB)	Cooking	28.2
Bogoya	Dessert	18.9
Sukali ndiizi	Dessert	15.5
Kisubi	Beer	9.2
FHIA 17	Dessert	8.0
Kayinja	Beer	8.0
Kivuvu	Dessert	5.9
FHIA 25	Juice	4.6
Gonja	Plantain	1.3
Yangambi Km5	Juice	0.4
Chi-square (X^2)		66.3160
Df		9
P value		<.0001

Source: Field data (2014)

4.1.3 Farmers' knowledge of pests and diseases of coffee and their management in the Mid-eastern coffee-banana agro-forestry systems of Uganda

4.1.3.1 Coffee pests and diseases

Respondents reported five (5) insect pests and three (3) diseases limiting coffee production in their fields (Fig. 2). Most respondents reported the black coffee twig borer (BCTB; 46%) and coffee wilt disease (CWD; 70%) as the most important insect pest and disease of coffee respectively.



Source: Field data (2014)

Figure 2: Major pests (a) and diseases (b) of coffee as reported by respondents in Mid-eastern coffee-banana agro-forestry systems of Uganda

A simple logistic regression analysis showed that knowledge of the black coffee twig borer depended (P=0.0391) on sex of the respondent (Table 4). However, knowledge of other biotic constraints was neither dependent on sex, age nor education level of respondents.

Table 4: Sex, age and education level as determinants of respondent's knowledge of the major pests and diseases of coffee in Mid-eastern coffee-banana agro-forestry systems in Uganda

Constraint	Parameter	Df	Standard Estimate	Wald Error	Chi-Square	Pr > ChiSq
Black Coffee Twig Borer						
	Intercept	1	-1.3344	1.3639	0.9573	0.3279
	Sex	1	1.1200	0.5428	4.2574	**0.0391**
	Age	1	0.00560	0.0172	0.1053	0.7456
	Education level	1	-0.2500	0.3263	0.5872	0.4435
Biting ants						
	Intercept	1	0.6977	2.0884	0.1116	0.7383
	Sex	1	-0.8678	0.7800	1.2377	0.2659
	Age	1	0.0340	0.0296	1.3162	0.2513
	Education level	1	0.9511	0.5288	3.2353	0.0721
Coffee Wilt Disease						
	Intercept	1	-1.7781	1.5249	1.3597	0.2436
	Sex	1	0.7319	0.5770	1.6091	0.2046
	Age	1	-0.00437	0.0188	0.0541	0.8161
	Education level	1	-0.0538	0.3457	0.0242	0.8763

Source: Field data (2014)

4.1.3.2 Management options for pests and diseases of coffee

Overall, most (80%) of the respondents reported that they were neither managing pests nor diseases of coffee (Table 5). However, 50% and 79% of the respondents reported they use phyto-sanitary methods to manage BCTB and CWD respectively.

Table 5: Managing options for the major coffee pests and diseases as reported by respondents in Mid-eastern coffee-banana agro-forestry systems of Uganda

Constraint	**Management option**		
	Phyto-sanitary	**Chemical**	**Nothing**
Pest			
Black coffee twig borer (BCTB)	50.3	1.4	46.7
Biting ants	11.1	22.1	66.7
Stem borer	0.0	0.0	100.0
Fire ants	0.0	0.0	100.0
Mites	0.0	0.0	100.0
Overall mean	*12.3*	*4.7*	*82.7*
Disease			
Coffee wilt disease (CWD)	79.3	2.1	18.8
Coffee leaf rust	0.0	0.0	100.0
Red blister disease	0.0	0.0	100.0
Brown eye spot	0.0	0.0	100.0
Overall mean	*19.8*	*0.5*	*79.7*

Source: Field data (2014)

A simple logistic regression analysis showed that knowledge of managing the major pests and diseases of coffee was neither dependent on sex, age nor education level of respondents (Table 6).

Table 6: Sex, age and education level as determinants of respondent's knowledge of managing the major pests and diseases of coffee in Mid-eastern coffee-banana agro-forestry systems of Uganda

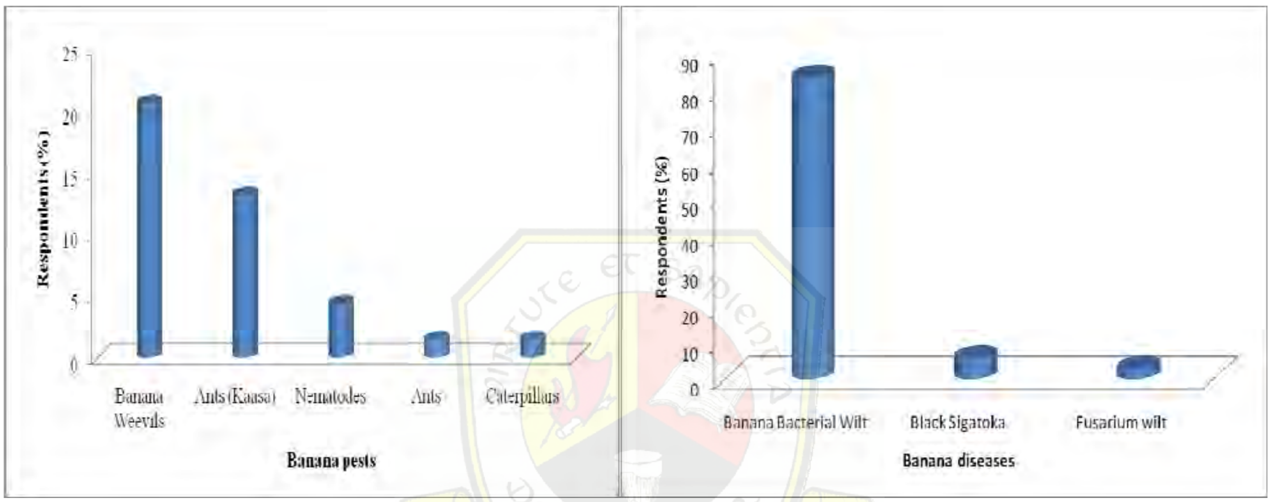
Constraint	Parameter	Df	Standard Estimate	Wald Error	Chi-Square	Pr > ChiSq
Black Coffee Twig Borer						
	Intercept	1	5.5333	2.4427	5.1313	0.0235
	Sex	1	-0.3751	0.8946	0.1758	0.6750
	Age	1	-0.00649	0.0239	0.0740	0.7856
	Education level	1	-0.8455	0.5900	2.0534	0.1519
Biting ants						
	Intercept	1	69.8379	364.2	0.0368	0.8479
	Sex	1	-24.1737	181.7	0.0177	0.8942
	Age	1	-0.3415	0.2177	2.4612	0.1167
	Education level	1	-7.3461	4.3223	2.8885	0.0892
Coffee Wilt Disease						
	Intercept	1	-4.1031	2.3669	3.0050	0.0830
	Sex	1	1.6073	0.9130	3.0993	0.0783
	Age	1	-0.00536	0.0297	0.0325	0.8570
	Education level	1	0.0681	0.4826	0.0199	0.8878

Source: Field data (2014)

4.1.4 Farmers' knowledge of pests and diseases of bananas and their management options in Mid-eastern coffee-banana agro-forestry systems of Uganda

4.1.4.1 Banana pests and diseases

Similarly, respondents reported five (5) pests and three (3) diseases limiting banana production in their fields (Fig. 3). Most respondents reported banana weevils (21%) and banana bacterial wilt (BBW; 84%) as the most important insect pest and disease of bananas respectively.



Source: Field data (2014)

Figure 3: Major pests (a) and diseases (b) of bananas as reported by respondents in Mid-eastern region

A simple logistic regression analysis showed that knowledge of pests and diseases of banana was neither dependent on sex, age nor education level of respondents (Table 7).

Table 7: Sex, age and education level as determinants of respondent's knowledge of pests and diseases of banana in Mid-eastern coffee-banana agro-forestry systems of Uganda

Constraint	Parameter	Df	Standard Estimate	Wald Error	Chi-Square	Pr > ChiSq
Banana weevil						
	Intercept	1	0.3598	1.6091	0.0500	0.8231
	Sex	1	0.5753	0.6665	0.7449	0.3881
	Age	1	-0.00576	0.0206	0.0783	0.7797
	Education level	1	0.3540	0.4073	0.7555	0.3847
Kaasa (ants)						
	Intercept	1	-1.7228	2.0112	0.7338	0.3916
	Sex	1	0.8712	0.7926	1.2084	0.2717
	Age	1	0.0485	0.0300	2.6168	0.1057
	Education level	1	0.3538	0.5058	0.4891	0.4843
Banana Bacterial Wilt						
	Intercept	1	-0.2800	1.8558	0.0228	0.8801
	Sex	1	0.2013	0.6985	0.0831	0.7732
	Age	1	-0.0239	0.0254	0.8846	0.3469
	Education level	1	-0.5746	0.4591	1.5668	0.2107

Source: Field data (2014)

4.1.4.2 Management options for pests and diseases of bananas

Overall, most (45% and 71%) of the respondents reported that they were employing phyto-sanitary options to manage the pests and diseases of bananas respectively (Table 8). However, all (100%) of the respondents reported that they were not managing caterpillars.

Table 8: Managing options for the major banana pests and diseases as reported by respondents in Mid-eastern coffee-banana agro-forestry systems of Uganda

Constraint	Management options		
	Phyto-sanitary	**Chemical**	**Nothing**
Pests			
Banana weevils	57.1	0.0	42.9
Nematodes	66.7	33.3	0.0
Ants (Kaasa)	55.6	0.0	44.4
Caterpillars	0.0	0.0	100.0
Overall mean	*44.9*	*8.3*	*46.8*
Diseases			
Banana bacterial wilt	87.7	0.0	12.3
Black Sigatoka	25.0	0.0	75.0
Fusarium wilt	100.0	0.0	0.0
Overall mean	*70.9*	*0.0*	*29.1*

Source: Field data (2014)

A simple logistic regression analysis showed that knowledge of managing the major pests and diseases of banana was neither dependent on sex, age nor education level of respondents (Table 9).

Table 9: Sex, age and education level as determinants of respondent's knowledge of managing the major pests and diseases in Mid-eastern coffee-banana agro-forestry systems of Uganda

Constraint	Parameter	Df	Standard Estimate	Wald Error	Chi-Square	Pr > ChiSq
Banana weevil						
	Intercept	1	-12.7822	218.0	0.0034	0.9533
	Sex	1	12.8040	218.0	0.0035	0.9532
	Age	1	-0.0155	0.0789	0.0383	0.8448
	Education level	1	0.7072	1.4761	0.2295	0.6319
Kaasa (ants)						
	Intercept	1	363.9	437.1	0.6931	0.4051
	Sex	1	-85.6209	103.8	0.6797	0.4097
	Age	1	-2.5096	3.1857	0.6206	0.4308
	Education level	1	-121.0	142.0	0.7256	0.3943
Banana Bacterial Wilt						
	Intercept	1	-0.5539	2.0383	0.0739	0.7858
	Sex	1	-0.7581	0.9145	0.6872	0.4071
	Age	1	-0.00300	0.0266	0.0127	0.9102
	Education level	1	-0.1900	0.5322	0.1274	0.7211

Source: Field data (2014)

4.1.5 Biotic factors within the coffee-banana agro-forestry systems of the Mid-eastern region of Uganda

4.1.5.1 Pests and diseases of coffee

Plant level assessment of coffee pests in the Mid-eastern region coffee-banana agro-forestry systems revealed 11 pests (Fig. 4a). Chi-square test showed that damage incidence of these pests varied significantly (X^2=237.0625, df=10, p=<.0001); with skeletonizers, tailed caterpillars and black coffee twig borer having the highest incidence (50%). On the other hand, four (4) diseases were observed on the sampled coffee plants (Fig. 4b) and their incidences varied significantly (X^2=32.9439, df=3, p=<.0001). The highest incidence (18%) was recorded for coffee leaf rust.

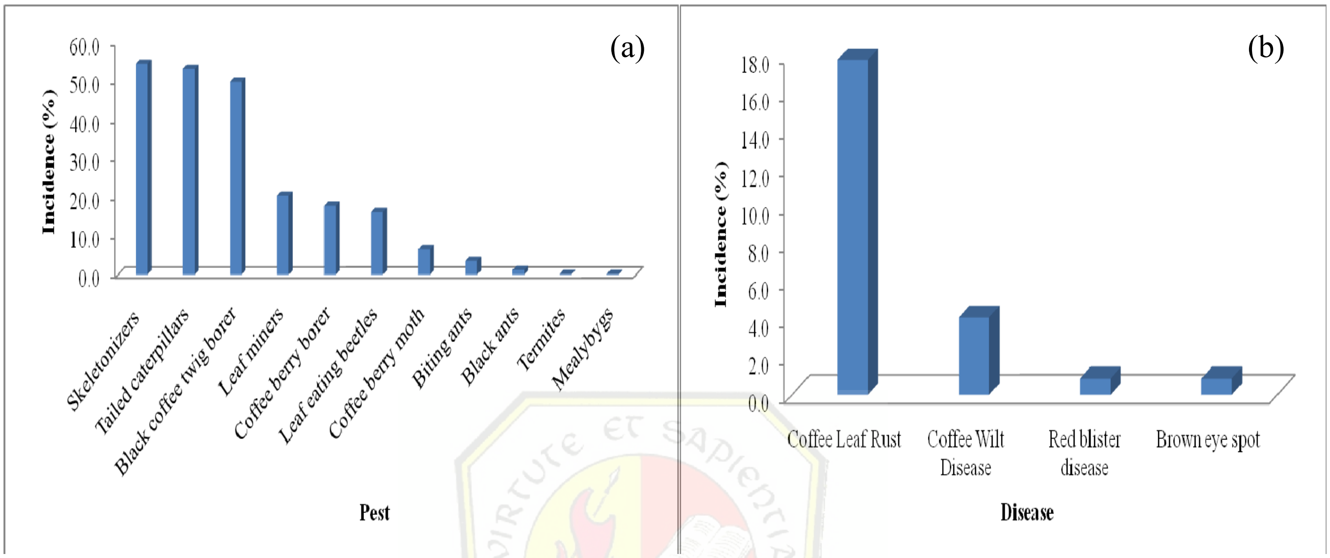


Figure 4: Pests (a) and diseases (b) observed on coffee in the Mid-eastern coffee-banana agro-forestry systems of Uganda

4.1.5.2 Pests and diseases of bananas

Only two (2) pests, the banana weevils and nematodes were observed on bananas (Fig. 5a). The incidence of banana weevils (4%) was significantly (X^2=1.8382, df=1, p=<.0001) more than that of nematodes (0.9%). On the other hand, four (4) diseases were observed on bananas (Fig. 5b) and their incidence varied significantly (X^2=98.9677, df=3, p=<.0001). The highest incidence (40%) was for siagtoka

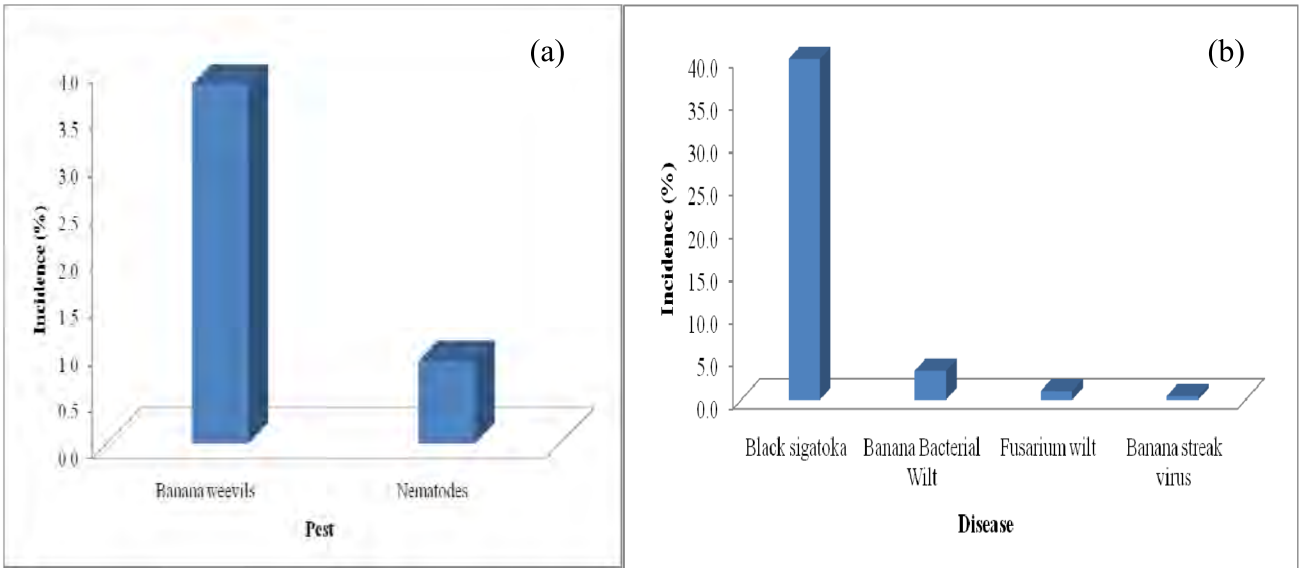
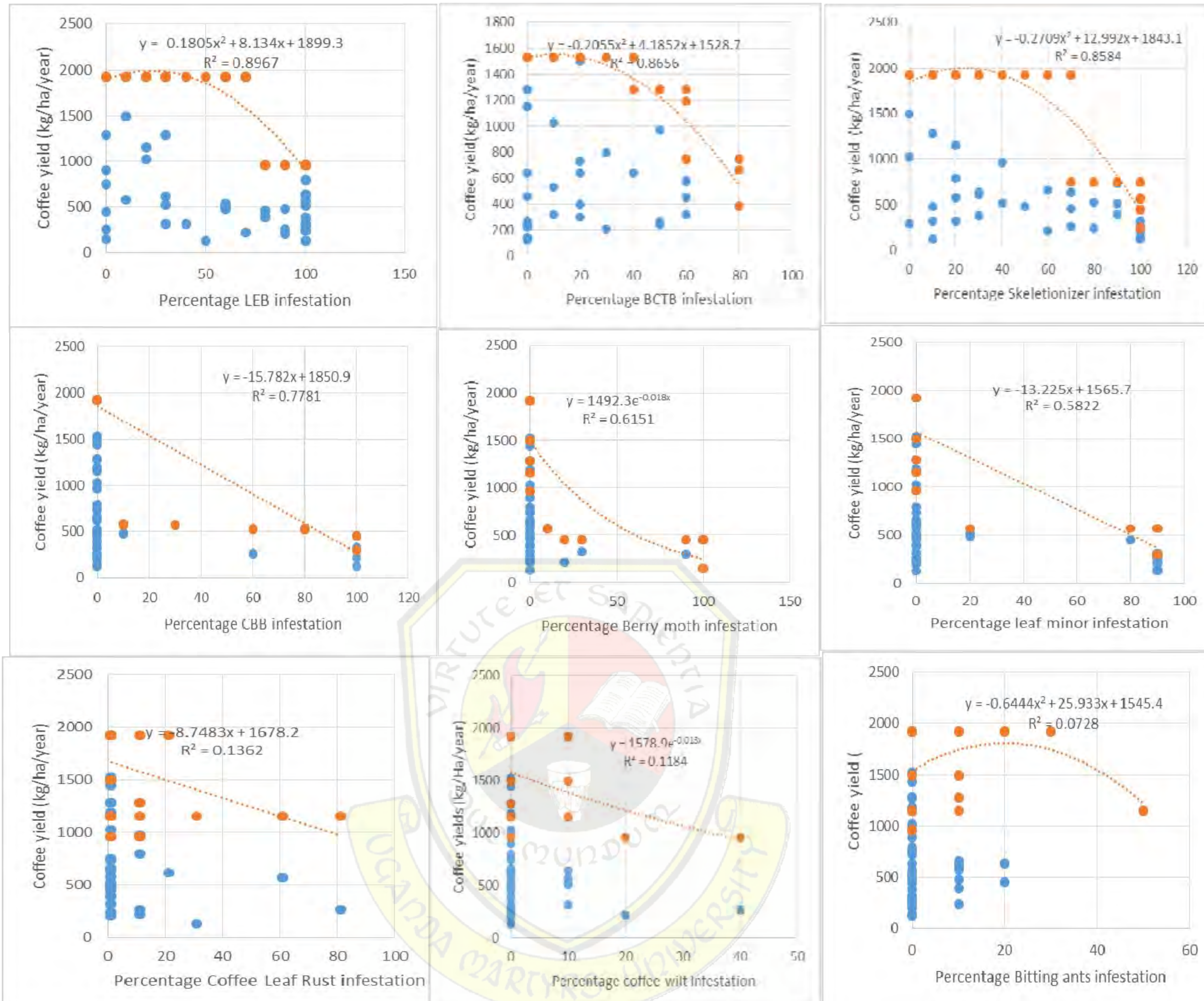


Figure 5: Pests (a) and diseases (b) observed on bananas in the Mid-eastern coffee-banana agro-forestry systems of Uganda

4.1.6 The key biotic factors most related to the coffee and banana yield losses

4.1.6.1 Relationships between coffee yield and the biotic factors

The relationship between coffee yield and biotic factors influencing it are summarized in fig. 6 below. Factors with $R^2 \geq 0.7$ were considered as the key biotic factors leading to coffee yield losses and these were, the leaf eating beetles ($R^2=0.8967$), black coffee twig borer ($R^2=0.8656$), skeletonizers ($R^2=0.8585$) and coffee berry borer ($R^2=0.7783$).

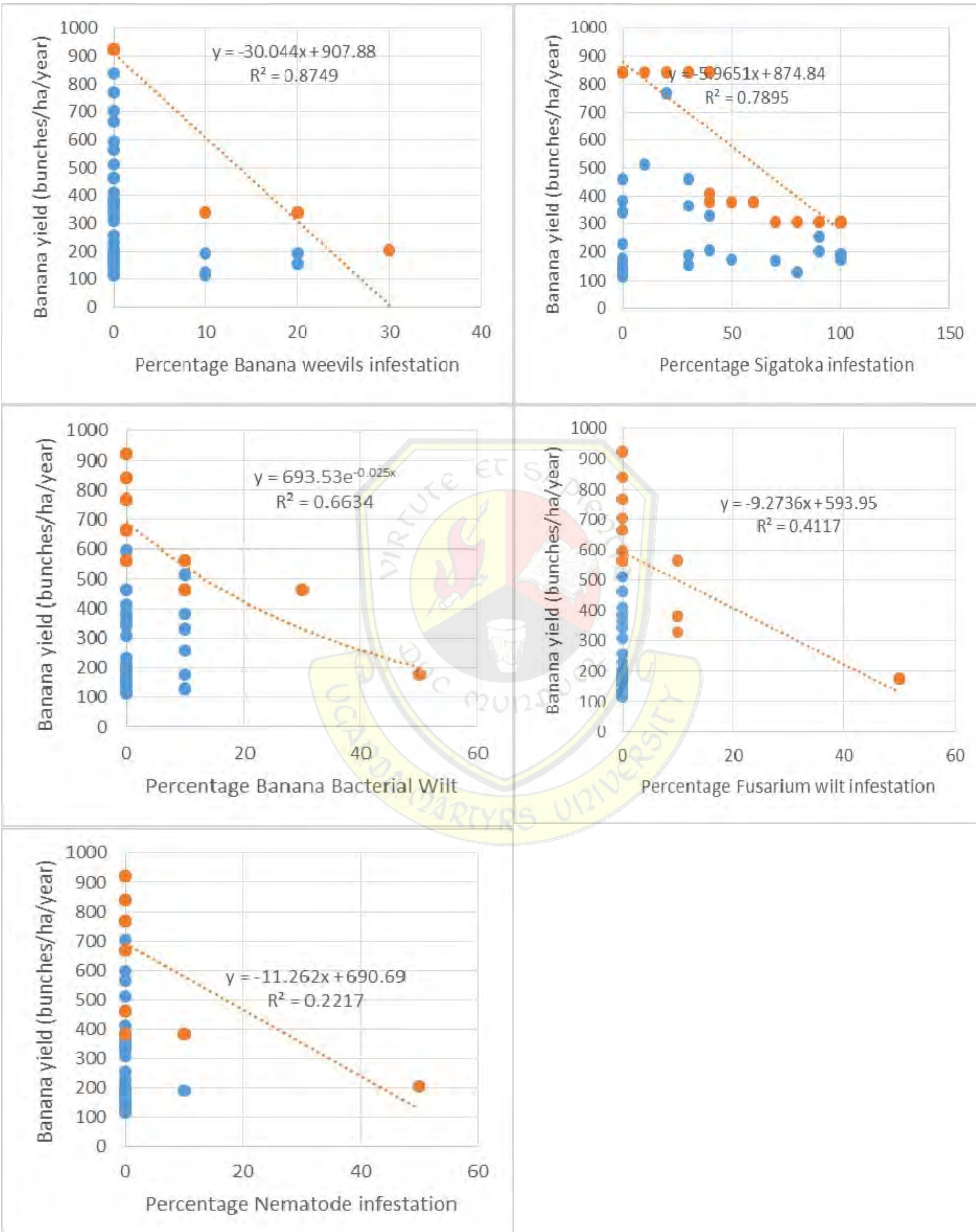


Source: Field data (2015)

Figure 6: Relationships between coffee yields and yield-related biotic factors. LEB=leaf eating beetles, BCTB=Black coffee twig borer, CBB=Coffee berry borer

4.1.6.2 Relationships between banana yield and the biotic factors

Figure 7 below shows the relationship between banana yield and the biotic factors influencing it. The scatter graphs show that the banana weevils (R^2=0.8749) and black sigatoka (R^2=0.7895) were the key biotic factors related to banana yield losses.



Source: Field data (2015)

Figure 7: Relationships between banana yields and yield-related biotic factors.

4.2 Discussion of findings

4.2.1 Farmers' knowledge on the biotic stresses and their coping mechanism

Results showed that equal numbers of females and males were interviewed in this study. This implies males and females equally participate in coffee and banana activities irrespective of their sex (Lwandasa *et al.,* 2014). Most of the respondents had attained only primary education (Jogo *et al.,* 2011; Lwandasa *et al.,* 2014); implying that most people involved in agricultural activities drop out of school at lower levels (Edmeades *et al.,* 2006; Lwandasa *et al.,* 2014). Most of the respondents belonged to an age range of 37-55 years. This age group represents the most economically active section of the community (Kagezi *et al.,* 2010). Most of the respondents had small pieces of land of less than 1 hectare; supporting Waluube (2013) who observed that the majority of the farmers in this region owned 0.8 hectares of land. This limited land is likely to exacerbate the food insecurity and poverty issues within the region.

The Black Coffee Twig Borer (BCTB), *Xylosandrus compactus* (Eichhoff) was the most reported pest limiting coffee production in the region by 46% of the respondents. The importance of the pest in the region is emphasized in surveys (Kagezi *et al.,* 2013, 2016). Presently, the region has the highest mean infestation in Uganda, with 100, 80.9 and 14.4% of the farms, coffee trees and primary branches infested respectively. Secondly, farmers know BCTB because it can be easily identified due to its distinct symptoms such as yellowing, wilt and death of the attacked plant part (Smith, 2003). The number of farmers who know about BCTB in the region has slightly increased from 42.5% observed in 2013 (Kagezi *et al.,* 2013). This means that more farmers are being exposed to the pest and therefore gain more experience and knowledge of it (Rebaudo and Dangles, 2011). In addition to BCTB, farmers recognized biting ants, *Macromischoides aculeatus* as one of the pests hindering coffee production in the region. These insect pests have been reported to cause yield reduction indirectly by hindering workers from harvesting coffee cherries due to their stings (Getachew *et al.,* 2015). Half of the respondents reported that they use phyto-sanitary measures to manage BCTB. These results are in line with various reports which have shown that farmers in Uganda (Egonyu *et al.,* 2009; Kagezi *et al.,* 2013, 2016) and elsewhere (Smith, 2003) rely on this method to control BCTB. Farmers usually prefer this method because it is readily available and effective if it is employed at community level (Kagezi *et al.,* 2013). However, it is labor intensive and might be uneconomical (Egonyu *et* *al.,* 2009). Chemical use for managing BCTB was very limited (1.4%); agreeing with Kagezi *et al.* (2013). However, 22% of the respondents reported that they control the biting ants by use of chemicals. Nevertheless, chemicals have a number of associated problems such being expensive and not readily available as well as being toxic to humans, animals and environment (Pimentel, 2005). Secondly, controlling BCTB with chemicals might be difficult because these insects spend almost their entire lifespan in the host galleries, with females only coming out to locate new galleries (Ngoan *et al.,* 1976; Egonyu *et al.,* 2009).

Coffee Wilt Disease (CWD), *Fusarium xylarioides* was the most important coffee diseases, reported by 72% of the respondents. Similarly, Unger (2014) reported that 70% of the respondents knew CWD in the southern district of Masaka. The high number of farmers who knew about CWD could be due to the fact that the disease is still a major problem in the region. According to results of a recent survey in the region, 76% of the farms were infected with CWD (Kagezi *et al.,* 2016). In addition, the disease is well known to most of the farmers in the Robusta coffee because it caused very significant damage between 2002 and 2006 (>50%; Adipala-Ekwamu *et al.,* 2001; Kangire, 2014). Farmers are also able to observe a plant infected with CWD because of its symptoms of complete wilting of the plant (Rutherford, 2006). Most of the respondents (79%) reported that they managing CWD by using phyto-sanitary measures including uprooting, cutting and/or burning of infected plants and/or plant parts. This was also observed in Masaka district by Unger (2014). Farmers claim that this method is effective but, very time consuming and tiresome (Unger, 2014). There was low usage of chemicals to management CWD (2%) and this could have been due to the fact that the pesticides are ineffective (Rutherford, 2006; Unger, 2014) since the fungus is soil inhibiting (Rutherford, 2006).

The banana weevil, *Cosmopolitus sordidus* (Germar) was reported by most (21%) of the respondents. It is the most important insect pest of bananas and plantain and because of its damage, plantations in the traditional banana-growing regions of central Uganda, which used to last 30-100 years, are now deteriorating after 5 or less years (Gold *et al.,* 1993, 1999). Most farmers (57%) reported that they use phyto-sanitary methods to manage the banana weevil. This supports work by Unger (2014) who report that 40% of the farmers were using cultural methods for managing the banana weevil. Cultural options such as use of clean planting materials, splitting pseudo stems and corms, trapping adult weevils and compacting soil over the cut rhizomes to prevent access by ovipositing weevils have been recommended for managing the banana weevil (Okech *et al*., 1999; Masanza, 2003). Farmers use this method because it is cheap and sustainable (Masanza, 2003).

The majority of farmers (84%) recognized Banana bacterial wilt (BBW), *Xanthomonas campestris* pv. musacearum as the most important disease of bananas in their region. This result is in line with Jogo *et al*. (2011) who reported that >90 of the farmers they sampled in Uganda and Kenya were aware of the disease and its symptoms. BBW is currently the most important disease of bananas in Uganda (Jogo *et al*., 2011; Kubiriba *et al.*, 2014) and it has been present in Mid-eastern region for more than a decade (Kagezi *et al*., 2006). Many farmers know BBW because it is easily recognized from its symptoms; yellowing and wilting of leaves as well as oozing out of puss-like sap from a cut plant material (Eden-Green, 2004; Tushemereiwe *et al.,* 2004). More than 80% of the respondents acknowledged using phyto-sanitary methods for managing BBW; agreeing with Jogo *et al.* (2011). This method involves: - using clean planting materials, destruction of infected plants or plant materials, removal of male buds, disinfecting tools etc. (Tushemereirwe *et al.,* 2004). This method is likely to slow and therefore a key step in preventing the disease spread, if adhered to (Karamura *et al*., 2005).

4.2.3 The biotic factors within the coffee-banana agro-forestry systems of the Mid-eastern region of Uganda

In this study, leaf skeletonizers, tailed caterpillars and black coffee twig borer were observed to be the most frequently occurring insect pests in the Mid-eastern region coffee-banana agro-forestry systems. Leaf skeletonizers, *Epiplema dohertyi* Warren (Lepidoptera: Epiplemidae) have been recognized as the most frequently observed insect pest on wild (Ababulgu, 2010) and plantation coffee (Million and Bayisa, 1986; Abedeta *et al.,* 2015; Samnegård, 2016) in Ethiopia. Similarly, this pest was one of the most important insect pests of coffee in Uganda, particular in lower altitudes (Jassogne *et al.,* 2013). Damage by this insect pest is caused by the larvae mining into the palisade tissue under the upper epidermis (Wrigley, 1988) and thus reducing the area for photosynthesis.

The second most observed insect pest was the tailed caterpillars, *Epicampoptera andersoni* (Tans) and *E. marathica Tams* (Drepanidae). This pest has been reported to occasionally occur in large numbers, with most severe outbreaks seen on Robusta particularly, near forested areas (Padi and Ampomah, 1995; Musoli *et al.,* 2001). Damage is caused by the feeding of the larvae of *Epicampoptera* sp. – the young ones feed on the under surface of the leaf leaving the upper surface intact whereas, the older ones feed at the edge of the leaf, eating everything except the mid rib. If the tree is completely defoliated, the larvae eat the berries and green bark (Hill, 1983). The high incidence of both skeletonizers and tailed caterpillars could probably in part be due to farmers' lack of knowledge on the damage they cause and thus not managing them.

The black coffee twig borer (BCTB), *Xylosandrus compactus* (Eichhoff) was also among the most observed insect pests on coffee plants in the region. Although BCTB is relatively new in Uganda compared to other pests of coffee (Egonyu *et al.,* 2009), the pest is rapidly gaining importance in the Mid-eastern region sub-region (Kagezi *et al.,* 2016). A 6-fold increase in the number of primary branches infested by BCTB has been recorded from 2.4% observed in 2013 (Kagezi *et al.,* 2013) to 14.4% in 2016 (Kagezi *et al.,* 2016). BCTB attacks the berry-bearing primary branches and young suckers causing them to wilt and eventually die within a few weeks (Hara & Beardsley, 1976; Ngoan *et al.,* 1976).

For the disease, coffee leaf rust which is caused by a fungus *Hemilea vastatrix* (Berkeley and Broome) was the most frequently observed. This disease has been recognized to be one of the most important on both Arabica and Robusta coffee in Uganda (Phiri *et al.,* 2011) and elsewhere (Zeru *et al.,* 2009; Hindorf and Omondi, 2011; Bigirimana *et al.,* 2012; Reuben and Mtenga, 2012). Severe disease causes serious defoliation. This results in low yields and poor grain quality due to reduced photosynthesis and die-back that may lead to eventual death of the attacked tree (Phiri *et al.,* 2011). It is estimated that coffee leaf rust can cause more than 30% loss in production in susceptible varieties if not managed (Cristancho and Escobar, 2008).

On the other hand, the banana weevil, *Cosmopolites sordidus* (Germar) was the most prevalent insect pest observed on bananas. This result is in line with several researchers who have recognized *C. sordidus* as the most important insect pest of bananas and plantains in Uganda (Gold, 2001; Gold *et al.,* 2004) and elsewhere (Dahlquist, 2008). Damage is caused by the tunneling of the weevil larvae into the rhizome or corm. This makes the host plant weak leading to snapping, toppling and deterioration or sometimes death of the attacked plant (Gold, 2001). The weevil can cause a yield loss of 40-100% if not managed (Rukazambuga *et al.,* 1998; Gold *et al.,* 2004).

Black Sigatoka (black leaf streak) caused by the fungus *Mycosphaerella fijiensis* was the most prevalent disease observed on the sampled banana plants. This disease has been reported to be a major constraint causing yield reduction on cooking bananas particularly in central Uganda where it is now considered a threat to food security (Tushemereirwe, 1996; Tushemereirwe *et al.,* 1993, 2004). It causes premature drying of leaves, leading to reduction in functional leaf area that results into incomplete filling of banana fingers (Tushemereiwe *et al.,* 2004). This is translated into decline in quality and quantity of the fruit. A 37% bunch weight loss due to black sigatoka has been observed in an on-station trial at Kawanda Research Station (Tushemereirwe, 1996; Tushemereirwe *et al.,* 2000).

4.2.4 The key biotic factors most related to the coffee and banana yield losses

This study aimed at determining the key biotic factors most related to coffee and banana yield losses in the Mid-eastern region coffee-banana agro-forestry systems of Uganda. Results showed that leaf eating beetles, black coffee twig borer (BCTB), leaf skeletonizers and coffee berry borers (CBB) were the key biotic factors most related to coffee yield losses. Aristizábal *et al.* (2013) also recognized the leaf beetles as one of the major phytophagous insect pest contributing to yield losses in coffee in Columbia. Leaf beetles have chewing mouthparts and typically attack the coffee leaves, removing developing foliage between secondary leaf veins. The leaves show irregular holes, tearing and notches on their edges, often beginning at the tip and from the edge towards the vein (Berrera, 2008). The feeding of these beetles therefore reduces the photosynthetic area of the coffee plant that leads to yield losses. The high incidence of these insect pests on farmers' fields could probably in part be due their lack of knowledge on the damage they cause and therefore inability to relate it to yield loss. This therefore leads to farmers not managing them.

The importance of the black coffee twig borer (BCTB), *Xylosandrus compactus* (Eichhoff) in reducing coffee yields cannot be overlooked. The pest attacks the berry-bearing primary branches, causing them to wilt and eventually die after a few weeks. Results from a survey conducted by NaCORI in April-May 2016 show that 9.6% of the primary branches of coffee in Uganda are infested by BCTB (Kagezi *et al.,* 2016). This infestation is equivalent to 9.6% loss in coffee export volumes since the attacked primary branches will not produce berries (Egonyu *et al*., 2009; Kagezi *et al*., 2013, 2014). If the pest is therefore not managed, this is translated into an estimated loss of US$57.5 million of foreign exchange (Kagezi *et al.,* 2016). BCTB is a major pest because it spreads rapidly within coffee fields and between fields; has a wide host plant species range; ability of the female BCTB to fly for over 200 meters in a single flight and therefore infest many host plants before they dies; short lifespan and high reproductive potential (Hara and Beardsley, 1976; Ngoan *et al.,* 1976). This is coupled with farmers' lack of knowledge as well as reluctance to manage the pest in the region as observed in a survey conducted by Kagezi *et al*. (2016).

The third key factor related to coffee yield losses were the leaf skeletonizers, *Epiplema dohertyi* Warren (Lepidoptera: Epiplemidae). Skeletonizers have been recognized as major pests of coffee in Uganda (Jassogne *et al.,* 2013) and elsewhere (Million and Bayisa, 1986; Padi and Ampomah, 1996; Ababulgu, 2010; Abedeta *et al.,* 2015; Samnegård, 2016). As with leaf eating beetles, coffee farmers have limited knowledge on the potential loss in yields cause by skeletonizers and therefore rarely manage them. For example, Ababulgu (2010) observed that skeletonizers had caused a leaf damage of 53% on wild coffee in Ethiopia. Damage by these pests is caused by the feeding of their larvae that takes place underside the leaves, usually near the midrib eating everything except the veins and the upper epidermis, leaving irregular lace-like patches in the leaf (Crowe and Gebremedhin, 1984). This reduces the area for photosynthesis of the plant (Wrigley, 1988).

Coffee berry borer (CBB), *Hypothenemus hampei* (Ferrori) is equally an important insect pest responsible for yield loss in coffee in Uganda (Kucel *et al.,* 2009) and elsewhere (Vegas *et al.,* 2009). The colonizing female bores into the berry and deposit eggs within galleries, upon hatching, larvae feed on the coffee seeds inside the berry, thus reducing yield and quality of the marketable product (Jaramillo *et al.,* 2006; Vegas *et al.,* 2009; Vijayalakshmi *et al.,* 2013). Severe infestation may result in up to 80% of berries being attacked in Uganda and Ivory Coast, and 96% in Congo and Tanzania (Waterhouse and Norris, 1989). Recent results from a survey conducted in April-May 2016 show that 19.6% of the coffee berries sampled in the Robusta coffee growing regions of Uganda were infested with CBB (Kagezi *et al.,* 2016). This can be translated into 19.6% loss in coffee export volumes valued at US$117.3 million.

For bananas, the banana weevil, *Cosmopolites sordidus* (Germar) and black sigatoka caused by the fungus *Mycosphaerella fijiensis* were identified as the key biotic factors related to banana yield losses. These results are in agreement with studies that have been conducted in central Uganda. For example, farmers in this region ranked *C. sordidus* as the most important factor restricting yields of banana (Gold *et al.,* 1999). Similarly, using boundary line analysis, Wairegi *et al.* (2010) reported the banana weevil as the most important biotic factor contributing to yield loss in central Uganda. Damage is caused by the larvae boring into the corm and the lower pseudo stem, leading to dying of suckers, snapping and toppling (Bosch *et al.,* 1995; Rukazambuga 1996). Injury to the corm also interferes with root initiation and sap flowing in the plant (Shillingford, 1988), resulting into yellowing, withering and eventual death of leaves. If not controlled, the pest can lead to a loss in yield of 40-100% in East African Highland Banana (Rukazambuga *et al.,* 1998; Gold *et al.,* 2004).

On the other hand, black sigatoka is one of the most important diseases contributing to yield loss in the East African Highland Bananas (EAHB's) in Uganda (Tushemereirwe, 1996; Tushemereirwe *et al.,* 1993, 2004). Sigatoka reduces the functional area of banana leaves since it causes them to dry prematurely. This then results into incomplete filling of banana fingers and thus decline in quality and quantity of the fruit (Tushemereiwe *et al.,* 2004). A 37% bunch weight loss due to black sigatoka has been observed in an on-station trial at Kawanda Research Station (Tushemereirwe, 1996; Tushemereirwe *et al.,* 2000). Similarly, in West Africa, yield losses of 33-50% have been observed on plantains (Mobambo *et al.,* 1993).

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter contains the summary of the finding, conclusions and recommendations.

5.1 Summary of the findings

The number of males and females sampled were not significantly different. Majority of the respondents ranged from 37-55 years and had completed primary level. The highest number of respondents (28.2%) grew East African Highland Bananas and 68.5% grew indigenous Robusta. The respondents had more knowledge on BCTB, CWD, banana weevils and banana bacterial wilt. This could have been because these biotic factors have been major threats to these crops. Overall, the majority of the respondents (80%) were not managing the biotic stresses. However, 50 and 79% of the respondents reported that they were using phyto-sanitary measures to manage BCTB and CWD respectively. Most of the respondents had no control for these biotic constraints. Few respondents were using phyto-sanitary and chemical methods. For bananas, 45 and 71% of the respondents were employing phyto-sanitary measures to manage banana weevil and BBW respectively. Farmers' knowledge on biotic constraints were not dependent on sex, age and education levels except for BCTB that was dependent on sex. Skeletonizers, tailed caterpillars and black coffee twig borers were the most important pests of coffee with 50% of the coffee plants infested with these pests; whereas, coffee leaf rust was the most observed coffee disease (18%). On the other hand, the most observed pest and disease of bananas were the banana weevils (4%) and black sigatoka (40%) respectively. The key biotic factor related to coffee yield losses were BCTB, LEB and skeletionizers while the ones for bananas were banana weevils and sigatoka.

5.2 Conclusions

Results of this study led to the following conclusions: -

- Farmers in the coffee-banana agro-forestry systems of Mid-eastern region had limited knowledge on pests and diseases of both crops as well as their management, apart from the black coffee twig borer, coffee wilt, banana weevils and banana bacterial wilt. .

- The most biotic constraints observed on coffee were: - skeletonizers, tailed caterpillars, black coffee twig borer and coffee leaf rust whereas; banana weevils and black sigatoka were the commonest constraints on bananas.
- The key biotic factors related to coffee yield losses were leaf eating beetles, BCTB, skeletionizers whereas; banana weevils and black sigatoka were for bananas.

5.3 Recommendations

From the conclusions above, the following recommendations are suggested: -

- Farmers should pay more attention in managing the identified key biotic factors most related to coffee and banana yield losses, including: - black coffee twig borer, leaf eating beetles, skeletionizers, banana weevils and sigatoka.
- Dissemination of information on the biotic constraints and how they are managed should be emphasized by all stake holders including extension and researchers.
- Research should therefore aim at developing management strategies for these biotic constraints.

5.4 Suggestions for further research

Therefore: -

- There is need to estimate the yield gaps of coffee and banana due to the biotic factors within the coffee-banana agro-forestry systems. This information forms a basis for developing management strategies.
- There is also need to further optimize the coffee-banana agro-forestry cropping system for management of biotic stresses in the region. Optimization will provide information on the best-bet combination for managing these pests and diseases in the coffee-banana-agroforestry systems.

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APPENDICES

Appendix I: data sheet

TOWARDS OPTIMIZING COFFEE-BANANA AGRO-FORESTRY CROPPING SYSTEMS FOR MANAGEMENT OF BIOTIC STRESSES IN MID-EASTERN COFFEE GROWING REGION OF UGANDA.

Dear Sir/Madam,

My name is KOBUSINGE JUDITH. Am currently a Master's of Science Agroecology student at Uganda Martyrs University. I am doing research in coffee-banana agro-forestry systems and you have been randomly selected to participate in this study. The main aim of the study is to acquire information that will provide a basis for recommendations for managing the major biotic factors in coffee-banana agro-forestry systems in Mid-eastern region of Uganda. My questionnaire has two sections, the socio economics and the biology. The socio economics section will be answered by you and the biology will be collected by the researcher. I believe you have crucial information on the above subject matter and thus request you to assist me answer the questions below appropriately. I assure you that the information that you provide will remain confidential and will not be used for any other purpose other than the intended purpose as outlined in the objectives of this research. I would like to sincerely thank you for accepting to participate in this study. God bless you

Yours,

Kobusinge Judith

A. SOCIO ECONOMICS.

1. FARM LOCATION.

Date:……………………….. Interviewer:……………………….

District:……………………. Sub-county:………………………..

Parish:…………………….. Village:……………………………..

Location (GPS) reading:………………….. Altitude……………………………

2. HOUSEHOLD DETAILS.

	Name	**Sex** ***1***=*male* ***2***=*female*	**Age** (years)	**Education level** ***0***= *none* ***1***= *primary* ***2***= *secondary* ***3***= *tertiary*
Respondent				
Household head				

3. FARM DATA.

Total farm size (acres)	**Proportion** ***0***=*0%* ***1***=*1-25%* ***2***=*26-50%* ***3***=*51-75%* ***4***= *>75%*			
	Annual crops	Coffee	Banana	Shade trees and shrubs

4. STATUS OF COFFEE AND BANANA PLANTATIONS.

i) Coffee clones grown.

Coffee	**Proportion 0**=0% **2**=<25% **3**=26-50% **4**=51**-**75% **5**=>75%
Indigenous Robusta	
Robusta elite	
Robusta clonal	
Nyasaland	
Improved Arabica	
Lowland Arabica (catmors)	
Others (specify)	

ii) Banana clones grown

Bananas	**Proportion 0**=0% **2**=<25% **3**=26-50% **4**=51-75% **5**=>75%
EAH bananas (Matooke & mbidde)	
Ndiizi	
Bogoya	
Gonja	
Kayinja	
Kisubi	
Kivuvu	
FHIA 17	
Km5	
FHIA 25	
FHIA 23	
Others (specify)	

EAHB (Matooke and mbidde) cultivars grown.

………
………
…………………………………………………………………………

iii) Crop yields in the last year.

Coffee	**Quantity (specify units)**	**Amount (Ug shs)**	**Who manages the money**
Number of units (specify) per season (main crop)			
Number of units (specify) per season (fly crop)			
Bananas			
Number of bunches of cooking bananas per month			
Number of bunches of beer bananas per month.			
Number of bunches of dessert bananas per month			

5. PRODUCTION CONSTRAINTS AND COPING STRATEGIES.

i) Pests.

Coffee	**0=no 1=yes**	**Coping mechanisms** ***0****=nothing* ***1****=phytosanitary (specify)* ***2****=cultural (specify)* ***3****= plant nutrient management* ***4****=trapping* ***5****=biological* ***6****=chemical (specify)* ***NA****= not applicable*
Black coffee twig borer (BCTB)		
Coffee berry borer (CBB)		
Stem borers		
Lace bugs		
Leaf minors		
Skeletonizers		
Mealybugs		
Scales		
Antestia bugs		
Coffee berry moth		
Fire ants		
Others (specify)		
Bananas		
Banana weevils		
Nematodes		
Aphids		
Others (specify)		

ii) Diseases

Coffee	**0=no 1=yes**	**Coping mechanisms** ***0****=nothing* ***1****=phytosanitary (specify)* ***2****=cultural (specify)* ***3****= plant nutrient management* ***4****=biological* ***5****=chemical (specify) 6=concoctions* ***NA****= not applicable*
Coffee wilt disease (CWD)		
Coffee leaf rust (CLR)		
Coffee berry disease (CBD)		
Red blister		
Brown eye spot		
Bacterial blight		
Armillaria rot		
Others (specify)		
Bananas		
Banana bacterial wilt (BBW)		
Sigatoka leaf spot		
Fusarium wilt		
Banana streak virus (BSV)		
Bunchy top		
Others (specify)		

B. BIOLOGY

1.FARM LEVEL

i) Slope of the farm (**1**=flat **2**=gentle **3**=steep)……………………………………

ii) Intercropping.

Crop	**Intensity 0=**none **1=**low **2=**medium **3=**high	**If yes, mention all the crop species present (NA=not applicable)**
Coffee		
Banana		

iii) Trees and shrubs

Crop	**Intensity 0=**none **1=**low **2=**medium **3=**high **NA=**not applicable	**If yes, mention all the tree species present (NA=not applicable)**
Coffee		
Banana		

2. PLANT LEVEL

2.1 COFFEE

Plant no.	Clone type*	Presence of pests and diseases 0=no 1=yes						
		BCTB	SB	CBB	CWD	CLR	RB	Others
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

***1**= Robusta elite **2**= Robusta clonal **3**= Nyasaland **4**=Improved Arabica **5**=Lowland Arabica (catmors) **6**= Others (specify)*

BCTB= Black Coffee Twig Borer **SB=** Stem Borer **CBB=** Coffee Berry Borer **CWD=** Coffee Wilt Disease

CLR= Coffee Leaf Rust **RB=** Red Blister

2.2 Banana

Mat no.	Clone type*	Presence of pests and diseases 0=no 1=yes					
		BW	Nem	FW	BBW	SGT	BSV
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

1** *=EAH bananas (matooke)* ***2= *Ndiizi (Kabalagala)* ***3=*** *Bogoya* ***4=*** *Gonja* ***5=*** *Kayinja (musa)* ***6=*** *Kisubi* ***7=*** *Kivuvu (Kidozi, Bokora)* ***8=*** *FHIA17* ***9=*** *Km5* ***10=*** *FHIA25* ***11=*** *FHIA23*

BW= Banana weevils **Nem=** Nematodes **BBW=** Banana bacterial wilt **FW=** Fusarium wilt **SGT=** Sigatoka **BSV=** Banana streak virus