MANAGING AGRONOMIC CONSTRAINTS TO ENHANCE PERFORMANCE OF COFFEE AND BANANAS IN COFFEE-BANANA AGRO-FORESTRY SYSTEMS

CASE STUDY: SOUTH-WESTERN UGANDA

A postgraduate dissertation presented to the Faculty of Agriculture in partial fulfillment of the requirements of the award of the degree Master of Science in Agro-Ecology

Uganda Martyrs University

NAKIBUULE LILIAN

2013-M152-20035

October, 2016

DEDICATION

To my parents (Mr. & Mrs. Kibuule), who raised and educated me. You have continuously supported and inspired me and enabled me to come this far.

ACKNOWLEDGEMENT

This work echoes the kind support received from my immediate supervisors Mr. Gelvan Kisolo and Dr. Kagezi Godfrey for their guidance and support they accorded to me. Their mentorship, unreserved advice and encouragements will always be remembered. To my other mentors who closely guided my research; Mr. Patrick Kucel of National Coffee Research Institute (NaCORI), Mr. David Mukasa and Mr. Bukomeko Hannington of International Institute of Tropical Agriculture (IITA), I appreciate your time and guidance invested to make this thesis a success.

In a more special way, am very grateful to the USAID-PEER project principal investigator, Dr. Kagezi Godfrey who gave me a chance to undertake this course plus the funding from the project. Am very grateful for this great value you have added to my career.

I extend my appreciation to the management of NaCORI under which I conducted my research for the good working environment accorded to me. To the NaCORI scientists who guided me along the chain of my thesis development am very grateful for your effort.

I wish to thank the staff of the Faculty of Agriculture for the dedication they showed while teaching me plus my colleagues in the Agro-ecology class, for the valuable contribution, support and team spirit they exhibited throughout the course.

Lastly, the collaboration of the farmers who generously accepted to be interviewed is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

cm:	Centimeters
$C0_2$:	Carbondioxide
CWD:	Coffee Wilt Disease
ha:	Hectare
IITA:	International Institute of Tropical Agriculture
mg:	Milligrams
mm:	Millimeters
m:	Meters
NaCORI:	National Coffee Research Institute
NARO:	National Agricultural Research Organization
UCDA:	Uganda Coffee Development Authority
yr:	Year

ABSTRACT

Coffee and bananas are major cash and food crops respectively for many smallholder farmers in Uganda. These two crops can be grown as a sole crop although there is a tendency to intercrop the two. Production of both crops is declining tremendously and yields are still below their potential. This is attributed to a number of constraints of which abiotic and agronomic constraints are pertinent. However, there is no information on the effect of these agronomic constraints on yield performance of both crops. Modern science has therefore envisaged agroforestry systems as an entry point to better manage these constraints. The study aimed at determining farmers' knowledge on the agronomic and abiotic constraints hindering coffee and banana production and their coping strategies in regard to the constraints. Furthermore, to identify the agronomic constraints in coffee-banana agroforestry systems at plant and plot level and to identify the agronomic constraints most related to coffee and banana yield loss in coffee-banana-agroforestry systems. Hence, this study purposively assessed the abiotic and agronomic constraints limiting yield of coffee and bananas in coffee-banana-agroforestry systems. The study was carried out in 9 districts of south-western Uganda taking 10 farmers per district with existing coffee-banana-agro-forestry systems. Data was collected through structured farmer interviews and use of biological assessment tools. More than 70% of farmers acknowledged importance of all constraints in limiting production. However, 96% reported on broad-leaved weeds (p=0.3153) as major agronomic constraints. These were not significantly different from those who reported on other agronomic constraints like grassy weeds and abiotic constraints like declining soil fertility, soil erosion and drought. As a way of coping with broadleaved and grassy weeds 78% and 71% of farmers respectively used hoes, 63% for declining soil fertility used organic fertilizers, 49% for soil erosion used trenches and 39% for drought used mulching. Using simple logistic regression, the knowledge on constraints and number of coping options was neither dependent on sex, age and education. Plot level management practices showed that most farms (48%) were moderately weeded, mulching was low on 43% of farms and >60% of farms had no manure, cover crops, trenches and terraces. Coffee plant level agronomic practices showed that farmers who were not de-suckering and pruning and those who had moderately desuckered and pruned their coffee was almost equal (30-40%). However, majority (70%) of them had not changed cycle of their coffee. Banana plant level management practices showed that generally farmers were practising de-suckering, deleafing and debudding (>50%) and atleast 30% were practising corm removal and propping. Most limiting factors for coffee yield were number of stems (R^2=0.76), de-suckering (R^2=0.99) and density of trees (R^2=0.91). For bananas they were de-leafing (R^2=0.89), corm removal (R^2=0.89) and density of trees (R^2 =0.77). All in all, farmers had knowledge of the abiotic and agronomic constraints limiting coffee and banana production in the region and how they manage them. They reported on broad-leaved and grassy weeds as agronomic constraints and soil fertility, soil erosion and drought as abiotic constraints. Most of the fields were moderately weeded as well as mulched. However, manuring, trenches, cover crops and terraces were rarely done. On the other hand, most coffee plants were moderately desuckered as well as prunned but there was no evidence of change of cycle. Also most banana plants had been desuckered, deleafed and debudded; however, corm removal and propping were practiced at a low level. Scatter plots identified desuckering, density of shade trees/shubs and number of coffee stems as agronomic constraints most related to coffee yields, whereas; corm removal, de-leafing and density of shade trees/shrubs were for bananas. Therefore, yield gap of coffee and banana caused by the agronomic constraints identified in this study should be estimated. This forms the basis for developing an effective and site-specific management strategy for these constraints in the coffee-banana agro-forestry systems of southwestern Uganda. Further studies should focus on optimizing coffee-banana agro-forestry systems to design the best-bet combinations for managing the agronomic and abiotic stresses of coffee and bananas.

Key words: Abiotic constraints, coffee-banana-agroforestry systems, agronomic constraints.

CHAPTER ONE

GENERAL INTRODUCTION

1.0 Introduction

This chapter presents the background, statement of the problem, specific objectives, research questions and hypotheses. The scope, justification of the study and the conceptual framework are also presented in this chapter.

1.1 Background of the study

Uganda is the 10th top coffee producer in the world (Vieira, 2008). With a total planted area of 272,000 ha, coffee is Uganda's primary cash crop and it accounts for approximately 20% - 30% of the annual export revenue which was valued at US$446 million in the coffee year 2012/11 (UCDA, 2012). More than 3.5 million households are engaged in coffee industry and approximately three quarters of Ugandans rely on coffee-related activities for household earning (UCDA, 2012). Small-scale farmers holding less than 2.5 ha land size are dominant in the coffee industry and contribute as much as 90% of Uganda's coffee production (Musoli *et al.,* 2001; UCDA, 2012). For smallholder farmers, coffee is of great importance as it is the major source of income for the households and it provides a cash boom once or twice a year (Jassogne, 2011). Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*) are the two major coffee species grown in Uganda. These represent 30% and 70% of the total coffee export respectively (Musoli *et al.,* 2001; UCDA, 2012). Amidst all this, coffee production is still far below the attainable yields. For example, the actual clean (green) Robusta coffee yields average 550 Kg ha^{-1} is almost four times less than the attainable yields of 2.2 t ha^{-1} (Café Africa, 2008). The main constraint has been the outbreak of Coffee Wilt Disease (CWD) in the early 1990's which wiped out more than half of the Robusta coffee (Adipala-Ekwamu *et al*., 2001). Thus, research has been focusing mainly on this disease through development of resistant genotypes (Musoli *et al*.,2001) and paying limited attention to other constraints (CIALCA, 2008). However, coffee production is equally threatened by both abiotic (declining soil fertility, moisture stress, erratic rainfall, poor soil and moisture management) and poor agronomic practices (pruning, de-suckering, change of cycle etc), (Shively and Hao, 2012; Jassogne *et al.,* 2013).

These constraints have resulted into low yields that pose large challenges to small-scale farmers' livelihoods (Mureithi, 2008).

Bananas on the other hand are one of the most important food crops in the world (Samson, 1992). Uganda is the second largest producer of the crop in the world, and the most important in Africa in 2007 (FAO, 2009). Although East African highland bananas (*Musa* spp., AAA-EAHB genomes) are a primary food and cash crop in Uganda, actual production is poor (<30$tha^{-1}year^{-1}$) compared to the attainable yield of >70$tha^{-1}year^{-1}$ (Bagamba, 2007). As with coffee, research has been mostly focused on pests (Gold, 2000; Gold *et al*., 2001) and diseases (Tushemereirwe *et al*., 1993, 1996, 2001; Rutherford and Kangire, 1998; Tushemereirwe and Opolot, 2005). However, numerous studies in Uganda have reported on biophysical production constraints such as declining soil fertility (Bekunda and Woomer, 1996) and moisture stress (Okech *et al.,* 2004), causing yield reductions in bananas. In addition, production constraints are ascertained to agronomic practices such as poor crop management (Okech *et al*., 2004).

The agronomic factors required for growth of both bananas and coffee include both crops being able to grow on well drained loam soils with high humus content (Zake *et al.,* 2000). Mulching is a very good agronomic practice in controlling soil erosion, retaining the level of organic matter in the soil (Defra, 2005) and conserving soil moisture (Bekunda, 1999). On the other hand, an abiotic factor such as soil temperature is necessary for growth of soil microorganisms, organic matter decay and nutrient absorption by roots (Scowcroft *et al.,* 2000). Water is also an essential element for growth of both crops because if moisture requirements are not met during growth periods, plant quality and yield is reduced (Moutonett, 2000).

Bananas and Coffee can predominantly be grown as monocultures on the same piece of land although there is an increased tendency to intercrop them, particularly in densely populated areas (Ssennyonga *et al.,* 1999). Both crops complement each other in terms of income and other benefits to farmers. Coffee provides revenues twice a year whereas bananas provide a small proportion but at least throughout the year (van Asten *et al*., 2011). In addition, bananas offer a continuous ground cover in order to keep erosion rates low (Lufafa *et al.*, 2003) and improve soil quality and fertility. The crops are also often grown together with shade trees such as *Albizia cinensis, Ficus natalensis* among others to form an agro-forestry system that may result into sustainable production of both crops (Albertin *et al.,* 2004). This shade in some instances can stabilize or increase coffee yield quantity, but also quality (Beer, 1987) and also reduce stress in coffee. The advantages of such an agroforestry system outweigh the mono-crop system whereby in agroforestry, higher returns per unit land is achieved compared to coffee that is mono-cropped, even if coffee yields decrease (Chipungahelo *et al.,* 2004; van Asten *et al.,* 2011).

In South-western Uganda, few studies have been carried out to explain the cause of the decline in productivity of both crops being grown as an intercrop system. In other studies for instance, the one by Gold *et al.,* (1999a) have pointed out that during the last few decades, banana management has deteriorated in south- western Uganda and is most likely the root of banana productivity problems. This controversy among research findings compels area specific studies that target agronomic constraints. Although it is generally agreed that coffee and banana productivity challenges in Uganda are induced by a combination of pests, diseases, poor soil fertility and drought stress, it is very important to isolate area specific agronomic constraints that are most related to yield loss to be able to find the best site-specific management strategies.

1.2 Statement of the Problem

Coffee and bananas are among the major cash and food crops respectively that have for over the years supported livelihoods for the rural and urban population in Uganda. They are therefore important food security crops and contributing to the income in the country (Karamura *et al*., 1998; Musoli *et al*., 2001; UCDA, 2008). These crops have predominantly been grown as monocrops although in densely populated areas there is a tendency to intercrop the two. However, yield trends over the years suggest a decline in production systems and hence a threat to food security and rural economy. For example, banana yields in central Uganda have declined resulting into a shift in major production to South-western Uganda (Gold *et al.,* 1999). During last few decades, banana management has deteriorated in south- western Uganda and is most likely the root of banana productivity problems. This controversy among research findings compels area specific studies on constraints associated to the decline such as abiotic and agronomic constraints- soil fertility, moisture stress and poor management among others resulting from poor ecological farming practices (Wairegi *et al.,* 2010). Modern science has therefore envisaged the integration of shade trees amongst these crops to manage these constraints better given the numerous advantages associated with the agroforestry system compared to monocrop systems. Given the knowledge on these constraints, no information exists on which specific agronomic constraints actually affect yield performance of coffee and bananas in coffee-banana agroforestry systems of south-western Uganda hence the study.

1.3 Objectives of the Study

1.3.1 Major Objective

To determine the effect of agronomic constraints on performance of coffee and bananas in coffee-banana agro-forestry systems of south-western Uganda.

1.3.2 Specific Objectives

- To identify farmers' knowledge on the agronomic and abiotic constraints hindering coffee and banana production and their coping strategies in regard to the constraints.
- To identify the agronomic constraints in coffee-banana agroforestry systems at plant and plot level.
- To identify the agronomic constraints most related to coffee and banana yield loss in coffee-banana-agroforestry systems.

1.4 Research questions

- Which knowledge do farmers possess on the abiotic and agronomic constraints as well as coping strategies in coffee-banana-agroforestry systems?
- What are the agronomic constraints in coffee-banana agroforestry systems at plant and plot level?
- What are the agronomic constraints most related to coffee and banana yield loss in coffee-banana-agroforestry systems?

1.5 Scope of the Study

The study was conducted on farmers' fields who maintain coffee-banana-agroforestry systems in south-western Uganda. Districts assessed included; Mitooma, Bundibugyo, Kabarole, Kibaale, Rubirizi, Kanungu, Isingiro, Ntungamo and Ibanda

1.6 Significance of the study

Recent research reveals agroforestry systems as a "win-win" strategy for managing abiotic as well as agronomic constraints in coffee-banana systems (van Asten *et al.,* 2011). Results from this study have important implications more so to the smallholder farmers who are already vulnerable to abiotic and agronomic constraints. If the agronomic constraints most related to yield loss of coffee and banana production are determined, this will help to inform the management of these constraints and hence an increase in production of both crops. In addition, the agroforestry system will serve as a better ecological approach of management with a minimal use of agro-chemicals that are harmful to humans, animals and the environment if they are constantly used (SAFE, 2004). Increase in production will result into increased household income which will lead to improved livelihoods in the long run.

1.7 Justification of the Study

Coffee-banana-agroforestry systems are dominantly practiced in various parts of Uganda (Ssennyonga *et al.,* 1999). However, most of the research activities have often looked at these crops independently and not a system under which they are grown and the constraints associated with it, hence limited information on how to intervene and reverse the decline in the system. These systems have many advantages for example producing higher returns per unit land compared to coffee or bananas that are mono-cropped, even if coffee or banana yields decrease (Chipungahelo *et al.,* 2004; van Asten *et al.,* 2011). Bananas offer a continuous ground cover in order to keep erosion rates low (Lufafa *et al.*, 2003) and improve soil quality and fertility when the leaves rot (Rishirumuhirwa and Roose, 1998). In coffee fields, bananas can also provide shade for coffee and shade has been shown to be advantageous for coffee production, especially in suboptimal growth conditions (DaMatta, 2004). Shade in some instances can stabilize or increase coffee yield quantity, but also quality (Beer, 1987). It helps in landscape level interactions such as nutrient flows, community reliance on fuel, timber, biomass (Zomer *et al.*, 2009). It also reduces stress in coffee and also creates a balance in the climate in order to avoid climatic extremes in temperatures. In addition, using agro-forestry shade systems will reduce the use of external inputs like chemicals and synthetic fertilizers which are costly, sometime unavailable and dangerous to the environment, human and animals (Garrett and McGraw, 2000; SAFE, 2004). Amidst all this, agronomic constraints continue to cause havoc to a small-holder farmer and therefore understanding the most related agronomic constraints to coffee and banana yield loss will help to manage them better.

1.8 Definition of key terms

Abiotic constraints: the negative impacts of non-living factors on the living organisms in a specific environment (Mittler, 2006).

Agroforestry system: an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops (Garrett *et al.*, 1994).

Agronomic constraints: are negative impacts that arise when farmers fail to manage their crops well by not improving soil quality, enhancing water use, managing crop residue and improving the environment through better fertilizer management (Fabian *et al.*, 2008).

1.9 Conceptual Framework

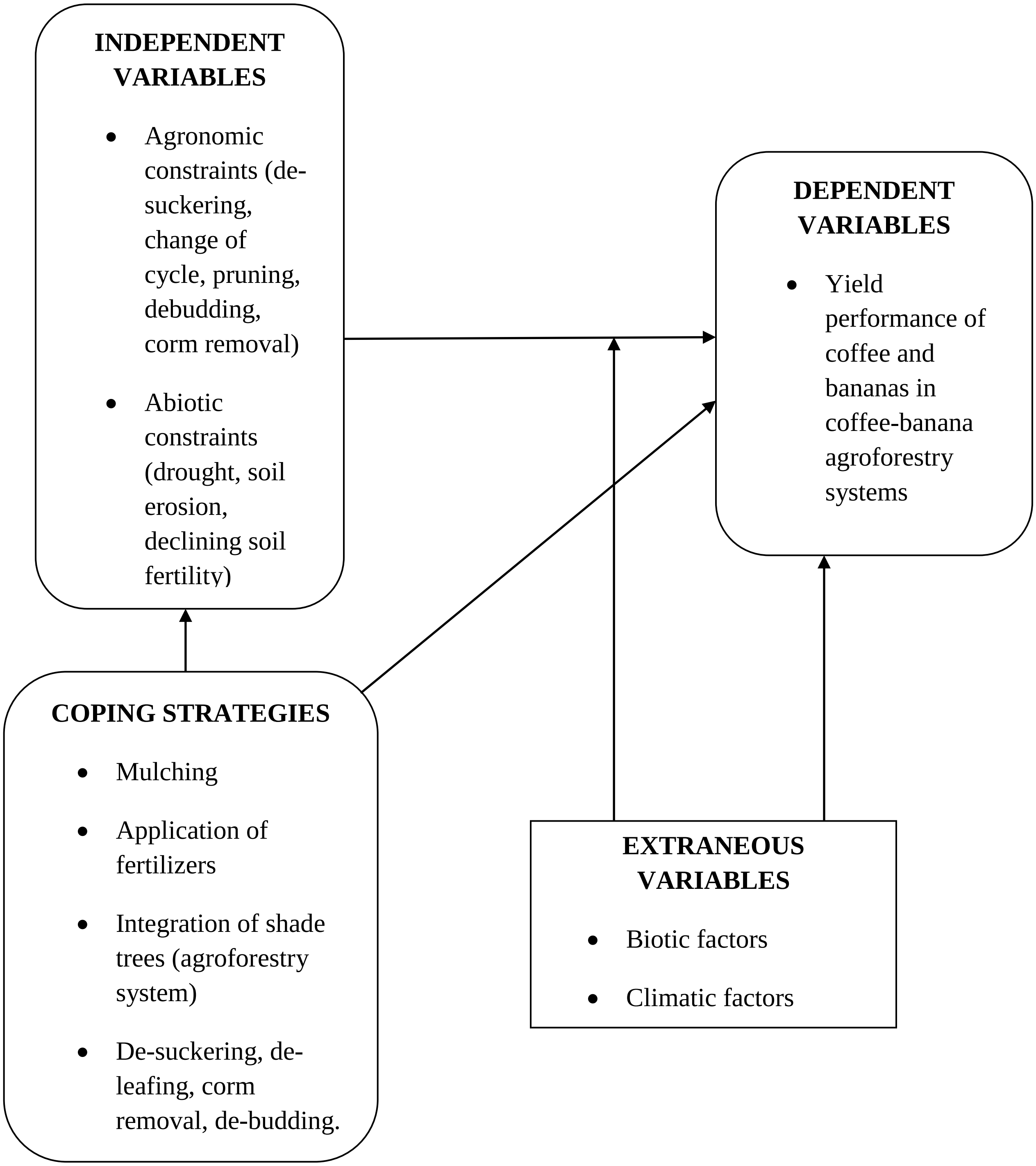


Figure 1: An illustration of abiotic and agronomic constraints limiting yield performance of coffee and bananas in coffee-banana agroforestry systems at plant and plot level.

Fig. 1 conceptualizes and gives a detailed picture about the abiotic and agronomic constraints that exist in coffee and banana production and how farmers are managing them. A new agronomic strategy of agroforestry systems is currently being advocated by research in order to increase production and best manage these constraints. However, production of these crops is also indirectly influenced by climatic factors and biotic factors such as pests and diseases. All these in association directly affect the yield performance of coffee and bananas. On the other hand, to manage well these constraints, the agronomic constraints most related to yield loss of each crop must be identified. This will help inform the management of these constraints thus an increase in production of both crops. This study only dealt with constraints at plant and plot level.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter focuses on reviewing the relevant literature about the research topic guided by three study objectives. It includes coffee and banana production and systems as well as the agroforestry strategy. In addition are some of the agronomic and abiotic constraints to banana and coffee production, farmer's coping strategies and the different coffee and banana agronomic management practices.

2.1 Coffee and Banana production

Coffee is one of the most important export crops in Uganda, contributing to 20% of total export revenue (UCDA, 2012). Uganda primarily cultivates two species; Robusta coffee in the central and northern part of the country and Arabica coffee in eastern, south-western and north-western part. The two species contribute 20% and 70% to the country's total coffee export respectively (UCDA, 2012). Smallholder farmers produce 90% of the total coffee on land holding less than 2.5 hectares (Musoli *et al.,* 2001; UCDA, 2012). However, amidst all this, Uganda's coffee industry is experiencing challenges among which low production is paramount. This is encountered directly by smallholder farmers (Bazaara *et al.,* 2000). The primary constraints at farm level include abiotic limitations and poor management practices that have posed challenges to the coffee industry (Mureithi, 2008).

On the other hand, Uganda ranks second after India in banana production in the world with an annual output of 9.84 million tonnes accounting for 11.18% of the world's total production (UNCST and PBS, 2007). Banana (*Musa* spp.) is the country's primary staple crop (Edmeades, 2006) estimated to meet 10% of the dietary energy requirements (FAOSTAT, 2010). The area under banana production is 1.3 million hectares and this constitutes 75% of arable land (NARO, 2000). The all year round fruiting habit of bananas puts the crop in a superior position in bridging the 'hunger gap' between crop harvests. However, production of the crop is still far below the potential yield. The actual yields on smallholder farms of 5−20 Mg ha−1 yr−1 FW are far from the estimated potential yield of 100 Mg ha−1 yr−1 FW (Nyombi, 2010). Research attributes this to abiotic constraints such as low soil fertility (Bekunda and Woomer, 1996) and inadequate moisture (Okech *et al.,* 2004).

2.2 Coffee and Banana production systems

In the East African Great Lakes region, there are two coffee production systems that smallholder farmers practice (Jassogne *et al*., 2011). These include the mono-cropped coffee and the intercropped coffee. These production systems have different results in terms of food availability, income and sustainability. In Uganda, intercropped coffee is more prominent with an integration of trees and annuals and has shown more positive results (Jassogne *et al*., 2011). Coffee intercropping systems offer more agronomic benefits to smallholder farmers than coffee mono-cropping systems. These include: increase in organic matter/nutrient recycling, productivity life cycle of coffee plants, higher biodiversity values and soil conservation (Moguel & Toledo, 1999; Diaz, 2012). These advantages make the production system to require less need for external inputs like agro-chemicals. More specifically, incorporating banana in the coffee fields adds an advantage of improving food availability and household income. According to van Asten *et al.*, (2011), coffee yields per hectare per year are not significantly affected by intercropping coffee and banana. Infact, the total annual revenues per hectare increase tremendously when coffee and banana are mixed in a plot.

2.3 Abiotic and agronomic constraints to banana production

Low banana production and decline in yields in Uganda are to a greater extent due to abiotic and agronomic (biophysical) constraints including low soil fertility and moisture stress (Bekunda and Woomer, 1996; Okech *et al.,* 2004; Wairegi *et al.,* 2010). Soils under which bananas are grown in Uganda are often Ferralsols and Acrisols, which are reported to also have low inherent fertility resulting into low yields in banana production (Sanchez *et al.,* 1989). Previous studies have shown that yields are limited by low soil fertility. For example, banana production is limited by Nitrogen (Wairegi *et al.,* 2010) and Potassium (Smithson *et al.,* 2004; Okech *et al.,* 2004) in the Robusta growing region and by Magnesium in the Arabica region (Wairegi and van Asten, 2010). Temperature is another important factor in successful commercial banana production, with the optimum temperature being approximately 27^{o} C. However, poor fruit production has been observed to occur if the temperature drops below 15^{o}C (Espino *et al.,* 1992). Despite the fact that most of the banana growing areas in southwestern Uganda receive sub-optimal rainfall, increase in temperature has led to drought and therefore moisture stress. Moisture stress continues to be a limiting factor to banana plant growth and yields (Taulya *et al.,* 2006). For example low annual rainfall (678 mm) reduced yields by about 50% in Mbarara, south west Uganda (Okech *et al.,* 2004). The banana plants sensitivity to soil moisture stress causes reduced growth through reduced stomatal conductance and leaf size. This then leads to reduction in photosynthetic pigments that manufacture food thus low yields (Kallarackal *et al.,* 1990).

2.4 Abiotic and agronomic constraints to coffee production

Amongst the primary constraints to coffee production at farm level are abiotic limitations which include declining soil fertility, drought and erratic rainfall patterns (Sserunkuuma, 2001). These are coupled with poor agronomic practices such as: inappropriate mulching, pruning and weeding among others (Sserunkuuma, 2001; Shively and Hao, 2012; Jassogne *et al.,* 2013). These constraints cause low yields that pose large challenges to small-scale farmers' livelihoods (Sserunkuuma, 2001). Coffee production relies highly on existing soil fertility and natural climatic conditions which may not be able to increase production. In addition to that, continued crop harvest throughout the years has led to nutrient mining which has caused degradation of soil fertility in Uganda's coffee growing areas (Tenywa *et al.,* 1999). Soil moisture stress due to drought inhibits growth, causes plant wilting and dieback. These in turn limit production by causing low yields (Gay *et al.,* 2006).

2.5 Agroforestry strategy

Modern science has envisaged agroforestry as an entry strategy to manage abiotic and agronomic constraints (Ma *et al.,* 2009; Nair *et al.,* 2010; Van Asten *et al.,* 2011). These tree-based systems (agro-forestry systems) have been identified to have some obvious advantages for maintaining production. These systems encompass woody perennials (e.g. trees, shrubs) which are integrated with crops or/and with livestock on the same land for increased social, economic, and environmental benefits (World Agroforestry Center, 2003). According to Verchot *et al.,* (2007), agroforestry systems are better positioned to withstand dry periods much better given their deep root systems that are able to explore a larger soil volume for water and nutrients. This will help to increase soil porosity, reduce runoff and increase soil cover. This thus leads to increased water infiltration and retention in the soil profile which reduces moisture stress during periods of drought. Additional advantages of agroforestry systems include: provision of fodder (FAO, 2005), they also provide shade which leads to lower solar radiation as the large canopy intercepts the sun's rays (Wilson *et al.,* 1995). Plant residues from trees and crops which are left on the ground form 'surface mulch' that decomposes over time. These in turn improve the organic matter content in the soil thus producing higher yields than soils depleted of nutrients (Magdoff and Van Es, 2009; Jones, 2012).

2.6 Tree species in coffee-banana agroforestry systems in Uganda

A wide range of shade tree species are commonly found intercropped on farms in Uganda (Katende *et al.,* 2000; Oluka-Akileng *et al.*, 2000). Farmers deliberately grow different tree species according to the benefits they require from them (Isabirye *et al.,* 2001). Different trees have different characteristics and benefits that they give to coffee and bananas. Benefits include; providing shade, nutrient cycling, soil moisture conservation among others (Oluka-Akileng *et al.,* 2000). Characteristics incorporate; fast growth, deep rooting, light canopy, suitable for compatibility with crops (Rusoke *et al.,* 2000). Some of the commonest tree species in coffee-banana-agro systems in Uganda include;

Avocado *(Persea americana)* is a densely leafy nature of the tree and the fact that it is able to grow up to 10 m or sometimes more makes it able to provide good shade to crops. However, it's root system is very dense and close to the surface, meaning that it competes with most crops for nutrients and water (Katende *et al.*, 2000).

Mango (*Mangifera indica*) is also a densely leafy tree with a rounded canopy. The tree is used as a shade tree, windbreak and aids in soil moisture conservation The tree also has a dense surface root system, which makes it very suitable for intercropping with other annual crops such as beans (Katende *et al.,* 2000). It's leaves can be used as fodder, green leaf manure and mulch (Dharani, 2011). However, the dense canopy provides much shade that reduces yield of food crops (Oluka-Akileng *et al.,* 2000).

Jackfruit (*Artocarpus heterophyllus*) is a very common tree that grows naturally in Uganda. The tree can grow from 5 m up to 20 m high giving a good shade because of its great size although the dense shade reduces yield of food crops (Oluka-Akileng *et al.,* 2000).

Markhamia (*Markhamia lutea)* is a tree commonly grown in the Lake basin regions. The tree is useful for use in soil conservation where erosion rates are high, it provides shade and acts as a wind breaker. In addition, it's leaves provide mulch which enhances soil moisture retention and increases organic matter (Orwa *et al.,* 2009). The tree however, has a negative effect to crops such as bananas when they are planted nearest to it. This is mainly due to root competition which rapidly reduces subsoil nitrate levels (Okorio *et al.,* 1994).

Bark-cloth fig *(Ficus natalensis)* is a common tree grown by most farmers that grows very large reaching up to 20m. The wide canopy helps to give good shade thus good to intercrop with banana and coffee as it increases produce quality (Katende *et al.,* 2000). The bark-cloth fig is able to grow well on both dry and wet areas thus being able to improve soil fertility and conserve soil moisture (Oluka-Akileng *et al.,* 2000).

Acaccia spp commonly known as wattle tree is an important multipurpose tree species (Cossalter, 1991) that fixes atmospheric nitrogen. It is also a source of fence posts, firewood and fodder (Katende *et al.,* 2000). The species extends over a wide ecological range that differs in rainfall, soil and altitude (Cossalter, 1991), a reason why it is common in most regions of Uganda.

2.7 Field management practices for coffee and bananas

2.7.1 Weeding

Regular integrated weed management is necessary for bananas as it contributes to increased production. Such practices include; planting cover crops, judicious use of herbicides, intercropping and hand weeding wherever necessary. Weeds associated with coffee range from annual grasses such as *Oxalis spp.* and *Parthenium spp* to persistent perennials like star grasses, *Paspalum* and *Laporlea* spp (Kimani *et al.,* 2002). They are more prominent in the cooler seasons as these favor their growth and if not managed well result into poorer soil aggregation. They are a nuisance to crops through competition for moisture, light, nutrients and water.

Competition is prominent when the demands of the weeds for these resources exceed the available supply more so in periods of drought (Sheley *et al.*, 1999). A number of small holder farmers hand-pull weeds to remove as much of the root as possible with minimal soil disturbance (Sheley *et al.,* 1998; Tushemereirwe *et al.*, 2001). They may also use tools to slash and dig (Young *et al.,* 1998) or chemicals such as herbicides to control the weeds (Bussan and Dyer, 1999). Mulching and burning can also be an effective method to suppress weed growth (Sheley *et al.,* 1999).

2.7.2 Integrating with shade trees

Naturally, coffee is a forest crop and traditionally it is grown in shaded agro-forestry systems where temperature and rainfall are not favorable (DaMatta *et al.*, 2007). In Uganda, a majority of coffee fields are covered by shade trees with diverse shading intensity (Van Asten *et al.,* 2012). Shade trees provide litter, which can act as natural mulch, reducing the need for fertilizers and herbicides and also help prevent soil erosion. Coffee can benefit from shade trees in diversified aspects in a way that shade trees help to modify the microclimate around coffee so that the extreme climatic conditions in form of temperatures are reduced (DaMatta *et al.,* 2007; Jassogne, 2011). Shade trees also serve as a buffer to mitigate the negative influence generated by prolonged dry season, heavy rainfall and frost (DaMatta *et al.*, 2007). It is recommended to plant shade trees in young coffee plantation to protect coffee from sunburn (UCDA, 2012). Moderate shading can lead to slow ripening of coffee beans and this promotes coffee beans' quality (Läderach *et al.,* 2011). However, excessive shading level due to sufficient rainfall can be harmful to coffee growth and production (DaMatta, 2004) as it affects light interception to coffee trees (DaMatta *et al.,* 2007). There might be competition between the shade trees and coffee for water under low rainfall conditions. In this case, the shade trees bring about favorable changes in the microclimatic conditions by influencing radiation flux, air temperature and wind speed (Monteith *et al.,* 1991). In addition, Shade systems have also been reported to promote some pests and diseases for example the Black coffee twig borer (Kagezi *et al.*, 2013).

2.7.3 Mulching

Mulching is an important agricultural technique that helps to control weeds and prevent loss of soil moisture (Bai and Blumfield, 2013). Mulch also helps to regulate soil temperature thereby increasing the survival coffee plant under extreme conditions (Murungu *et al.,* 2011). In addition, it also improves organic matter content and soil fertility, soil water storage capacity, and infiltration rate thus increasing crop growth and yield (Ogban *et al.*, 2001).

The low productivity of bananas evidenced by the declining soil fertility (Gold *et al.,* 1999) can be managed by crop residues which have been reported to increase their productivity (Bananuka *et al.,* 2000). Forge *et al.,* (2003); Tushemereirwe *et al.*, (2001) indicated that a large variety of organic materials can be used as mulches to improve crop performance in various ways. These include grasses such as elephant grass (*Pennistum purpureum .L*), banana plant residues and annual crop residues which can be recycled on the farm (Bekunda, 1999). The practice can also improve soil fertility as the material decomposes (RELMA, 2003) as well as suppressing weeds (Ramakrishna *et al.*, 2006).

2.7.4 Intercropping

Intercropping is commonly practiced in densely populated areas where land is limited and food security is threatening in order to obtain maximum production. In Uganda, coffee is usually intercropped with bananas (Oduol and Aluma 1990). However, it is also grown together with other annual crops such as beans, maize, yams, ground nuts among others. Coffee intercropping systems have proved to offer more agronomic benefits to smallholder farmers than monocropped coffee (van Asten *et al.,* 2011). These intercrops help to increase organic matter and aid in nutrient recycling, soil conservation, productivity life cycle of coffee plants and higher biodiversity values (Diaz, 2012) Legume cover crops such as lablab (*Lablab purpureus*) and beans can also be used for weed control and soil fertility improvement. (Mureithi *et al.,* 2003).

In Uganda, banana is commonly cultivated together with coffee and a number of annual and perennial crops by small-scale farmers with the motivation of enhancing land use sufficiency, providing shade to coffee, supplying mulch materials and reducing soil erosion (van Asten *et al.*, 2010 ; Jassogne *et al.,* 2013). In addition, intercropping coffee with banana also contributes to enhancing food security at household level since bananas can be harvested throughout the season while the coffee is still growing (van Asten *et al.,* 2011).

2.7.5 Soil fertility management

Among several factors that affect coffee productivity is declining soil infertility and low use of organic matter (Bucagu *et al.*, 2013). Fertility management is critical to the general health of the plant, particularly where coffee is grown on poor soils with low nutrient levels (Kimani *et al.*, 2002). With constant cultivation of coffee fields, it is evident that soils become exhausted and deficient of major mineral elements that enhance productivity. It is at such points that organically based mineral sources from livestock manure, compost, inter crops are applied to improve soil fertility. (Place *et al.*, 2003). Soil fertility management using commercial fertilizers has significant problems such as depletion of soil organic matter, deterioration of soil structure and the acidification of the soil (Kimani *et al*., 2002). In the study, on banana production in the similar smallholder farming systems as coffee, Wairegi *et al.*, (2010) indicated that low soil fertility is the principal constraint to banana production in Uganda and significant yield improvement was observed on fertilizer application. Therefore use of organic fertilizers is recommended as they help to improve the soil by increasing nutrients, and improving yields and the quality of the produce (Haggar *et al.*, 2011). Composting is a natural amendment practice which utilizes microorganisms naturally present in organic matter and soil to decompose organic material. It is very effective in improving the fertility of the soil as it increases the organic matter content, improve the soil structure and improve the water holding capacity which helps maintain the soils moist during dry periods (Wintgens, 2009). The soil organic matter plays an important role in moisture retention and is therefore considered as a climate change adaptation strategy (A El-Kader *et al.*, 2010).

2.7.6 Soil and water management

Construction of bands and trenches is a practice commonly done in hilly regions that have challenges of the surface runoff water that removes the top soil. Micro catchments like contour bands, infiltration trenches are constructed therefore to trap the rainwater thus supplying the run-off to crops (Ngigi, 2003). This technique contributed to higher crop yields than normal conventional tillage because it stops runoff and minimizes soil evaporation losses (Botha *et al.*, 2005). Grass bands like hedges are also constructed to control soil erosion thus ensuring that the most productive part of the soil is conserved to ensure sustainable production (Bekunda, 1999).

2.8 Agronomic practices

2.8.1 Coffee agronomic practices

2.8.1.1 Pruning

Coffee production and quality has for long been declining due to several improper pre and post harvest management practices of which lack of pruning is key (Tena, 2011). To boost production however, proper pruning needs to be done to rejuvenate old coffee trees as they tend to become less productive as they age (Ren'e Coste, 1992). There are two methods of doing this practice; by single and multi-stemmed pruning (Snoeck and Lambot, 2009). When unwanted branches and stems are removed, it gives chance for new stems to build up resulting into bigger berries of higher quality than small berries that would result from overbearing (Kimani *et al.,* 2002). Excessive pruning however creates hormonal imbalance between auxins that stimulate root growth and gibberellins which stimulates canopy growth. This imbalance results into a multi-year decline in canopy growth hence low yields (David *et al.*, 2014). Pruning involves a number of practices that include;

2.8.1.2 Change of cycle/ Stumping

The practice is done after 5-7years used for high density plantations and for old, long and unproductive stems to allow uniform vegetative growth. It involves completely cutting down a coffee stem down to 30-40cm. The incision is done by a chain saw at an angle to prevent water accumulation. Stumping helps to renew stem cycle and improve productivity of the crop by preventing it from pests such as stem borers (Ren'e Coste, 1992).

2.8.1.3 Training

This is a practice of bending a 6-month old coffee plant up to 45^0 to stimulate additional branching and growth of suckers for maximum production. Only 2-3 healthy looking suckers that originate from the base of the trained plant are allowed to grow (Uganda Training Materials for Coffee Production, 2014). However, due to improper structural training while the tree is young, the tree may become prone to wind and snow damage as it matures and gets destroyed (David *et al.*, 2014).

2.8.1.4 Desuckering

When young verticals growing on a coffee stem reach 3-6inches in length, and are not wished to develop into bearing verticals, they are removed by this practice. In this case, even unwanted stems and suckers, dead, weak and unproductive branches are removed using secateurs to encourage new growth and improve productivity (Ren'e Coste, 1992).

2.8.2 Banana agronomic practices

2.8.2.1 Desuckering

A few months after planting, banana plants produce suckers which compete with the main plant for water and nutrients hence reducing productivity (Oluwafemi, 2013). Therefore, sucker management is important to ensure that good plant population is maintained resulting into healthy plants (Karamura *et al.*, 2004). The yield potential of the banana plantation is maximized by choosing the correct number of suckers per mat since higher densities reduces fruit size (Robinson, 1995; Oluwafemi, 2013). According to (Oluwafemi, 2013), a good plant population of 2 suckers per a banana mat should be maintained since the more the number of suckers per plant, the lower the yield.

2.8.2.2 Deleafing

This practice of removing dead, non-functional leaves from a banana mat enables light penetration. If these leaves are left on the mat, air movement around the plant is reduced thus causing build up of humidity (Tushemereirwe *et al.*, 2001).

2.8.2.3 Debudding

Also called bud removal involves the removal of a male bud more so when fingers on the cluster start turning upwards. The practice helps to reduce diseases like *xanthomonas wilt* that are transmitted by insects that visit the bud bracts (Blomme *et al.*, 2008).

2.8.2.4 Corm removal

A corm is a rhizome found at the end of a banana mat that has a number of growing points that later turn into suckers. To achieve maximum production, it is therefore necessary to remove corms inorder to prevent pests from attacking the crop since a number of pests find it conducive to gain nourishment from the corms (Tushemereirwe *et al.*, 2001).

2.8.2.5 Propping

This is a common practice carried out by farmers in order to prevent the plants with maturing bunches from falling down and to also enable uniform development of the bunch. Due to heavy weight of the bunch and other conditions like dry seasons, strong winds, nematodes and weevils weaken the plant. These cause the bearing plant to go out of balance and may lodge thus affecting production and quality. In this regard, the plant is propped with the help of wooden forked poles by placing them against the stems on the leaning side to give support (Tushemereirwe *et al.*, 2001).

2.9 Existing gap

In South-western Uganda, few studies have been carried out to explain the cause of the decline in productivity of coffee and bananas being grown as an intercrop system. In other studies for instance, the one by Gold *et al.,* (1999a) have pointed out that during the last few decades, banana management has deteriorated in south- western Uganda and is most likely the root of banana productivity problems. This controversy among research findings compels area specific studies that target agronomic constraints. Although it is generally agreed that coffee and banana productivity challenges in Uganda are induced by a combination of pests, diseases, poor soil fertility and drought stress, it is very important to isolate area specific agronomic constraints that are most related to yield loss to be able to find the best site-specific management strategies.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

The chapter focuses on the methods that were used to implement the study. It includes the research design, area of study, study population and sampling procedures which encompass sample size and sampling techniques. Also, the data collection methods and instruments that were used, quality control methods, data management and processing, data analysis, ethical considerations to be followed as well as limitations to the study.

3.1 Research design

A descriptive research design in form of a cross-sectional survey was used to obtain farmers' knowledge on the abiotic and agronomic constraints existing in coffee-banana agroforestry systems as well as their coping strategies. This design was used because descriptive studies could yield rich data that leads to a detailed analysis. The survey adopted quantitative approaches of data collection and analysis. Quantitative data was collected using questionnaires and biological assessment tools on house-holds with coffee-banana-agroforestry systems. The questionnaire elicited socio-demographic information, farm size, coffee and banana clones grown, intercrops, tree species grown and management practices. The biological tool assessed for the plot and plant level management, intensity of the practices, intercropping as well as integration with tree species. The independent variables in this study were the abiotic and agronomic constraints, whereas the dependent variable was performance of coffee and bananas in terms of yield parameters.

3.2 Area of Study

The study was conducted in 9 randomly selected districts from the southwestern region of Uganda. This region is characterized by tropical rain forest vegetation and bimodal rainfall with annual rainfall ranges of 900mm to more than 1350mm in the highlands. Rainfall is generally spread throughout the year with two rainy seasons, from March to May for the first rains, and the second rains from September to November. Mean annual temperature is about 26°C (Mwebaze, 2002). The terrain ranges from rolling savannah to high mountains characterized by fertile soils that enable agriculture to be the most important economic activity practiced. Mixed farming predominates in the area and the main food crop is bananas, and coffee being an important cash crop. The two crops are grown solely or in densely populated areas as intercrops together with annual crops like; cassava, maize, groundnuts, sweet potatoes among others. In the lower areas, where rainfall is least, the soils are quite poor and such areas are mostly used for extensive grazing of cattle, sheep and goats, with very small household plots of food crops (Mwebaze, 2002). Dominant tree species that are found within coffee and banana fields include; *Markhamia lutea*, *Ficus natalensis*, *Mangifera indica*, *Persea amiricana*, *Artocarpus heterophyllus*, *Accacia spp* among others (Katende *et al.,* 2000; Oluka-Akileng *et al.,* 2000).

3.3 Study population

The survey targeted only farmers with existing coffee-banana-agroforestry systems.

3.4 Sampling Procedures

3.4.1 Sample size

In the south-western region, a total of 9 districts were randomly selected and 10 households with coffee-banana-agroforestry systems purposively selected in each district giving a total of 90 households.

3.4.2 Sampling techniques

Random sampling was used to select the districts whereas households having coffee-banana-agroforestry systems were purposively selected. The sampling techniques employed enabled a choice of districts and households that best meet the research objectives.

3.5 Data collection methods and instruments

3.5.1 Questionnaire

The survey was conducted with the aid of the questionnaire to obtain farmers' knowledge on the agronomic and abiotic constraints of coffee and bananas. A structured questionnaire with both closed-and open-ended questions (Appendix 1) was pretested before being administered to the sampled households. This was to ensure that there were no errors in wording of questions that could lead to ambiguity of words and misinterpretation of questions. This helped to reduce errors which would have been associated with the study. Pretesting was also necessary to provide an opportunity to give a feedback to ensure that a proper protocol of data collection procedures was followed to aid objectivity in the exercise. The questionnaire elicited socio-demographic information, farm size, status of coffee and banana plantations, yield data, farmers' knowledge on field (abiotic) and crop (agronomic) constraints as well as farmer's coping strategies.

3.5.2 Biological assessment

To put the socioeconomic information into a biological context, an assessment tool was designed to capture field-diagnostic biological information (Appendix 1). It was pretested first and administered in a 25 x 25 m transect in the sampled fields. The tool captured the level of plot and crop management and intensity of inter-planting. Ten (10) coffee plants and banana mats were randomly selected along a transect and scored for the agronomic constraints. This included the variety of coffee and banana, number of stems and suckers for coffee, number of plants per mat for bananas and level of agronomic practices determined on each coffee and banana plant/mat. Information from the biological studies was used to identify the agronomic constraints most related to coffee and banana yield loss in coffee-banana-agroforestry systems.

3.6 Quality Control Methods

To reduce on errors in data collection, the questionnaire was pre-tested before actual data collection to identify any ambiguous and out of context questions. Questions were open-ended in a local and farmer-friendly language to allow the farmer to express him/her self as he/she wishes. Also, closed-ended questions that have exhaustive alternatives were used in order to cover a range of possible answers.

3.6.1 Validity

Pre-testing of the questionnaire was conducted by visiting and interviewing one model farmer with an existing coffee-banana agro-forestry system. Adjustments were then made to the survey instrument following the pre-testing. Several questions were dropped and others added to ensure the correct format for data collection and that the final survey questions were appropriate. To avoid respondent bias, and by way of introduction of the research, a one -page statement of intent preceded the survey questions.

3.6.2 Reliability

Upon completion of the draft collection tools, the questionnaire and interview guide, these were piloted to ascertain their reliability of building confidence and capacity of the field data collector in getting reliable data. The questionnaire was given to people of expertise to see whether the questions were rightly stated and then tested using Croncbach Alpha method provided by SPSS (Foster, 1998).

3.7 Data management and processing

Data obtained was coded and entered in MS Excel program. Before analysis, the data was cleaned by validating, sorting and filtering in order to reduce on the errors.

3.8 Data Analysis

3.8.1 Farmers' knowledge on the agronomic and abiotic constraints and their coping methods

Descriptive statistical analysis using Excel program was employed to obtain means, ranges, standard deviations and frequencies. The results were summarized in form of tables and graphs. In addition, the relationships of farmers' knowledge with socio-demographics (sex, education and age) were determined using simple logistic regression analysis of the SAS program.

3.8.2 Agronomic constraints at plant and plot level.

To determine agronomic constraints at plant and plot level, percentages of the management options were obtained using excel program to generate graphs.

3.8.3 Agronomic constraints most related to coffee and banana yield loss.

These were obtained using boundary line analysis (Wairegi *et al.,* 2010; Wang *et al.,* 2015). This analysis has been widely applied to understand yield reduction factors or to evaluate the relationship of an individual production factor to yield reduction. Boundary lines were developed by grouping of data points (yield and abiotic/agronomic constraints), then identification and removal of outliers based on empirical knowledge (coffee yields exceeding 2500kg/ha/yr and banana yield exceeding 1111 bunches/ha/yr). This was followed by identification of attainable yield and boundary points and thereafter fitting of a boundary curve to identify the boundary points. Trend lines of the boundary points were fitted and an equation and R^2 value obtained.

Three graphs per crop observed to have the highest coefficient of determination, R^2 were taken to be the agronomic constraints that are most related to coffee and banana yield loss in coffee-banana agroforestry systems.

3.9 Ethical Considerations

Prior to administering the questionnaire, respondents were clearly explained the purpose of the study and their consent sought for participation. Emphasis was made to the participants that the information collected from them would be treated with due confidentiality. This was to allow the respondents to gain confidence while answering the study questions. Open, generative questions were asked first at the start of a new section; supplementary questions used to probe for more detail and closed questions asked last to avoid a pattern of short responses. The approach was an informal one involving mixing questions with a discussion such that the respondents are allowed to explain their points fully. The study made all efforts possible to avoid any sort of psychological and physical harm to the respondents and their fields. Making any careless reference, assumptions and other statements considered cruel to the respondents was avoided as much as possible. In the same view, due respect to the culture of the respondents was paid to avoid approaching them judgmentally (Piper & Simons, 2005).

3.10 Limitations of the Study

The study had a limitation of gaining entry into farmer's fields since the researcher was a visitor to the village and consequently it took time to establish rapport with the farmers. Some farmers that the researcher wanted to elicit information from had left the home or died. Therefore, a considerable amount of time was spent to get the right person who had the information needed.

Secondly, the information that some farmers provided were based on their memory of agricultural practices. In this case, the researcher had to spend some time waiting for them to recall some of the information and this required a lot of perseverance.

The study was conducted at a time when farmers were constantly occupied in their fields and with household chores which made it difficult for them to sit down and answer questions. This meant that rapport needed to be established in order to convince them and show the need for the study and how they themselves would benefit from it.

In addition, some of the sampled farmers were aged and illiterate thus reluctant to answer questions. Being that the researcher was educated would intimidate many of them and make them uncomfortable. Therefore, the farmers were reminded that the study is for academic purposes hence putting them at ease to answer questions more openly.

CHAPTER FOUR
PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

4.0 Introduction

This chapter summarizes results on farmers' knowledge on abiotic and agronomic constraints limiting coffee and banana production, their coping strategies. In addition to these are agronomic constraints at plant and plot level and lastly the agronomic constraints most related to yield loss of both coffee and banana. Also included here is the interpretation of the results and discussion as per objective.

4.1 Objective 1: Farmers' knowledge on the abiotic and agronomic constraints limiting coffee and banana production, their coping strategies.

4.1.1 Socio-demographic characteristics of the respondents in southwestern coffee-banana ago-forestry systems of Uganda

Table 1 summarizes the socio-demographic characteristics of the study area. The interviewed females were significantly (P=0.0008) more than the males. The mean age of the respondents was 48 years. The number of respondents in the various age ranges varied significantly (P<.0001); with the majority (42%) being observed in age range 36-55 years. The education level in the study area was generally low, with the majority (59%) of the respondents having not studied beyond primary level of education. There was significant (P=0.0005) variation in the number of respondents in the various education levels, with most (40%) of them having attained primary level of education. On average, farmers owned 2.4 ha of land. However, most of them (43%) owned less than 1ha of land, though the number of respondents in this category was not significantly (P=0.0853) different from other categories.

Table 1: Socio-demographic characteristics of respondents of southwestern coffee-banana agro-forestry systems of Uganda

Parameter	Respondents (%)	Chi-square (X^2)	P value	Df
Sex				
Females	66.7	11.155	0.0008	1
Males	33.3			
Age (years)				
≤18	2.2	35.7320	<.0001	3
19-36	22.2			
37-55	42.2			
<55	33.3			
Mean±SD	48.4 (Range =10-82)			
Education level				
None	18.9	17.6504	0.0005	3
Primary	40.0			
Secondary	28.9			
Tertiary	12.2			
Farm size (Hectares)				
<1.0	43.3	4.9238	0.0853	2
1.0-2.0	25.6			
>2.0	31.1			
Mean±SD	2.5±3.8 (Range=0.2-24)			

Source: Field data, 2016

4.1.2 Farmers' knowledge of agronomic and abiotic constraints in the southwestern coffee-banana agro-forestry systems of Uganda

Farmers reported five (5) major agronomic and abiotic constraints limiting coffee and banana production in their fields (Fig. 2). Most (≥70%) of the respondents acknowledged the importance of agronomic and abiotic constraints in limiting production of coffee and bananas. Broad-leaved weeds were the most reported on agronomic constraints, by 96% of the respondents. However, these were not significantly (P=0.3153) different from the number of respondents who reported other agronomic constraints like grassy weeds and abiotic constraints like declining soil fertility, soil erosion and drought (moisture stress).

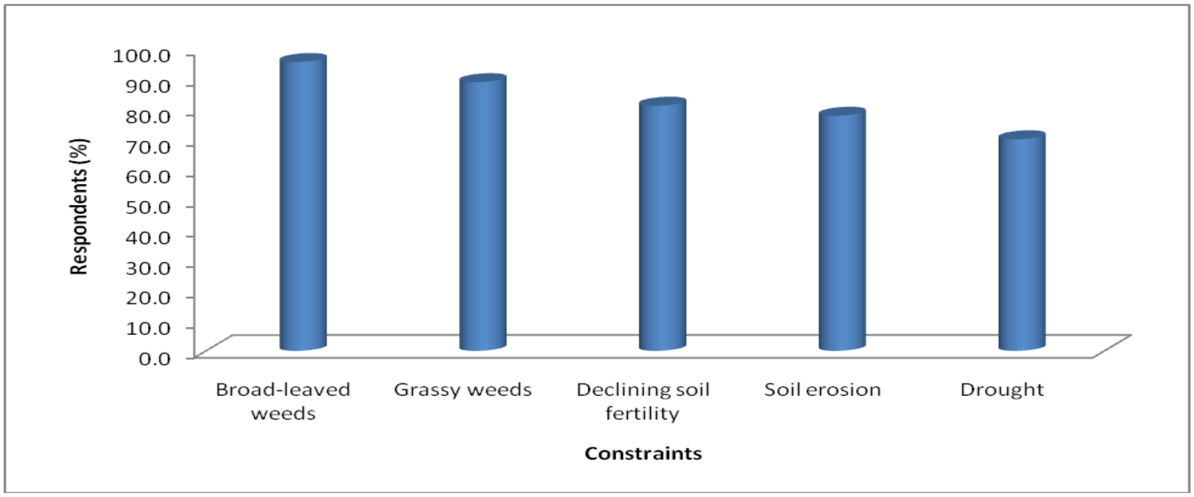


Figure 2: Agronomic and abiotic constraints hindering coffee and banana production as reported by respondents in southwestern coffee-banana ago-forestry systems of Uganda

Source: Field data, 2016

A simple logistic regression analysis showed that knowledge of the constraints limiting coffee and banana production was neither dependant on sex, age nor education level of respondents (Table 2).

Table 2: Sex, age and education level as determinants of respondent's knowledge of the constraints limiting coffee and banana production

Constraint	Parameter	DF	Estimate	Standard Error	Wald Chi-Square	P value
Broad-leaved weeds						
	Intercept	1	11.7196	185.7	0.0040	0.9497
	Sex	1	-11.9419	185.7	0.0041	0.9487
	Age	1	-0.0181	0.0372	0.2380	0.6257
	Education	1	-1.3116	0.8092	2.6274	0.1050
Grassy weeds						
	Intercept	1	-1.3148	2.0618	0.4067	0.5237
	Sex	1	-0.7770	0.8756	0.7874	0.3749
	Age	1	0.00739	0.0225	0.1084	0.7420
	Education	1	-0.1095	0.4071	0.0723	0.7880
Declining soil fertility						
	Intercept	1	-1.3678	1.6570	0.6814	0.4091
	Sex	1	-0.5113	0.6657	0.5901	0.4424
	Age	1	0.0113	0.0181	0.3853	0.5348
	Education	1	0.0105	0.3253	0.0010	0.974
Soil erosion						
	Intercept	1	-2.5843	1.5790	2.6788	0.1017
	Sex	1	0.6161	0.5852	1.1085	0.2924
	Age	1	0.00364	0.0172	0.0445	0.8330
	Education	1	0.4646	0.3151	2.1743	0.1403
Drought						
	Intercept	1	-0.8706	1.3870	0.3940	0.5302
	Sex	1	-0.00151	0.5276	0.0000	0.9977
	Age	1	0.000911	0.0153	0.0035	0.9526
	Education	1	-0.0140	0.2790	0.0025	0.9600

Source: Field data, 2016

4.1.3 Farmers’ coping options of abiotic and agronomic constraints in the southwestern coffee-banana agro-forestry systems of Uganda

4.1.3.1 Broad-leaved weeds

Farmers reported six (6) options for managing broad-leaved weeds (Fig. 3). The percentage of the respondents varied significantly (X^2=170.202, df=5, P<.0001) across the options; with most of respondents (78%) reporting using hoe weeding for managing the broad-leaved weeds.

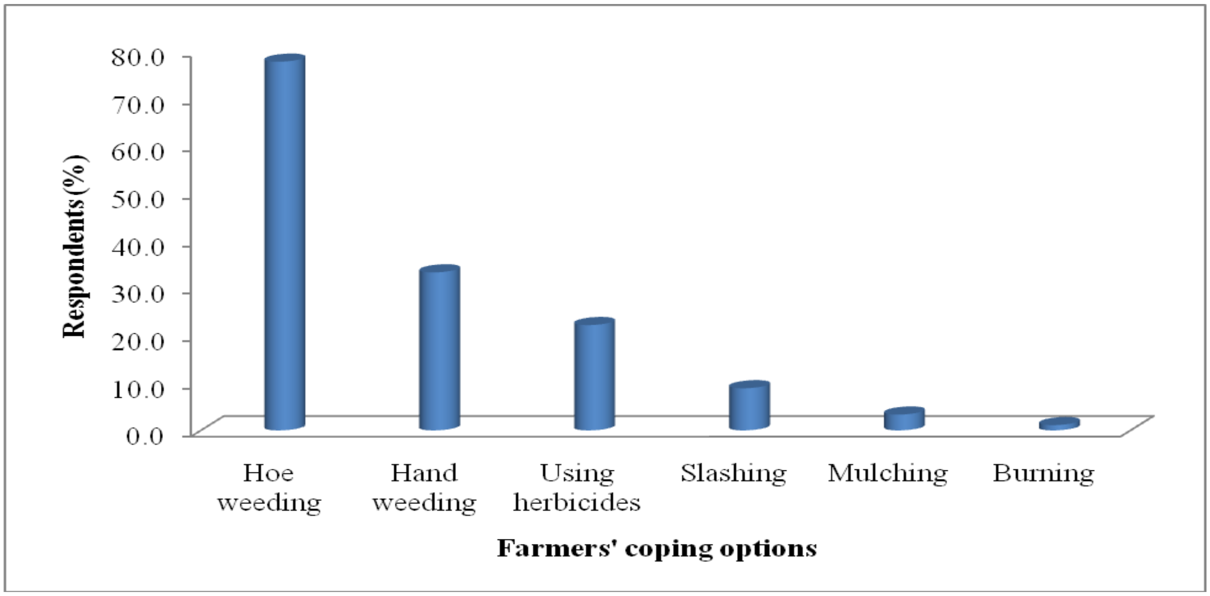


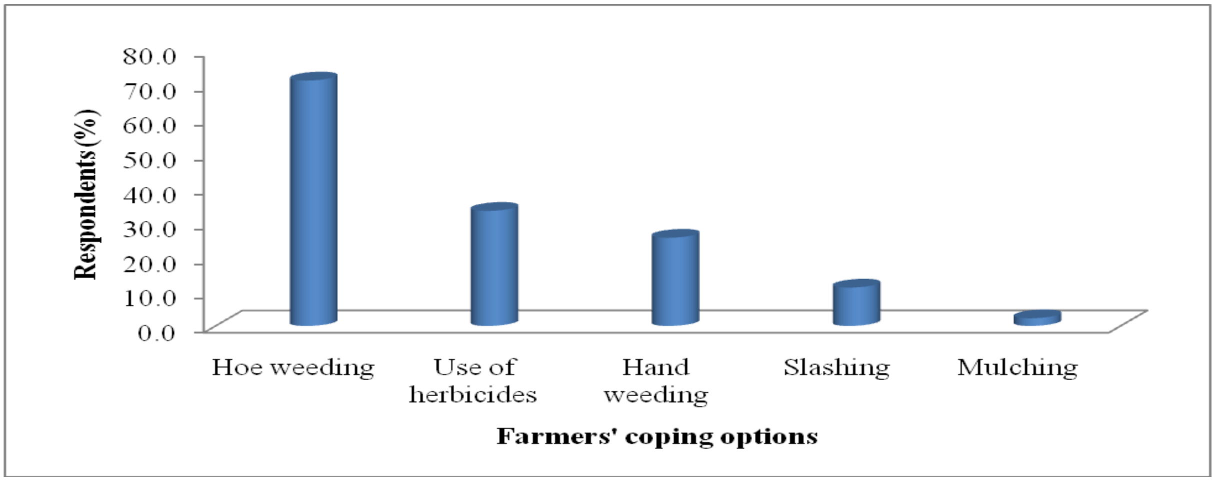
Figure 3: Farmers’ options for managing broad-leaved weeds in the southwestern coffee-banana agro-forestry systems of Uganda

Source: Field data, 2016

4.1.3.2 Grassy weeds

Farmers reported five (5) options for managing grassy weeds (Fig. 4). The percentage of the respondents varied significantly (X^2=99.0870, df=4, P<.0001) across the options; with most of respondents (71%) reporting using hoe weeding for managing the grassy weeds.

Figure 4: Farmers' options for managing grassy weeds in the southwestern coffee-banana agro-



forestry systems of Uganda

Source: Field data, 2016

4.1.3.3 Declining soil fertility

Respondents reported four (4) options for managing the declining soil fertility (Fig. 5). The percentage of the respondents using the different option for managing declined fertility varied significantly (X^2=151.9829, df=3, P<.0001) with the majority (63%) reporting using organic fertilizers.

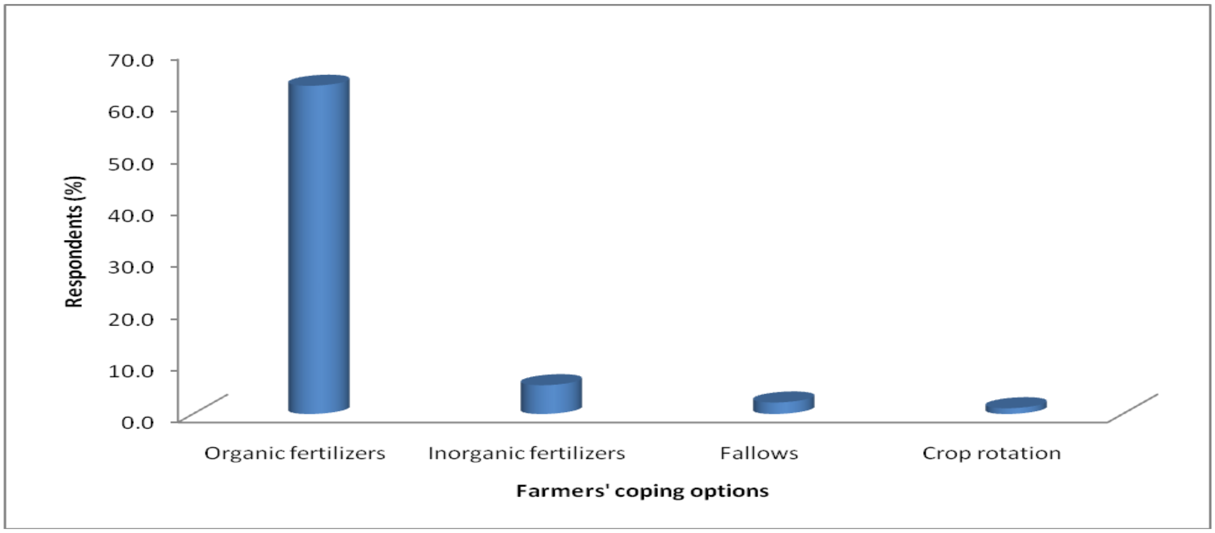


Figure 5: Farmers' options for managing declining soil fertility in the southwestern coffee-banana agro-forestry systems of Uganda

Source: Field data, 2016

4.1.3.4 Soil erosion

Respondents reported four (4) options for managing soil erosion in their fields (Fig. 6). The percentage of the respondents using the different options for managing soil erosion varied significantly (X^2=57.0, df=3, P<.0001). Most of the respondents (49%) reported that they use trenches for managing soil erosion.

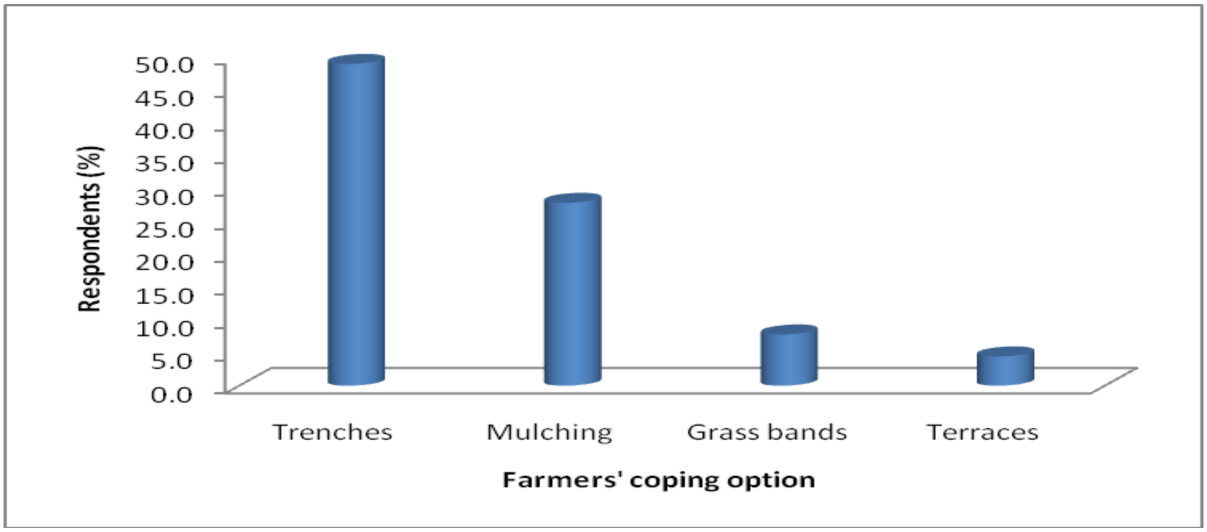


Figure 6: Farmers' options for managing soil erosion in the southwestern coffee-banana agro-forestry systems of Uganda

Source: Field data, 2016

4.1.3.5 Drought

The number of respondents (39%) who reported that they use mulches to manage drought (moisture stress) was significantly (X^2=20.7407, df=1, P<.0001) more than those of shade trees (Fig. 7).

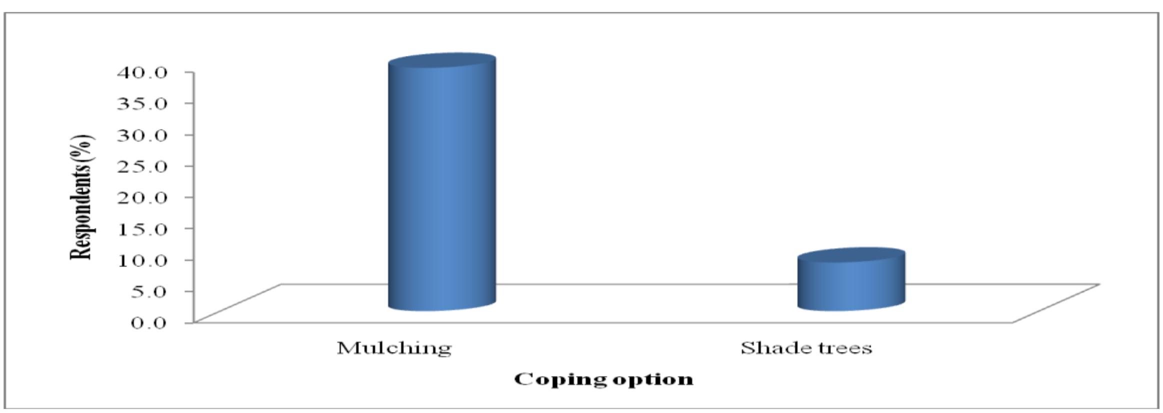


Figure 7: Farmers' options for managing drought in the southwestern coffee-banana agro-forestry systems of Uganda

Source: Field data, 2016

4.1.4 Relationship between sex, age and education level of respondent and the number of coping options reported

A simple logistic regression analysis showed that the number of coping options for all the agronomic and abiotic constraints as reported by a respondent was neither dependant on sex, age nor education level of respondents (Table 3).

Table 3: Sex, age and education level as determinants of respondent's knowledge of the number of coping options for the abiotic and agronomic constraints in coffee-banana agro-forestry systems

Parameter	Df	Parameter Estimate	Standard Error	t Value	Pr > |t|
Broad-leaved weeds					
Intercept	1	1.21883	0.43988	2.77	0.0069
Sex	1	0.09451	0.16745	0.56	0.5739
Age	1	0.00424	0.00487	0.87	0.3860
Education level	1	-0.06205	0.08851	-0.70	0.4851
Grassy weeds					
Intercept	1	0.85505	0.46769	1.83	0.0710
Sex	1	0.23526	0.17803	1.32	0.1899
Age	1	0.00538	0.00517	1.04	0.3009
Education level	1	0.00295	0.09410	0.03	0.9751
Declining soil fertility					
Intercept	1	1.08244	0.36925	2.93	0.0043
Sex	1	-0.02701	0.14056	-0.19	0.8481
Age	1	-0.00656	0.00408	-1.61	0.1120
Education level	1	-0.00500	0.07430	-0.07	0.9465
Soil erosion					
Intercept	1	1.34983	0.50458	2.68	0.0089
Sex	1	-0.13311	0.19208	-0.69	0.4902
Age	1	-0.00479	0.00558	-0.86	0.3927
Education level	1	-0.03819	0.10153	-0.38	0.7077
Drought					
Intercept	1	0.58134	0.36239	1.60	0.1123
Sex	1	0.00850	0.13795	0.06	0.9510
Age	1	-0.00056109	0.00401	-0.14	0.8890
Education level	1	-0.07352	0.07292	-1.01	0.3162

Source: Field data, 2016

4.1.5 Discussion

This study was carried out to determine farmers' knowledge of the abiotic and agronomic factors that limit coffee and banana production as well as their coping strategies in southwestern Uganda. Significantly more females were interviewed than males; supporting the fact that most coffee and banana field activities in rural settings are performed by the women (Edmeades *et al.,* 2006). The education level in the study area was generally low, with most of the respondents having attained only primary education. This implies that agriculture in Uganda is mainly practiced by resource poor and poorly educated people who drop out of school at an early level. These can hardly get employment in other sectors of economy (Edmeades *et al.,* 2006). Most farmers belonged to the age range of 36-55years. This range represents the most economically active section of the community (Kagezi *et al.,* 2010). Most farmers generally owned small pieces of land (<1 ha) and this could be attributed to land pressure issues common in the region (Edmeades *et al.*, 2006).

Respondents reported two (2) agronomic and three (3) abiotic factors limiting coffee and banana production. There was no significant (P=0.3153) difference in the percentage of respondents who reported these constraints; implying that according to them, these factors limit coffee and banana production equally. Among these, broad-leaved and grassy weeds were the most reported agronomic constraints. This agrees with experimental results where weed pressure in southwestern Uganda led to yield reductions (Wairegi *et al.*, 2010). Weeds compete with crops for water, nutrients and direct sunlight (De Graaff, 1986). The more this competition can be reduced by minimizing or eliminating weeds, the less yield loss the farmer will experience (Maro *et al.*, 2013). A range of weeds are associated with coffee-banana systems, ranging from annual grasses (*Peperomica* and *Synedrella* spp.) and broad leaved weeds (*Oxalis* spp. and *Parthenium* spp.), which are relatively easy to control, to persistent perennials (e.g. *Paspalm* and *Laporlea* spp.) that are more difficult to manage (Kimani *et al.,* 2002).

Soil fertility degradation was also another major abiotic constraint of coffee and bananas reported by respondents; agreeing with Bekunda (1999), Muzoora *et al.,* (2011) and Woniala and Nyombi (2014). Similarly, studies by Womer *et al.,* (1998) show that banana fields with low soil fertility tend to have low yields being attributed to soil nutrient depletion. The declining soil fertility is due to limited on-farm use of inorganic fertilizers by farmers due to poverty and limited subsidies (Muzoora *et al.,* 2011) as well as farmers' reluctance to invest in fertilizers (Condliffe *et al.,* 2008). This translates to poor soil fertility. Soil erosion which is closely related to decline in soil fertility was also prominently reported by the respondents as a major abiotic factor hindering coffee and banana production. This is in line with studies conducted in Uganda (Muzira *et al.,* 2007; Barungi *et al.,* 2013) and elsewhere (Corbeels *et al.*, 2000; Okoba and De Graaff, 2005; Amsalu and de Graaff, 2006). These studies recognize erosion and run-off as a major avenue of depleting the existing soil nutrient reserves and the therefore lead to yield losses (Ataroff and Monasterio, 1996a).

Results of this study further showed that drought (moisture stress) was recognized by farmers as a major abiotic constraint to coffee and banana production. Similarly, Jassogne *et al.*, (2013) reported that farmers in western district of Kasese, perceived that droughts were becoming longer, rainfall during the rainy season was becoming more erratic, and that the rains were shorter. This impacted the coffee at flowering stage (i.e. abortion of flowers); at the filling of the berries stage (i.e., poor filling); and therefore negatively impacted coffee yield in general. Similarly, farmers in Rwanda, Burundi and Eastern DRC identified drought stress as the second most important constraint to production, following declining soil fertility (Murekezi and van Asten, 2008; Bouwmeester *et al.*, 2009). These results are in line with experimental studies by Wairegi *et al.*, (2010) who found that drought stress was the primary yield constraint in a quarter of studied farmer fields in Southwest Uganda.

Farmers reported several strategies they utilize to manage the abiotic and biotic constraints they encounter in the coffee-banana agro-forestry systems of southwestern Uganda. The majority of respondents reported they manage weeds in their coffee-banana agro-forestry systems by using hoes. This in line with the fact that hoes have for long been the traditional method of weeding and have proved to be economical for resource-limited farmers operating on small farms (Hahn *et al.,* 1979; Araujo-Junior *et al.,* 2012). On the other hand, most farmers were using organic manures in regard to declining soil fertility. Organic manures are the most important fertility amendments that farmers apply in their coffee-banana systems. Farmers usually utilize crop residues, livestock manure and household waste (Bekunda, 1999; Mora *et al.*, 2013; Woniala and Nyombi, 2014). Further, most of the respondents reported that they were using trenches to manage soil erosion. This is in line of what the Government of Uganda and other stakeholders are promoting particularly in hilly areas such as the study area (Mowo *et al.*, 2002; Aklilu, 2006; Barungi *et al.,* 2013). However, construction of trenches required intensive labor consuming large percentage of useful time that would be used in the conventional work (Muzira *et al.,* 2007). In order to adapt to drought or moisture stress, most of the farmers reported that they mulch their coffee-banana fields (Jassogne *et al.*, 2013). Mulching is a common management strategy to increase water availability to the plant by promoting infiltration of rainwater and reducing evaporation (McIntyre *et al.*, 2000).

4.2 Objective 2: Agronomic constraints at plant and plot level

4.2.1 Management practices in the coffee-banana agro-forestry systems of southwestern Uganda

4.2.1.1 General plot level management practices

Figure 8 shows the level of field management practices in the coffee-banana agro-forestry systems of south-western Uganda. Most (48%) farms were moderately weeded whereas; the level of mulching on 43% of the farms was low. Most (>60%) of the farms had no manure, trenches nor terraces.

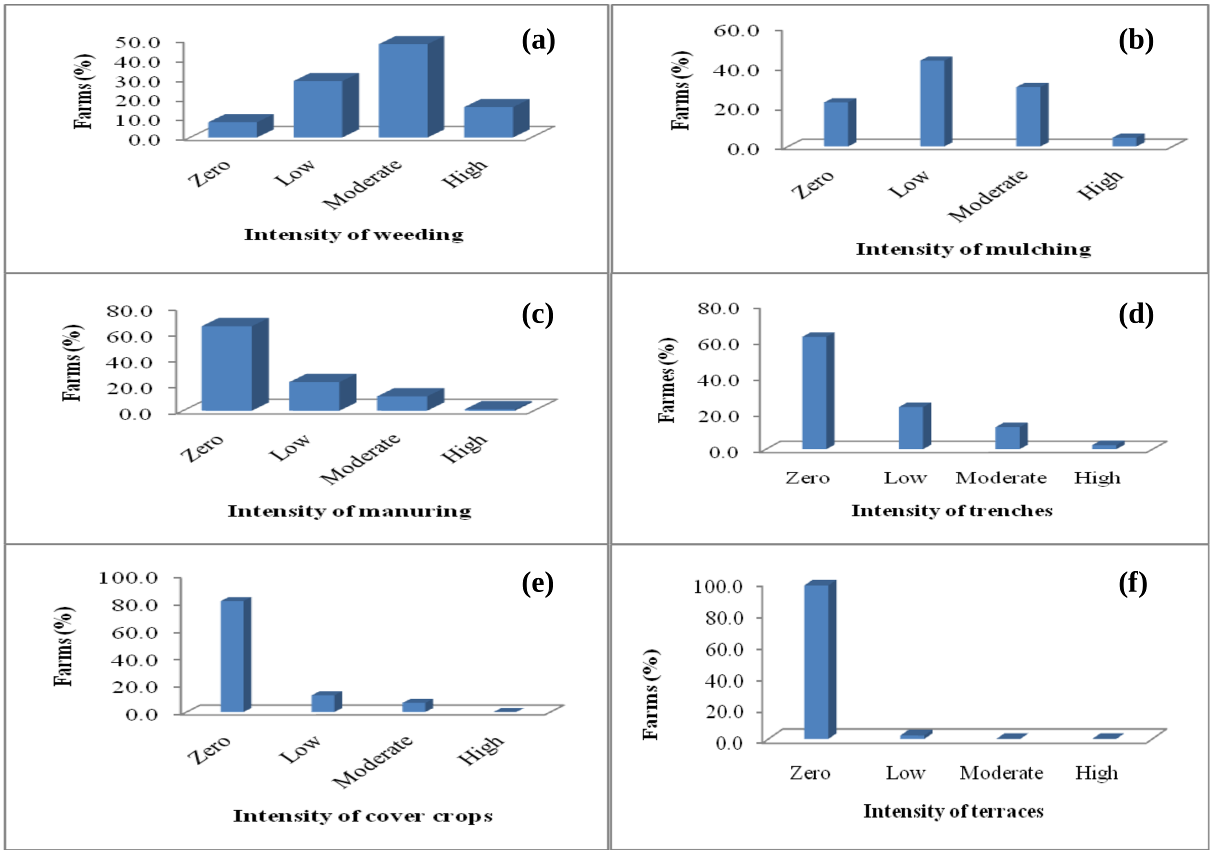


Figure 8: Levels of weeding (a), mulching (b), manuring (c), trenches (d), covercrops (e) and terraces (f) as observed in the coffee-banana agro-forestry systems of southwestern Uganda

Source: Field data, 2016

4.2.1.2 Coffee plant level agronomic practices

The levels (intensity) of coffee agronomic practices (i.e. desuckering, pruning and change of cycle) as observed in the coffee-banana agro-foresty systems of southwestern Uganda are shown in fig 9. The percentage of farmers who were not de-suckering and those who had moderately de-suckered their coffee was almost equal (30-40%). On the other hand, the majority (70%) of the farmers had not changed cycle of their coffee.

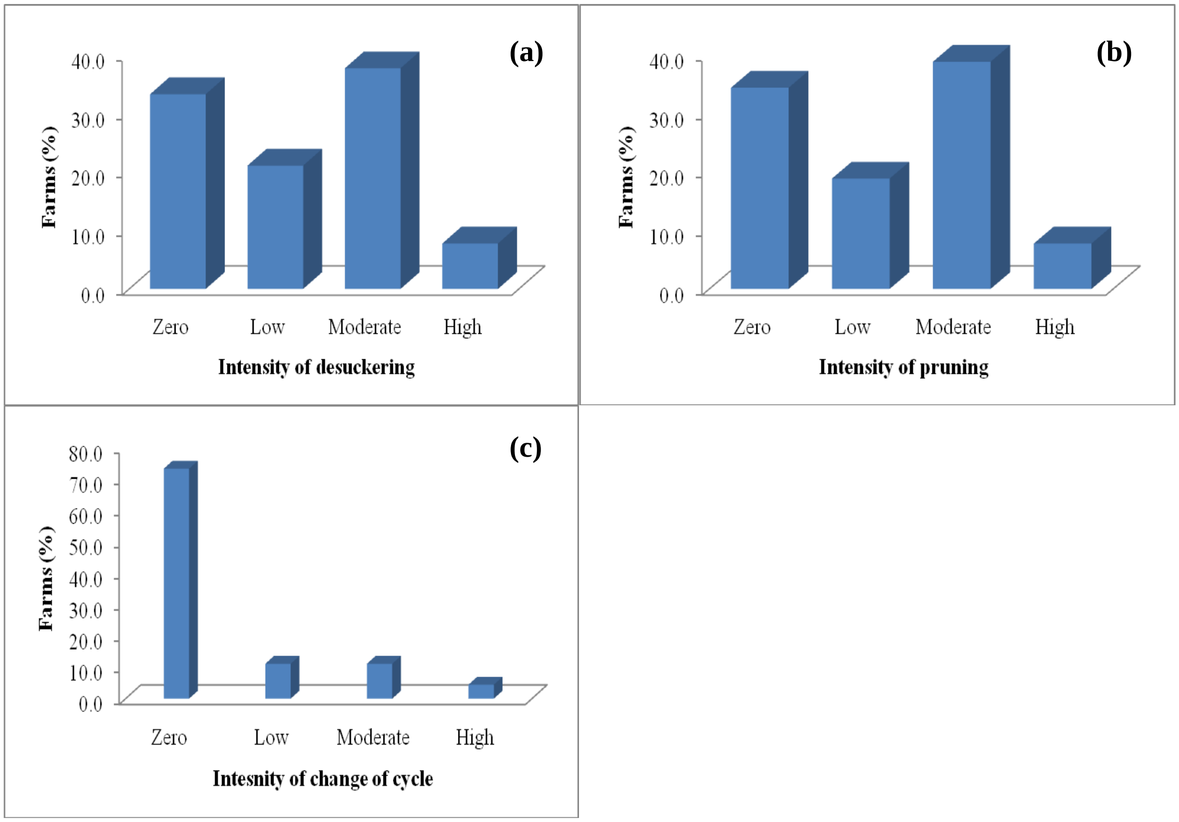


Figure 9: Level of coffee agronomic practices in the coffee-banana agro-forestry systems of southwestern Uganda. (a) de-suckering (b) pruning (c) change of cycle

Source: Field data, 2016

4.2.1.3 Banana plant level agronomic practices

The levels (intensity) of banana agronomic practices (i.e. desuckering, deleafing, debudding, corm removal and propping) as observed in the coffee-banana agro-foresty systems of southwestern Uganda are shown in fig 10. Generally, farmers were practicing desuckering, deleafing and debudding; >50% of the them had at least moderately done these practices. Further, at least 30% of the farmers were practicing corm removal as well as propping their bananas.

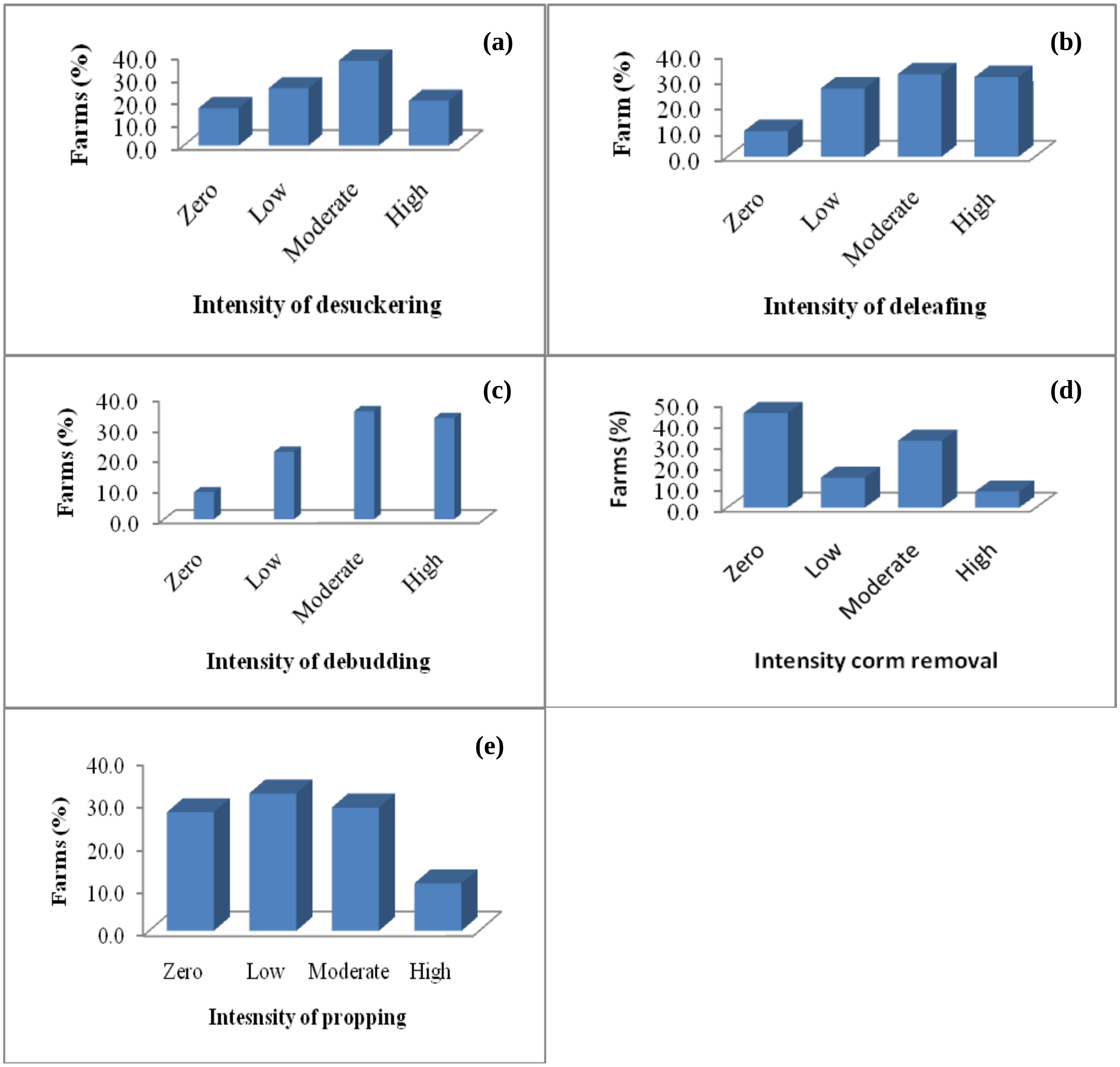


Figure 10: Level of banana agronomic practices in the coffee-banana agro-forestry systems of southwestern Uganda. (a) de-suckering (b) deleafing (c) de-budding (d) corm removal (e) propping

Source: Field data, 2016

4.2.1.5 Discussion

This study aimed at identifying the agronomic constraints at plot and plant level. Results showed that most of the farms were moderately weeded; implying that farmers are aware of the dangers the weeds cause to their coffee and bananas. Weeds compete with crops for water, nutrients and direct sunlight (De Graaff, 1986; Sheley *et al.,* 1999) and thus lead to yield loss in both bananas and coffee (Wairegi *et al.,* 2010). A number of weeds are usually associated with the coffee-banana agro-forestry systems (Concenço *et al.,* 2014). These include: - broad leaved weeds such as *Oxalis* spp. and *Parthenium* spp. as well as annual grasses such as *Peperomica* and *Synedrella* spp. and perennials grasses such as *Paspalm* and *Laporlea* spp. (Kimani *et al.,* 2002).

The majority of the farms (>70%) were mulched, implying that farmers appreciate the advantages associated with mulching. Through experience, farmers know the direct relationship between mulching and better yields (Cannell, 1973), although they might not be fully aware of all the beneficial effects that lead to this relationship (Tibanyenda *et al.,* 1989). Mulch controls soil erosion, reduces weed pressure, preserves soil water, and contributes organic matter and nutrients to the soil (Mitchell, 1988; Sheley *et al.,* 1999; CIALCA, 2008). The use of mulch can contribute towards the sustainability of the system, but availability is often limited in densely populated areas (van Asten *et al.,* 2011). Though most (>60%) of the farms had no manure, trenches nor terraces, the benefits from these practices in relationship to enhancing soil fertility (Bekunda, 1999; Sseguya *et al.,* 1999) and contributing to soil and water management (Nyombi, 2013) in coffee-banana agro-forestry systems respectively cannot be overlooked.

More than 60% of the farms had de-suckered as well as prunned coffee although the intensity varied; with atleast 30% of the fields moderately desuckered and prunned. Similarly, van Asten *et al.,* (2011) reported moderate desuckering and pruning of coffee in this region. Banana and coffee are perennial crops and therefore need to be carefully managed by pruning the coffee trees and desuckering the banana plants to maintain an optimal crop leaf canopy of both coffee and banana plants (Ren'e Coste, 1992; Wairegi *et al.,* 2014). These two practices also reduce incidences of pests and diseases, for example the coffee berry borer (Kucel *et al.,* 2009) and the black coffee twig borer (Kagezi *et al.,* 2015). Contrary, the majority (70%) of the farmers had not changed cycle (stumped) of their coffee. However, stumping is a coffee tree rejuvenation technique done after 5-7 years (Ren'e Coste, 1992) for increasing yield of coffee (Netsere *et al.,* 2015).

For bananas, most (>50%) of the farmers in the study area had desuckered, deleafed and debudded their bananas. This implies that farmers are aware of the benefits associated with these agronomic practices. De-suckering is an important practice that ensures maintaining the recommended spacing of bananas; thus, reducing competition by plants for the resources (Oluwafemi, 2013; Karamura *et al.,* 2004). This leads to increase in yield (Robinson, 1995; Oluwafemi, 2013). Deleafing on the other hand, is a practice of removing dead, non-functional leaves from a banana plant (Tushemereirwe *et al.,* 2001). This practice has been reported to reduce incidence of diseases, for example, black sigatoka disease (Vargas et al., 2009; Engwali *et al.,* 2013). De-budding on the other hand is the removal of the male bud (Tushemereirwe *et al.,* 2001). The practice helps to reduce diseases like the banana bacterial wilt (BBW) that are transmitted by insects that visit the bud bracts (Blomme *et al.,* 2008). Results further show that at least 30% of the farmers were practicing corm removal as well as propping their bananas. Corm removal helps in eliminating weevil refuges from breeding sites and to reduce weevil numbers (Gold *et al.,* 2001). Propping on the other hand, is done to prevent the plants with maturing bunches from falling down and to also enable uniform development of the bunch (Tushemereirwe *et al.,* 2001).

4.3 Objective 3: Agronomic constraints most related to coffee and banana yield loss in coffee-banana agroforestry systems

4.3.1 Coffee

Scatter plots of the relationship between level of application of agronomic practices and yield of coffee are shown in fig. 11. Desuckering, density of shade trees/shubs and number of coffee stems were identified as the factors with the largest regression coefficient (R^2) of 0.972, 0.914 and 0.758 respectively.

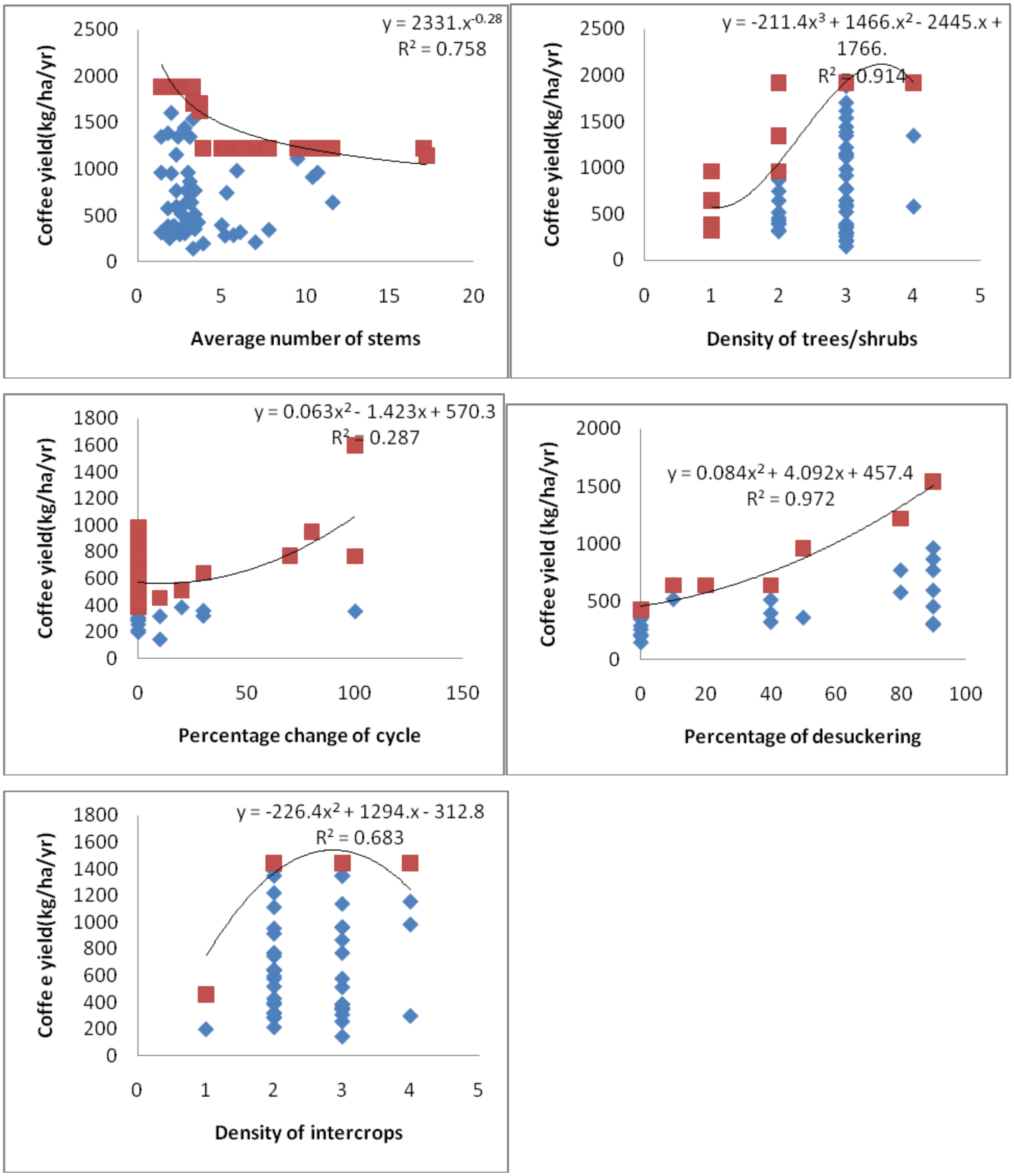


Figure 11: Relationship between level of application of agronomic practices and yield of coffee in the coffee-banana agro-forestry systems of southwestern Uganda.

Source: Field data 2016

4.3.2 Bananas

Scatter plots in fig. 12 show the relationship between level of application of agronomic practices and yield of banana in the coffee-banana agroforestry systems of southern Uganda. The three (3) factors that had the largest coefficent of regression (R^2) were: - corm removal (R^2=0.899), de-leafing (R^2=0.870) and density of shade trees/shrubs (R^2=0.768).

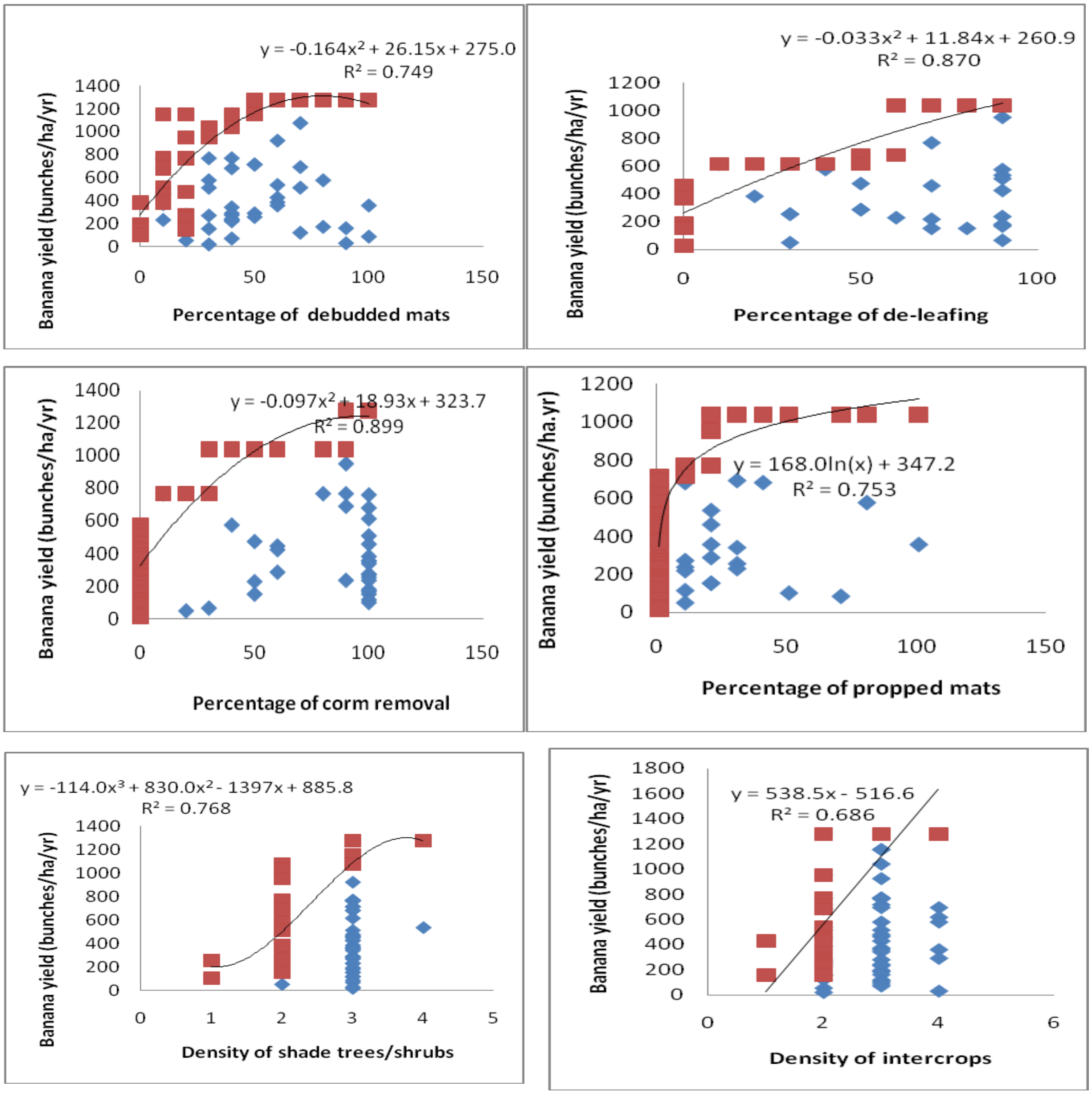


Figure 12: Relationship between level of application of agronomic practices and yield of bananas in the coffee-banana agro-forestry systems of southwestern Uganda.

Source: Field data 2016

4.3.3 Discussion

This study aimed at establishing the relationship between the level of agronomic practices of coffee as well as bananas to their performance in terms of yield loss in the coffee-banana agro-forestry systems of south-western Uganda. From the scatter plot, de-suckering, density of shade trees/shrubs and number of coffee stems were found to be most correlated with yields, indicated by the coefficient of regression (R^2). Yield of coffee increased exponetially with increasing level of de-suckering. These results support earlier studies which showed that if unwanted suckers are removed, it encourages new growth and improve productivity (Ren'e Coste, 1992). De-suckering coffee reduces competition of suckers and the bearing stems for resources. In contrast however, van Asten *et al.,* (2011) reported no significant relationship between level of de-suckering and coffee yields in a coffee-banana intercrop. Coffee yields also increased polynomially with increasing number of shade/shrub trees and then declined. This implies that yields increase with increasing shading till optimum amount beyond which the yields begin decreasing.

Shade trees have been associated with increased yields in coffee yields (Alemu, 2015) due to reduced stress on the coffee plant (Beer *et al.,* 1998). Shading is known to trigger differences in physiological behavior of the coffee plants in terms of improved photosynthesis, resulting in better performance (Bote and Struik, 2011). Increase in coffee yields in shade systems can be partially attributed to heavier and arger chierries due to reduction in overbearing, suppression of weeds, reduction of evapotranspiration of the shaded crop, and reduction of soil erosion on slopes (Beer, 1987). However, high shade tree densities have been observed to lead to reduction in coffee yields (Nzeyimana *et al.,* 2013) due to increased shade intensities (Akyeampong *et al.,* 1999). This is partly due to inter-specific competition for water and soil nutrients (DaMatta, 2004). Results further showed that coffee yields decreased exponentially with increase in the number of stems on the coffee plant. The number of stems of a coffee plant has been reported to be one of the most important characteristics determining yield in Robusta coffee (Panyatona and Nopchinwong, 2008). These results are in line with studies by Amoah *et al.,* (1997) who reported that cumulative yield of coffee at 2 stems per stool was superior to the other treatments over the experimental period. Traditionally, farmers maintain 3 or 4 trees on their Robusta coffee and after a 4-year production cycle, the trees were cut back to rejuvenate their coffee (Kimani *et al.*, 2002).

On the other hand, results show that banana yields increased with increasing level of corm removal. This is in part due to the fact that this process removes possible surplus suckers that would otherwise compete with the mother plant (Oluwafemi, 2013). Also, de-leafing increases yield in bananas (Ayodele & Ikotun, 2007) because it reduces competition for light (Tushemereirwe et al. 2001) as well as leaf diseases such as black Sigatoka disease (Engwali *et al.,* 2013; Erima *et al.,* 2016). In fact, to guarantee good development of the bunch and high quality fruits, a plant must have not more than 8 functional leaves during its whole growth period (Ortiz and Vuylsteke 1994; Orjeda 1998; Tushemereirwe *et al.,* 2003). Banana yield also increased with increasing number of shade trees/shrubs upto some optimal level (3 trees/shrubs) and then decreased. This implies that bananas require some amount of shade for better yields (Torquebiau and Akyeampong, 1994). However, when the shade levels become too much, yields start to decrease (Israel *et al.,* 1995).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter presents summary of findings, conclusions and recommendations about the study and suggestions for further research.

5.1 Summary of findings

Most farmers (≥70%) acknowledged the importance of all constraints in limiting production and thus reported on 2 agronomic and 3 abiotic constraints. Broad-leaved and grassy weeds were the most reported on agronomic constraints although farmers who reported on these were not significantly different from those who reported on other abiotic constraints like declining soil fertility, soil erosion and drought. This implied that all the constraints equally limited production. As a way of coping with these constraints, most farmers used hoes to manage broadleaved and grassy weeds, organic manure for declining soil fertility, trenches for soil erosion and mulches for drought/moisture stress. Plot level management practices showed that most farms (48%) were moderately weeded, mulching was low on 43% of farms and >60% of farms had no manure, cover crops, trenches and terraces. Coffee plant level agronomic practices showed that farmers who were not de-suckering and pruning and those who had moderately desuckered and pruned their coffee was almost equal (30-40%). However, majority (70%) of them had not changed cycle of their coffee. Banana plant level management practices showed that generally farmers were practising de-suckering, deleafing and debudding (>50%) and atleast 30% were practising corm removal and propping. Basing on the highest coefficient of regression (R^2), the agronomic constraints most related to coffee and banana yield loss were number of stems (R^2=0.76), de-suckering (R^2=0.97) and density of trees (R^2=0.91). For bananas they were de-leafing (R^2=0.87), corm removal (R^2=0.89) and density of trees (R^2 =0.77).

5.2 Conclusions

This study

- Farmers had knowledge of the abiotic and agronomic constraints limiting coffee and banana production in the region and how they manage them. They reported broad-leaved and grassy weeds as agronomic constraints and soil fertility, soil erosion and drought as abiotic constraints.

- Most of the fields were moderately weeded as well as mulched. However, manuring, trenches, cover crops and terraces were rarely done. On the other hand, most coffee plants were moderately desuckered as well as prunned but not no evidence of change of cycle. Also most banana plants had been desuckered, deleafed and debudded; however, corm removal and propping were practiced at a low level.
- Scatter plots identified desuckering, density of shade trees/shubs and number of coffee stems as agronomic constraints most related to coffee yields, whereas; corm removal, de-leafing and density of shade trees/shrubs were for bananas.

5.3 Recommendations

Therefore, yield gap of coffee and banana caused by the agronomic constraints identified in this study should be estimated. This forms the basis for developing an effective and site-specific management strategy for these constraints in the coffee-banana agro-forestry systems of southwestern Uganda.

5.4 Suggestions for further research

- The coffee-banana agro-forestry systems should be optimized to design the best-bet combinations for managing the agronomic and abiotic constraints of coffee and bananas.
- The intercropping design should be determined that is most suitable to describe competition effects in coffee-banana agroforestry systems.

References/Bibliography

ADIPALA-EKWAMU., OPIO, O., KYETERE, D., HAKIZA, G., TUSHEMEREIRWE, W., BUA, A., KISANZI, D., KOBYO, G. 2001. Background and importance of Coffee Wilt Disease in Uganda. *National Agricultural Research Organisation (NARO) research progress report* (1997-2000). pp. 1-16

A, EL-KADER., S, SHAABAN., M, EL-FATTAH. 2010. Effect of irrigation levels and organic compost on okra plants (Abelmoschus esculentus l.) grown in sandy calcareous soil, *Agriculture and Biology Journal of North America*. 1(3), 225-231.

AKLILU A. 2006. Caring for the Land: *Best Practices in Soil and Water Conservation in Beressa Watershed, Highlands of Ethiopia*: [Doctoral Thesis]; Wageningen University, p. 149.

AKYEAMPONG, E.L., HITIMANA, E., MUNYEMANA, T.P.C., 1999. Multistrata agroforestry with beans, bananas and Grevillea robusta in the highlands of Burundi. *Exp. Agric*. 35, 357–369.

ALBERTIN, A., NAIR, P. 2004. Farmers' perspectives on the role of shade trees in coffee production systems: an assessment from the Nicoya Peninsula, Costa Rica. *Human Ecology* 32 (4) pp. 443-463

ALEMU B, HUNDERA K, ABERA B. 2015. Floristic composition and structural analysis of Gelesha forest, Gambella regional State, Southwest Ethiopia. *J Ecol Nat Environ.* 7:218–227.

AMOAH, F.M., OSEI-BONSU, K., OPPONG, F.K., 1997. Response of improved Robusta coffee to location and management practices in Ghana. *Exp. Agric.* 33, 103–111.

AMSALU, A., AND DE GRAAFF, J. 2006. *Determinants of adoption and continued use of stone terraces for soil and water conservation in the Ethiopian highland watershed*. Ecological Economics.

ATAROFF,M., AND MONASTERIO, M. 1996a. *Impacto ecologico de los agroecositemas cafetaleros en el Estado Merida*. In: R. Giacalone (Editor), Merida a Traves del Tiempo. Tomo 3. Capitulo 8. Universidad de Los Andes, Merida, Venezuela.

AYODELE M. & IKOTUN T. 2007. *Cultural and chemical control of black leaf streak in plantain.* p 71. In *Recent advances in banana crop protection for sustainable crop production and improved likelihoods*. 10 -14 September. South Africa.

BAGAMBA, F. 2007. *Market Access and Agricultural Production*: The Case of Banana Production in Uganda. PhD Thesis, Wageningen University, The Netherlands.

BANANUKA, J.A., RUBAIHAYO, P.R., ZAKE, J.Y.K. 2000. Effect of organic mulches on growth, yield components and yield of East African highland bananas. *Acta Horticulturae.* (ISHS) 540pp. 293-300.

BARUNGI, D., NG"ONG"OLA, H., EDRISS, A., MUGISHA,J., WAITHAKA,M. AND TUKAHIRWA, J. 2013. Factors Influencing the Adoption of Soil Erosion Control Technologies by Farmers along the Slopes of Mt. Elgon in Eastern Uganda. *Journal of Sustainable Development* 6: 9-22.

BEER, J.W. 1987 Advantages, disadvantages and desirable characteristics of shade trees for coffee, cacao and tea. *Agroforestry Systems.* 5pp. 3–13

BEER, J.,MUSCHLER, R., KASS, D., & SOMARRIBA, E. 1998. *Shade Management in Coffee and Cacao Plantations. Agroforestry Systems, 38,* 139-164. http://dx.doi.org/10.1023/A:1005956528316

BEKUNDA, M.A., WOOMER, P.L. 1996. Organic resource management in banana-based cropping systems of the Lake Victoria Basin, Uganda. *Agriculture ecosystems and environment.* 5pp. 171–180.

BEKUNDA, M. 1999. Farmers' response to soil fertility decline in banana-based cropping systems of Uganda. *Managing African Soils.* 4pp. 1–20.

BLOMME, G., TURYAGYENDA, L.F., MUKASA, H., SSEKIWOKO, F., MPIIRA, S., EDEN-GREEN, S. 2008. The effect of prompt removal of inflorescence-infected plants, early debudding and bagging of inflorescences on the control of *Xanthomonas wilt* of banana. ISHS/ProMusa symposium: Recent advances in banana crop protection for sustainable production and improved livelihoods. *Acta Horticulturae (in press).*

BOTE AD, STRUIK PC. 2011. Effects of shade on growth, production and quality of coffee (Coffea arabica) in Ethiopia. *Journal of Horticulture and Forestry* 3(1):336-341.

BOTHA, J.J., VAN RENSBURG L.D., ANDERSON J.J., HENSLEY M. 2005. *Evaluating the agronomic sustainability of the in-field rainwater harvesting technique*. OECD workshop on agriculture and water: sustainability, markets and policies, Barmera.

BOUWMEESTER, H., VAN ASTEN, P., OUMA, E., 2009. *Mapping Key Variables of Banana Based Cropping Systems in the Great Lakes Region* ,Partial Outcomes of the Baseline and Diagnostic Surveys.CIALCA Technical Report 11.http://www.cialca.org/IITA, Ibadan www.cialca.org.

BUCAGU, C., VANLAUWE, B. AND KEN GILLER, E. 2013. Managing Tephrosia mulch and fertilizer to enhance coffee productivity on smallholder farms in the Eastern African Highlands. *European Journal of Agronomy*. 48pp. 19–29.

CANNELL, M.G.R., 1973. *Effects of irrigation, mulch and N-fertilizers on yield components of Arabica coffee in Kenya*. Exp. Agric. 9, 225–232.

CASÃO-JUNIOR, R., J., GUILHERME DE ARAÚJO, A., FUENTES-LLANILLO, R. 2012. *No-Till Agriculture in Southern Brazil*. Food and Agriculture Organization of the United Nations, Rome, Italy. 77 pp.

C. GAY., F. ESTRADA., C. CONDE., H. EAKIN., L. VILLERS. 2006. “Potential impacts of climate change on agriculture: a case of study of coffee production in Veracruz, Mexico,” *Climatic Change*, vol. 79, no. 3-4, pp. 259–288.

CHIPUNGAHELO, G.S., TERI, J.M., MATOWO, P.J., MSAKY, J., MAGINA, F.I., MALINGA, S., MBOWE, D., KIMARO, W. 2004. A review of coffee-banana based cropping systems in Tanzania: *The economics.* pp. 870-877

CIALCA. 2008. Final Report Phase 1 – CIALCA: January 2006–December 2008. Progress Report 5. Consortium for Improving Agriculture Based Livelihoods in Central Africa. < http://www.cialca.org/files/files/CIALCA-I_final_technical_report.pdf> (viewed 04-11-14).

CONCENÇO, G.2, MOTTA, I.S.2, CORREIA, I.V.T.3, SANTOS, S.A.4, MARIANI, A.3, MARQUES, R.F.5, PALHARINI, W.G.3, and ALVES, M.E.S.2014. *Infestation of weed species in monocrop coffee or intercropped with banana, under agroecological system*. Planta Daninha, Viçosa-MG, v. 32, n. 4, p. 665-674.

CONDLIFFE K, KABUCHI W, LOVE C, RUPARELL R 2008. Kenya coffee: *A cluster analysis*. Harvard Business School. P. 34. http://www.isc.hbs.edu/pdf/Student_Projects/Kenya_Coffee_2008.pdf visited 22 February, 2012.

CORBEELS M, SHEFERAW A, MITIKU H 2000. *Farmers' Knowledge of Soil Fertility and Local Management Strategies in Tigray, Ethiopia*. Managing African Soils 10: 23.

COSSALTER, C. 1991: *Acacia senegal, gum tree with promise for agroforestry*. NFT Highlights, NFTA 91-02. Nitrogen Fixing Tree Association, Hawaii.

DAMATTA, F.M. 2004. Ecophysiology on the production of shaded and unshaded coffee*:* a review. *Field crops research* 86 (2) pp. 99–114.

DAMATTA, F.M., RONCHI, C.P., MAESTRI, M., BARROS, R. 2007. *Ecophysiology of Coffee Growth and Production.* Brazilian Journal of Plant Physiology. 19pp. 485-510. http://dx.doi.org/10.1590/S1677-04202007000400014

DAVID, W., ALISON O., ERIC H. 2014. *Structural Training of Young Shade Trees.* CMG GardenNotes, Colorado State University Extension. 613-10pp

DEFRA, 2005. *Controlling Soil Erosion*: a Manual for the Assessment and Management of Agricultural Land at Risk of Water Erosion in Lowland England. Revised September 2005a. Department for Environment, Food and Rural Affairs, London.

DE-GRAAFF J, 1986. *The economics of coffee.* Wageningen, The Netherlands: Pudoc Wageningen.

DHARANI, N. 2011. *Field Guide to Common Trees & Shrubs of East Africa*. Second edition. Cape Town, South Africa: Struik Nature.

DIAZ, M. 2012. *Improving coffee quality: a strategy for small growers*. 7th African Scientific Coffee Conference. Addis Ababa, Ethiopia. (Viewed 04-09-2014).

EDMEADES, S., SMALE, M., AND KARAMURA, D. 2006. Demand for Cultivar Attributes and the Biodiversity of Bananas on Farms in Uganda. In Smale, M., editor, Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change, pages 1–16. CABI Publishing, Cambridge, MA.

ENGWALI FD, NFOR TD, ALAIN K. 2013. On-farm evaluation of deleafing frequency on the severity of black sigatoka disease *Mycosphaerella fijiensis* Morelet) and Yield of Banana (*Musa* spp.). *(Am. J. Exp. Agric.* 3(3):595-605.

ERIMA, R., SSEBULIBA, J. M., NANKINGA, C. M. K., RAGAMA, P., BAREKYE, A., TUSHEMEREIRWE, W. 2016. Yield performance of East African highland banana hybrids on farmers' fields under high disease pressure. *African journal of agricultural research,* Vol. 11(13), pp. 1141-1149, 31 March

ESPINO, R.R.C., JAMALUDDIN, S.H., SILAYOI, B., NASUTION, R.E. 1992. Musa L. (edible cultivars). In: EWM Verheij, RE Coronel, eds. *Plant Resources of South-East Asia* No. 2 Edible Fruits and Nuts. PROSEA, Bogor, Indonesia.

FABIAN M, THOMAS B, DAVE B, DENNIS C, MARTY M, BRUCE M, KENT MV, PERRY M, RACHEL S, DAVID W. 2008. An Introduction to the Principles and Practices of Sustainable Farming. *Agriculture and Natural Resources (Farm Management)* .New November 2008 500-1108SA. Montana state university extension. 4pp

FAO. 2005. State of the world's forests. Realizing the economic benefits of agroforestry: experiences, lessons and challenges. Part II Selected current issues in the forest sector. 85-95. ftp://ftp.fao.org/docrep/fao/007/y5574e/y5574e09.pdf

FAO. 2009. FAOSTAT. In the Food and Agriculture Organization of the United Nations.FAO,Rome(Verified26February,2009)http://faostat.fao.org/site/567/default.aspx.

FAOSTAT. 2010. Online statistical database. Food and Agriculture Organization of the United Nations, Rome. Available at: http://faostat.fao.org/ (viewed 12-10- 2014).

FORGE, T.A., HUGUE, E., NEILSEN, G., NEILSEN, D. 2003. Effects of organic mulches on soil microfauna in the root zone of apple: implications for nutrient fluxes and functional diversity of soil food web. *Applied Soil Ecology*. 22pp. 39-54.

GARRETT, H.E., MCGRAW, R.L. 2000. Alley cropping practices. In Garrett H.E., Rietveld, W.J. and Fisher, R.F. (eds). North American agroforestry: an integrated science and practice. *American Society of Agronomy*. pp. 149- 188

GARRETT, H.E., W.B. KURTZ, L.E., BUCK, J.P., LASSOIE, M.A., GOLD, H.A. PEARSON., H.L. HARDESTY AND J.P. SLUSHER, 1994. *Agro Forestry: An Integrated Land use Management System for Production and Farmland Conservation.* USDA- Soil Conservation Service Report 68-3A75-3-134, USA p: 58.

GAY, C., ESTRADA, F., CONDE, C., EAKIN, H., VILLERS, L. 2006. Potential impacts of climate change on agriculture: a case study of coffee production in Veracruz, Mexico. *Climate Change* 79 259-288.

GOLD, C.S., KARAMURA, E.B., KIGGUNDU, A., BAGAMBA, F., ABERA, A.M.K. 1999. Monograph on geographic shifts in highland cooking banana (Musa, group AAA-EA) production in Uganda. *African Crop Science Journal.* 7 (3) pp. 223–298.

GOLD, C.S. 2000. Biology and integrated pest management of banana weevil, Cosmopolites sordidus (Germar). *International Network for the Improvement of Banana and Plantain-The Banana Asia-Pacific Network.* 10 pp. 28-33.

GOLD, C.S., PENA, J.E., KARAMURA, E.B. 2001. Biology and integrated pest management for the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Integrated Pest Management. Reviews.* 6 pp. 79-155.

HAGGAR, J., BARRIOS, M., BOLA˜NOS, M., MERLO, M., MORAGA, P., MUNGUIA, R., PONCE, A., ROMERO, S., SOTO, G., STAVER, C., VIRGINIO, E.D.M.F. 2011. Coffee agro-ecosystem performance under full sun, shade, conventional and organic management regimes in Central America. *Agroforestry Systems.* 82pp. 285–301.

HAHN, S.K, TERRY, E.R, LEUSCHNER,K, AKOBUNDU, I.O, OKAII,C AND LAL, R. 1979.Cassava improvement in Africa. *Field crops research* 2: 193-226

ISABIRYE, M., MAGUNDA, M., SSALI, C.K. 2001. *People and agroecosystems: Issues and strategies for sustainable land management in Mayuge district*. Land use management technical report No.7. Lake Victoria Environment Management Project, NARO-Kawanda, Uganda.

ISRAELI, Y., PLAUT, Z., SCHWARTZ, A. 1995: Effect of shade on banana morphology, growth and production, *Scientia Horticulturae* 62 (1995) 45-46, pp.45 - 56

JASSOGNE, L. 2011. "*Climate change impact and opportunities in coffee-banana systems in Uganda".* Technical report, International Institution of Tropical Agriculture, (IITA-Uganda). 16pp.

JASSOGNE, L., NIBASUMBA, A., WAIREGI, L., BARET, P.V., DERAECK, J., MUKASA, D., WANYAMA, I., BONGERS, G., ASTEN, P.V. 2011. Coffee-banana intercropping as an opportunity for smallholder farmers in Uganda. CIALCA conference, Kigali, Rwanda. pp. 144-149.

JASSOGNE, L., VAN ASTEN, P.J.A., WANYAMA, I., BARET, P.V. 2013b. Perceptions and outlook on intercropping coffee with banana as an opportunity for smallholder coffee farmers in Uganda. *International journal of agricultural sustainability.* 11 (2) pp. 144-158

JONES, A. 2012. *The State of Soil in Europe*, Luxembourg: Publications Office of the European Union.

KAGEZI, G.H., KAIB, M., NYEKO, P. AND BRANDL, R. 2010. Termites (Isoptera) as food in the Luhya community (Western Kenya). *Sociobiology* 55(3): 831-845.

KAGEZI, G.H., P. KUCEL,, J. KOBUSINGE., L. NAKIBUULE., R. WEKHASO., G. AHUMUZA., P. MUSOLI., A. KANGIRE. 2013. Influence of shade systems on spatial distribution and infestation of the Black Coffee Twig Borer on coffee in Uganda. *Uganda Journal of Agricultural Sciences.* 14 (1) pp. 1-12.

KAGEZI, G., KUCEL, P., OLAL, S., PINARD, F., SERUYANGE, J., MUSOLI, P., KANGIRE, A. 2015. In vitro inhibitory effect of selected fungicides on mycelial growth of ambrosia fungus associated with the black coffee twig borer, Xylosandrus compactus Eichhoff (Coleoptera: Curculionidae) in Uganda. *African journal of agricultural research.* Vol.10(23), pp. 2322-2328

KALLARACKAL, J., MILBURN, J.A., BAKER, D.A. 1990. Water relations of the banana. III effects of controlled water stress on water potential, transpiration, photosynthesis and leaf growth. *Australian Journal of Plant Physiology*.17:79-90

KARAMURA, D.A., GOLD, C.S., PICKERSGILL, B., VUYLSTEKE, D. 1998. *The pattern of variation in the East African Highland bananas race* (Musa AAA-East AiXca) as portrayed by multivariate statistics. Genetic Resources and Evolution (In press]

KATENDE, A.B., BIRNIE, A., TENGNÄS, B. 2000. *Useful Trees and Shrubs for Uganda. Identification, Progagation and Management for Agricultural and Pastoral Communities.* Technical handbook 10. Nairobi:Regional Land Management Unit (RELMA/sida).

KIMANI, M., LITTLE, T AND VOS, J.G.M. 2002. *Introduction to coffee management through discovery learning.* 35p.

KUCEL, P., KANGIRE, A. AND EGONYU, J.P. 2009. *Status and current research strategies for management of the coffee berry borer (Hypothenemus hampei Ferr) in Africa.* ICO Seminar on the Coffee Berry Borer. http://dev.ico.org/eventpdfs/cbb/presentations /Kangire%20 NaCRRI. pdf.

LÄDERACH, P., OBERTHÜR, T., COOK, S., ESTRADA, I.M., POHLAN, A.J., FISHER, M., LECHUGA, R.R. 2011. Systematic agronomic farm management for improved coffee quality. *Field crops research.* 120 (3)pp. 321-329

LOBELL D.B, CASSAM K.G, FIELD C.B. 2009. Crop Yield Gaps: Their Importance, Magnitudes, and Causes. *Annual Review of Environment and Resource*. 34pp. 1-26.

LUFAFA, A., TENYWA, M. M., ISABIRYE, M., MAJALIWA, M. J. G., WOOMER, P. L. 2003. Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. *Agricultural Systems.* 76 (3) pp. 883–894.

MA, X., J.C. XU., Y. LUO., S.P. AGGRAWAL., J.T. LI. 2009. Response of hydrological processes to land-cover and climate changes in Kejie water-shed, south-west China. *Hydrological Processes* 23pp: 1179 –1191.

MAGDOFF, F., VAN, E.S, H. 2009. *Building Soils for Better Crops and Sustainable Soil Management.* 3rd edition. Vermont: Sustainable Agriculture Network Handbook Series 10.

MCINTYRE, B. D.,SPEIJER,P.R.,RIHA,S.J.,KIZITO,F.,2000. Effects of mulching on biomass, nutrients, and soil water in banana inoculated with nematodes. *Agronomy Journal*. 92, 1081–1085.

MITCHELL, H.W., 1988. *Cultivation and harvesting of the Arabica coffee tree*. In: Clarke, R.J., Macrae, R. (Eds.), Coffee, Agronomy, vol. 4. Elsevier Applied Science, London, pp. 43–90.

MITTLER, RON. 2006. "Abiotic stress, the field environment and stress combination." *Trends in Plant Science* 11(1): 15–19.

MOGUEL, P., TOLEDO, V. M. 1999. Biodiversity Conservation in Traditional Coffee Systems of Mexico. *Conservation Biology* 13(1) pp: 11-21.

MORA C, FRAZIER AG, LONGMAN RJ, DACKS RS, WALTON MM, TONG EJ, SANCHEZ JJ, KAISER LR, STENDER YO, ANDERSON JM, AMBROSINO CM, FERNANDEZ-SILVA I, GIUSEFfi LM, GIAMBELLUCA TW. 2013. *The projected timing of climate departure from recent variability*. Nature 502:183–187

MOUTONNET, P. 2000. *Yield response factors of field crops to deficit irrigation.* In: Deficit Irrigation Practices FAO Water Report 22. Rome, Italy: Food and Agriculture Organization of the United Nations.

MOWO, J.G., MWIHOMEKE, T.S. AND MZOO, J.B. 2002. *Managing natural resources in the West Usambara Mountains*: A glimmer of hope in the horizon. Paper Presented at the Mountain High Summit Conference for Africa, 6-10 May 2002, Nairobi. UNEP.

MUREITHI, J.G., GACHENE, C.K.K., WAMUOGO, J.W. 2003. Legume Cover crops Research in Kenya: Experiences of the Legume Research Network Project. Highlights of Phase 1 Research Activities (1994-2000). KARI Technical Note Series No. 12, February 2003

MUREITHI, L. 2008. "Coffee in Kenya: Some challenges for decent work" International Labour Office, *Sectoral activities Program, working Paper*, No.260

MUREKEZI, C.,VANASTEN,P.J.A. 2008. *Farm banana constraints in Rwanda*: a farmer's perspective. In: Dubois, T., Coyne, D. (Eds.), Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Book of Abstracts, Mombassa, Kenya, 5–9 October 2008.

MURUNGU, F.S., CHIDUZA , C., MUCHAONYERWA, P., MNKENI, P.N.S. 2011. Mulch effects on soil moisture and nitrogen, weed growth and irrigated maize productivity in a warm-temperate climate of South Africa. *Soil and Tillage Research* 112 (1) pp. 58–65.

MUSOLI, P.C., HAKIZA, G., BIRINKUNZIRA, J.B., KIBIRIGE-SEBUNYA., KUCEL, P. 2001. Coffee (Coffea spp). In: Mukiibi, J.K. (Eds.), *Agriculture in Uganda* Vol. II. Fountain Publishers/CTA/NARO. pp. 376-436.

MUZOORA, A. K., TURYAHABWE, N. & MAJALIWA, J. G. M. 2011. Validation of farmer perceived soil fertility improving tree species in agropastoral communities of Bushenyi District. International Journal of Agronomy, 2011, 1–10. doi:10.1155/2011/212515

MWEBAZE, S. M. N. 2002. *Country pasture/forage resource profiles.* In Grassland and Pasture Crops. FAO (Food and Agriculture Organization), Rome.

NARO. 2000. The Republic of Uganda: *Banana Production Manual*. 71 pp

NAIR, P.K.R., NAIR, V.D., KUMAR, B.M., SHOWALTER, J.M. 2010. Carbon sequestration in agroforestry systems. *Advances in Agronomy*. 108, 237–307.

NETSERE, A., TAYE, K., TESFAYE, S. 2015. Review of Arabica Coffee Management Research in Ethiopia. *Journal of Biology, Agriculture and Healthcare*. Vol.5, No.13, 2015

NGIGI, S.N. 2003. *Rain water harvesting for Improved Food Security*. Promoting Technologies in the Greater Horn of Africa. Greater Horn of Africa Rainwater Partnership (GHARP).Kenya Rainwater Association (KRA).

NYOMBI, K. 2010. *Understanding growth of East Africa highland banana*: Experiments and simulation, Phd Thesis, Wageningen University. 198pp.

NYOMBI, K. 2013. Towards sustainable highland banana production in Uganda: opportunities and challenges. *African Journal for Food, Agriculture, Nutrition and Development,* 13:7544–61.

NZEYIMANA, I., HARTEMINK, A.E., DE GRAAFF, J., 2013. Coffee farming and soil management in Rwanda. *Outlook Agric.* 42 (1), 47–52.

ODUOL, P.A., ALUMA, J.R.W. 1990. The banana *(musa spp.)* – coffee robusta: traditional agroforestry system in Uganda. *Agroforestry systems,* 11, 213–226.

OGBAN, P.I.; EKANEM, T.P.; ETIM, E.A. 2001. Effect of mulching methods on soil properties and growth and yield of maize in south-eastern Nigeria. *Tropical Agriculture*. (Trinidad). 78pp. 82-89.

OKECH, S.H., VAN ASTEN, P.J.A., GOLD, C.S., SSALI, H. 2004. Effects of potassium deficiency, drought and weevils on banana yield and economic performance in Mbarara, Uganda. *Journal of Agricultural Sciences.* 9:511-519.

OKECH, S.H.O., VAN ASTEN, P.J.A., GOLD, C.S., SSALI, H., 2004. *Factors contributing to yield loss in a long-term banana trial in Mbarara.* Submitted for presentation at the September 2004 10 NARO Conference in Kampala, Uganda.

OKOBA, B.O. AND DE GRAAFF, J. 2005. *"Farmers' Knowledge and Perceptions ofSoil Erosion and Conservation Measures in the Central Highlands,* Kenya:' Land Degradation and Development. 16(5): 475-487.

OKORIO, J., BYENKYA, S., WAJJA, N., PEDEN, D. 1994. Comparative performance of seventeen upperstorey tree species associated with crops in the highlands of Uganda. *Agroforestry Systems* 26pp:185–203

OLUKA-AKILENG, I., ESEGU, J. F., KAUDIA, A. A., LWAKUBA, A. 2000. *Agroforestry handbook for the banana-coffee zone of Uganda - Farmers' practices and experiences.* Technical Handbook 21. Nairobi: Regional Land Management Unit (RELMA/Sida). 96pp.

OLUWAFEMI, A.B. 2013. Influence of number of sucker per plant on the growth, yield and yield components of Plantain (Musa sp) in Ado-Ekiti, Nigeria. *Agricultural Science Resource Journal* 3(2) pp. 45-49.

ORJEDA, D., 1998. *Evaluation of Musa Germplasm for Resistance to Sigatoka Disease and Fussaruim Wilt.* INIBAP Technical Guide 3. International Plant Genetic resources Institute, Rome, Italy, International Agricultural Network for Improvement of Banana and Plantain, Montpellier, France, ACP-EU Technical Center for Agricultural and Rural Cooperation, Wageningen, The Netherlands.

ORWA, C, .A., MUTUA, KINDT R ,JAMNADASS R, S ANTHONY. 2009. Agroforestree Database:a tree reference and selection guide version 4.0 (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp)

ORTIZ R, VUYLSTEKE DR 1994. Genetics of apical dominance in plantain (*Musa* spp., AAB Group) and improvement of suckering behavior. *J. Am. Soc. Hortic. Sci*. 119:1050-1053.

PANYATONA S., AND NOPCHINWONG P., 2008. Selection characteristics for predicting yield potential of robusta coffee. *Acta Hort.* (ISHS) 787: pp. 141-146

PIPER, H., SIMONS, H. 2005, 'Ethical responsibility in social research', in Somekh, B. and Lewin, C., (eds.), *Research Methods in the Social Sciences,* London: Sage, pp.56-64.

PLACE, F., B.B., CHRISTOPHER, H., ADE FREEMAN, J. J., RAMISCH., VANLAUWE, B. 2003. Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. *Food Policy.* 28: 365-378.

RAMAKRISHNA, A., H.M. TAM., S.P. WANI., T.D. LONG. 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Research*. 95pp. 115-125.

RELMA. 2003. *Agroforestry handbook for the Montane zone of Uganda*. Nairobi Kenya

REN'E COSTE, 1992. Coffee the Plant and the Product. The Macmillan press Ltd, London and Basingstoke.

RISHIRUMUHIRWA T., ROOSE, E. 1998. The Contribution of Banana Farming Systems to Sustainable Land Use in Burundi. *Advances in Geo Ecology*. 31pp:1197-1204.

ROBINSON, J.C. 1995. *Systems of cultivation and management*, p.p. 15-62. In: S. Gowen (ed). Bananas and Plantains. Chapman and Hall.

RUSOKE, C., NYAKUNI. A., MWEBAZE, S., OKORIO, J., AKENA, F. & KIMARU, G. 2000. *Uganda Land and Resources Manual. A Guide for Extension Workers*. Technical handbook 20. Nairobi: Regional Land Management Unit (RELMA/Sida).

RUTHERFORD, M.A. AND KANGIRE, A. 1998. *Prospects for the Management of Fusarium Wilt of Banana* (Panama disease) in Africa. Review of IPM Research Activities Pathology. pp. 177-188.

SAMSON, J.A. 1992. *Tropical Fruits.* 2nd Edition. Tropical Agriculture series. Longmans, London. 400pp.

SAFE. 2004. *Silvorable Agroforestry for Europe*. (Viewed 28-9-2014). http://www.montpellier.inra.fr/safe

SANCHEZ, P.A., PALM, C.A., SZOTT, L.T., CUEVAS, E., LAL, R. 1989. *Organic input management in tropical agroecosystems*. In: Coleman, D.C., Oades,J.M., Uehara, G.

(Eds.), Dynamics of Soil Organic Matter in Tropical Ecosystems. NifTAL Project, Paia,HI. pp. 125–152.

SCOWCROFT, P.G., TURNER, D.R., VITOUSEK, P.M. 2000. Decomposition of Metrosideros polymorpha leaf litter along elevational gradients in Hawaii. *Global Change Biology* 6, 73-85.

SHELEY, R. L., J. S. JACOBS., M. E CARPINELLI. 1998. Distribution, biology, and management of diffuse knapweed *(Centaurea diffusa)* and spotted knapweed *(Centaurea maculosa). Weed Technology*. 12:353-362.

SHELEY, R., S. KEDZIE-WEBB, AND B. MAXWELL. 1999. *Integrated weed management on rangeland*. In: Biology and Management of Noxious Rangeland Weeds (R. Sheley and J. Petroff, Eds.). pp. 57–68. Oregon State Univ. Press, Corvallis, Ore.

SHIVELY, G. AND HAO, J. 2012. *"A Review of Agriculture, Food security and Human Nutrition Issues in Uganda".* Available at http://www.agecon.purdue.edu/ staff/shively/uganda_review.pdf (Accessed: 4th December, 2014)

SMITHSON P.C., B.D. MCINTYRE, C.S. GOLD, H. SSALI, G. NIGHT AND S. OKECH. 2004. *Potassium and magnesium fertilizers on banana in Uganda: yields, weevil damage, foliar nutrient status andDRIS analysis*. Nutrient Cycling in Agroecosystems 69:43-49.

SNOECK, J., LAMBOT, C. 2009. *Crop Maintenance.* In J. N. Wintgens (Ed.), *Coffee: Growing, Processing, Sustainable Production* 2nd ed., pp. 250-327. Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA.

SSEGUYA H, SEMANA AR AND MA BEKUNDA.1999. Soil fertility management in the banana-based agriculture of central Uganda: farmer's constraints and opinions. *Afr. Crop Sci. J.*; 7: 559-567.

SSENNYONGA, J.W., BAGAMBA, F., GOLD, C.S., TUSHEMEREIRWE, W. K., SSENDEGE, R. AND KATUNGI, E. 1999. *Understanding Current Banana Production* *with Special Reference to Integrated Pest Management in Southwestern Uganda*. International Center of Insect Physiology and Ecology, Nairobi, Kenya, 47 pp.

SSERUNKUUMA, D. 2001. *Coping with the Problem of Reduced Soil Fertility in the Banana-Coffee Lakeshore System.* Paper Prepared for the National Seminar of Policies for Improved Land Management in Uganda, Kampala, Uganda, June 25-26.

TAULYA, G., VAN ASTEN, P.J.A., OKECH, S.H.O., C.S, GOLD. 2006. *Effect of drought on the yields of an East African highland banana (cv. Kisansa) in Uganda.* Paper presented at the Soil Science Society of East Africa Conference, Masaka, Uganda.

TENA GOBENA, 2011. *Coffee production system as tool for rehabilitation of degraded land in case of Haru.* MSc Thesis, submitted to post graduate of Jimma University College of Agriculture and Veterinary Medicine.

TENYWA, M.M., ISABIRYE, M.I., LAL, R., LUFAFA, A., ACHAN, P. 1999. Cultural practices and production constraints in smallholder banana-bases cropping systems of Uganda's Lake Victoria basin. *African Crop Science Journal.* 7pp. 613–623.

TORQUEBIAU E. & E. AKYEAMPONG. 1994. *Shedding some light on shade.* Agroforestry Today Oct-Dec 1994: 14-15.

TUSHEMEREIRWE, W.K., GOLD, C.S., SPEIJER, P.R., HOLDERNESS, M. 1993. Foliar diseases of bananas in Uganda: Results from a diagnostic survey. *African Crop Science Journal* 1 (2) pp. 145-149.

TUSHEMEREIRWE, W.K., HOLDERNESS, M., GOLD, C.S., KARAMURA, E.B. 1996. *Distribution and importance of the leaf spot complex on Highland bananas in Uganda. MusAfrica* 10: Poster abstract 82. International Conference on Banana and Plantain for Africa, 13 – 18 October 1996, Kampala, Uganda.

TUSHEMEREIRWE W.K., D. KARAMURA, H. SSALI, D. BWAMIKI, I. KASHAIJA, C. NANKINGA, F. BAGAMBA, A. KANGIRE AND R. SSEBULIBA. 2001. *Bananas (Musa spp). in Uganda.* In Volume II: Crops. (J.K. Mukiibi, Ed.). Agriculture, Fountain Publishers, Kampala, Uganda. Pp. 281-321

TUSHEMEREIRWE WK, KASHAIJA N, TINZARA W, NANKINGA C, NEW S 2003. *A guide to successful banana production in Uganda*. Banana production manual. Second ed. National Agricultural Research Organisation (NARO).

TUSHEMEREIRWE, W., OPOLOT, O. 2005. *BXW history, status and national strategies*. Paper presented at the workshop "Assessing the impact of the banana bacterial wilt Xanthomonas campestris pv. Musacearum on household livelihoods in East Africa", held on Dec. 20th 2005 in Kampala, Uganda.

UCDA, Uganda Coffee Development Authority (various issues). Annual Reports. 2008 Kampala, Uganda. http://www.ugandacoffee.org/ (viewed 12-08-2014)

UCDA, Uganda Coffee Development Authority (various issues). Annual Reports. 2012 Kampala, Uganda. http://www.ugandacoffee.org/ (viewed 12-08-2014)

Uganda Training Materials for coffee production 2014. First edition. CAFÉ AFRICA. 9pp

UNCST & PBS. 2007. *"The Biology of Bananas and Plantains."* Uganda National Council for Science and Technology (UNCST) in collaboration with Programs for Biosafety Systems (PBS). (Retrieved 22-04-2010) pp.1–14 from http://www.biovisioneastafrica.com/publications/BIOLOGY%20OF%20BANANAS%20AND%20PL ANTAINS---BZ%20Jul07.pdf

VAN ASTEN, P.J.A., WAIREGI, L.W.I., MUKASA, D., URINGI, N.O. 2011. Agronomic and economic benefits of coffee–banana intercropping in Uganda's smallholder farming systems. *Agricultural Systems.* 104pp. 326–334.

VAN ASTEN, P., WANYAMA, I., MUKASA, D., NANSAMBA, R., KISAAKYE, J., SSERUBIRI, I., BONGERS, G., JASSOGNE, L. 2012. *Mapping and evaluating improved intercrop and soil management options for Ugandan coffee farmers.* In *Technical Report*, 90: International Institute of Tropical Agriculture (IITA)/ Livelihoods and Enterprises for Agricultural Development (LEAD).

VAN ITTERSUM, M.K., CASSMAN, K.G., GRASSINI, P., WOLF, J., TITTONELL, P., HOCHMAN, Z. 2013. Yield gap analysis with local to global relevance. *Field Crop Research*. 143 pp. 4–17

VARGAS. A, ARAYA.M, GUZMÁN.M AND MURILLO.G. 2009. Effect of leaf pruning at flower emergence of banana plants (Musa AAA) on fruit yield and black Sigatoka (*Mycosphaerella fijiensis*) disease. *International Journal of Pest Management* Vol. 55 , Iss. 1,

VERCHOT, L.V., VAN NOORDWIJK, M., KANDJI, S., TOMICH, T., ONG, C., ALBRECHT, A., MACKENSEN, J., BANTILAN, C., ANUPAMA, K.V. & PALM, C. 2007. Climate change: linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies to Globalal Change.* 12(1) pp. 901-918.

VIEIRA, H. D. 2008. Coffee: *The plant and its cultivation*. Plant-Parasitic Nematodes of Coffee, Springer. pp. 3-18.

WAIREGI, L.W.I., VAN ASTEN, P.J.A., 2010. The agronomic and economic benefits of fertilizer and Mulch use in highland banana systems in Uganda. *Agricultural Systems*. 108pp. 543–550.

WAIREGI, L.W.I., VAN ASTEN, P.J.A., TENYWA, M.M., BEKUNDA, M.A. 2010. Abiotic constraints override biotic constraints in East African highland banana systems. *Field Crop Research.*117pp.146–153.

WAIREGI LWI, VAN ASTEN PJA, GILLER KE, FAIRHURST T. 2014. *Banana–coffee system cropping guide.* Africa Soil Health Consortium, Nairobi.

WANG, N., JASSOGNE, L., VAN ASTEN, P.J.A., MUKASA, D., WANYAMA, I., KAGEZI, G., GILLER, K.E. 2015. Evaluating coffee yield gaps and important biotic, abiotic, and management factors limiting coffee production in Uganda. *European Journal of Agronomy* 63, 1–11

WILSON, S.M., WHITHAM, J.A.H., BHATI, U.N., HORVATH, D., TRAN, Y.D. 1995. Survey of trees on Australian farms: 1993-1994, ABARE Research Report 95.7. Canberra, Australia.

WINTGENS, J.N., ED. 2009. *Coffee: Growing, Processing, Sustainable Production:* A guide book for Growers, Processors, Traders, and Researchers. Wiley-VCH, Weinheim, 984pp.

WOOMER, P.L., BEKUNDA, M.A., KARANJA, N.K, MOOREHOUSE, T. AND OKALEBO, J.R. 1998. Agricultural resource management by smallholder farmers in East Africa. *Nature and Resources* 34(4):22-33.

WONIALA J, NYOMBI, K. 2014. Soil fertility management by smallholder farmers and the impact on soil chemical properties in Sironko District, Uganda. *Research Journal of Agriculture and Forestry Sciences* 2: 5-10.

World Agroforestry Center. 2003. http://www.worldagroforestrycentre.org/. (Viewed 12-05-2015).

YOUNG, J. A., D. E. PALMQUIST., R. R. BLANK. 1998. The ecology and control of perennial pepperweed (Lepidium latifolium L.). *Weed Technology*. 12pp. 402-405.

ZAKE Y.K., D.P. BWAMIKI AND C. NKWIINE. 2000. *Soil management requirements for banana production on the heavy soils around Lake Victoria in Uganda*. Pp. 285-292 in Proceedings of the first International Symposium on Banana and Plantain for Africa. (K. Craenen, R. Ortiz, E.B. Karamura and D.R. Vuylsteke, eds.). pp. 285-292. Acta Horticulturae nr. 540. International Society for Horticultural Science, Leuven, Belgium.

ZOMER, R., TRABUCCO., J.A, RICHARD, C., PLACE, F. 2009. *Tress on farm*: Analysis of global extent and geographical patterns of agroforestry. In, ICRAF Working paper no.89.World Agroforestry Centre, Nairobi, Kenya.

Appendices

Appendix 1: QUESTIONNAIRE GUIDE FOR FARMERS WITH EXISTING COFFEE-BANANA AGROFORESTRY SYSTEMS.

Dear Sir/Madam,

My name is NAKIBUULE LILIAN. I am a student at Uganda Martyrs University carrying out research on management of abiotic and agronomic constraints through optimization of coffee-banana agroforestry systems in south-western Uganda. I would like to assess your knowledge on the major agronomic and abiotic constraints hindering coffee and banana production and the strategies you are using to manage them. The information that you will provide will help in identifying which abiotic and agronomic constraints in coffee and bananas contribute to the yield-gap in coffee-banana-agroforestry systems inorder to best manage them.

I believe you have crucial information on the above subject matter and thus request you to give me feedback on the questions below. I request you to be as truthful as you can in providing me with this information. Your information will receive the utmost confidentiality it deserves, and will be analyzed for the purpose herewith stated. Finally, I would like to sincerely thank you for accepting to participate in this study.

SUSTAINABLE COFFEE-BANANA AGROFORESTRY SYSTEMS (SOCIOECONOMICS)

1. **FARM LOCATION**

Date: …………………………... **Village: ………………………………………..**

District: ……………………….. **Location (GPS) reading: ……………………….**

Sub county: …………………… **Altitude: …………………………………………**

Parish: ………………………… **Interviewer: ……………………………………..**

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	Bananas	Trees and shrubs

4. STATUS OF COFFEE AND BANANA PLANTATIONS

Crop	Coffee	Banana
i) Field status (***1***=*still in use* ***2***=*cut down* ***3***=*uprooted****4***=*semi abandoned* ***5***= *abandoned*)		
If abandoned, why? ***1***=*black coffee twig borer (BCTB)* ***2***=*coffee berry borer (CBB)* ***3***=*coffee wilt disease (CWD)* ***4***=*coffee leaf rust* ***5***=*banana weevils* ***6***=*nematodes* ***7***=*banana bacterial wilt (BBW)* ***8***=*Sigatoka* ***9***=*Fusarium wilt* ***10***=*other pests (specify)* ***11***=*other diseases (specify)* ***12***=*soil fertility* ***13***=*moisture stress* ***14***=*others (specify)* ***NA***=*not applicable*		

i) Clones grown

Coffee	Proportion ***0***=0% ***1***<25 ***2***=26-50% ***3***=51-75% ***4***=>75%
Indigenous Robusta	
Robusta elite	
Robusta clonal	
Nyasaland	
Improved Arabica	
Lowland Arabica (catmors)	
Others (specify)	

Bananas	**Proportion** ***0***=0% ***1***<25 ***2***=26-50% ***3***=51-75% ***4***=>75%
EAH bananas (matooke & mbidde)	
Ndiizi	
Bogoya	
Gonja	
Kayinja	
Kisubi	
Kivuvu	
FHIA17	
Km5	
FHIA 25	
FHIA 23	
Others (specify)	

ii) EAHB (matooke and mbidde) cultivars grown

____

____

____

iii) Source of planting materials

Source	**Coffee**	**Bananas**
1=own ***2***=other farmers ***3***=forest **4**=nursery ***5***=government/extension ***6***=NGO's (specify) ***7***=researchers ***8***=politician ***9***=others (specify)		

iv) Crop yields in the last year

Coffee	**Quantity** (specify units)	**Amount** (UgShs)
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 (probe!)

Soil and water constraints

Constraints	***0***=no ***1***=yes	**Coping mechanisms**	**Coffee**	**Banana**
Declining soil fertility		***0****= nothing* ***1****=organic fertilizers* ***3****=inorganic fertilizers (specify)* ***4****=others (specify)* ***NA****=not applicable*		
Soil conservation (erosion)		***0****= nothing* ***1****=grass bands* ***3****=terraces* ***4****=mulching* ***5****=trenches* ***6****=others (specify)* ***NA****=not applicable*		
Drought/moisture stress		***0****= nothing* ***1****=mulching* ***2****=irrigation* ***3****=shade trees* ***4****=others (specify)* ***NA****=not applicable*		

6. COFFEE-BANANA-AGROFORESTRY SYSTEMS

6.1 Intercropping

i) Crop species grown in coffee/banana systems (excluding trees and shrubs)

Crop	***0****=no* ***1****=yes*	**If yes, specify** (***NA****=not applicable*), ***<u>if both crops are grown together, fill one row only</u>***
Coffee		
Banana		

ii) Advantages and disadvantages of intercropping (circle applicable)

Advantages	**Disadvantages**
1*=none* ***2****=diversify food production* ***3****=diversify income* ***4****=shade* ***5****=better utilization of space* ***6****=moisture retention* ***7****=pest and disease management* ***8****=mulching material* ***9****=manure* ***10****=suppression of weeds* ***11****=reduce impact of climate change* ***12****=improve quality of coffee* ***13****=conservation of biodiversity* ***14****=promotion of ecological processes e.g. decomposition and pollination* ***15****=others (specify)*	***1****=none* ***2****=competition for nutrients, moisture and light* ***3****=soil exhaustion* ***4****=harbor pests (specify)* ***5****=harbor diseases (specify)* ***6****=others (specify)*

6.2 Trees and shrubs

i) Presence of trees and shrubs

Crop	***0****=no* ***1****=yes*	**If yes, specify** (***NA****=not applicable),* ***<u>if both crops are grown together, fill one row only</u>***
Coffee		
Banana		

ii) Advantages and disadvantages of trees and shrubs (circle applicable)

Advantages	**Disadvantages**
1*=none* ***2****=shade* ***3****=food (fruits)* ***4****=income* ***5****= timber* ***6****= firewood* ***7****= herbal medicine* ***8****= making backcloth* ***9****= fodder (animal feed)****10****=mulching materials* ***11****= manure* ***12****=better utilization of space* ***13****=moisture retention* ***14****=pest and disease management* ***15****=suppression of weeds* ***16****=reduce impact of climate change* ***17****=improve quality of coffee* ***18****= improve quality of bananas* ***19****=conservation of biodiversity* ***20****=promotion of ecological processes e.g. decomposition and pollination* ***21****=others (specify)*	***1****=none* ***2****=competition for nutrients, moisture and light* ***3****=soil exhaustion* ***4****=harbor pests (specify)* ***5****=harbor diseases (specify)* ***6****=falling trees/branches damage coffee* ***7****=compact soils* ***8****=others specify*

SUSTAINABLE COFFEE-BANANA AGROFORESTRY SYSTEMS (BIOLOGY)

1. FARM LOCATION

Date: .... **Interviewer: ....**

District: .... **Village: ....**

Sub-county: .... **Location (GPS) reading: ....**

Parish: …………………………….. **Altitude: ………………………………………**

2. FARM LEVEL

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

ii) Farm management

Practice	**Intensity** ***0****=not practicing* ***1****=low* ***2****=medium* ***3****=high*	**Method**	**Coffee**	**Bananas**
Weed control		***1****=hoe* ***2****=mulching* ***3****=slashing* ***4****=burning* ***5****=herbicide (specify)* ***6****=others (specify)* ***NA****=not applicable*		
Mulching		***1****=self* ***2****=annual crop residues* ***3****=grasses (specify)* ***4****=maize stover* ***5****=others (specify)* ***NA****=not applicable*		
Manuring		***1****=cow dung* ***2****=poultry manure* ***3****=composit manure* ***4****=others (specify)* ***NA****=not applicable*		
Cover crops		***1****=grass (specify)* ***2****=leguminous plants (specify)* ***3****=other annual crops (specify)* ***4****=others (specify)* ***NA****=not applicable*		
Trenches				
Terraces				

iii)Crop management

Crop	**Intensity 0**= *not practicing* ***1****=low* ***2****=medium* ***3****=high*						
Coffee	**Desuckering**	**Pruning**	**Change of cycle**	**Deleafing**	**Debudding**	**Corm removal**	**Propping**
Banana							

iv) Intercropping

Crop	**Intensity** *0=no intercrops* ***1****=low* ***2****=medium* ***3****=high*	**If yes, mention all the crop species present** *(**NA**=not applicable)*
Coffee		

Bananas		

iv) Trees and shrubs

Crop	**Intensity** *0=no intercrops **1**=low **2**=medium **3**=high*	**If yes, mention all the tree species present** *(**NA**=not applicable)*
Coffee		
Bananas		

2. PLANT LEVEL

2.1. COFFEE

Plant no.	**Clone type***	**No. of stems**	**Desuckered** ***0**=no **1**=yes*	**Change of cycle** ***0**=no **1**=yes*
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)*

2.2. BANANAS

Mat no.	**Clone type***	**No. of banana plants**			**Deleafed** ***0****=no* ***1****=yes*	**Debudded** ***0****=no* ***1****=yes*	**Corm removal** ***0****=no* ***1****=yes*	**Propping** ***0****=no* ***1****=yes*
		Fl	**PF**	**Sck**				
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*

Fl=Flowered **PF**=Pre-flowered **Sck**=Suckers

Appendix 11: FIELD PICTURES

Source; *field data: Interviewing a farmer to obtain knowledge on the abiotic and agronomic constraints and coping strategies in coffee and bananas*

Source; *field data: Coffee-banana intercrop system*

Source; *field data: Coffee-banana-agro-forestry systems*