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Constraints and opportunities for coffee productivity on the slopes of mt. Kilimanjaro in the face of climate change

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CONSTRAINTS AND OPPORTUNITIES FOR COFFEE PRODUCTIVITY ON THE SLOPES OF MT. KILIMANJARO IN THE FACE OF CLIMATE CHANGE

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Limited scientific information on decreasing productivity of Arabica coffee (*Coffea arabica L*.) in Tanzania has been observed. Poor agricultural practices, pests, diseases and climate change are among important factors limiting coffee production. This study assessed how the coffee yield gap was influenced by pests, diseases and agricultural practices. Data were collected through interview, measurements and observations methods. Data collected cover demonstration plots and control plots. Results of the analysis show that, coffee banana plus other shade trees is mostly practiced system. Plots were affected by pests and diseases across the altitude gradient. However, the demonstration plots were performing better with mean yield of 807 kg ha^{-1} and range from 35 to 1800 kg ha^{-1} as compared to control plots, which had a mean yield of 550 kg ha^{-1} and range from 18 to 1800 kg ha^{-1}. Large yield gap was partly attributed to the incidence of red spider mite (*Tetranychus urticae*) and interaction effects of coffee berry disease (*Colletotrium caffeanum*) and coffee thrips (*Diarthrothrips coffeae*). Poor agricultural practices especially decreased shade trees density and banana mats density, interactions effects of mulching and weeding and weeding and replanting of coffee trees contributed to the substantial yield gap. In addition mulching, irrigation and shade trees and management are best opportunities to mitigate current global rise in temperature. Thus, it can be concluded that, priorities such as adaptation measures of climate change, pests and diseases control and improved agricultural practices such weeding, fertilizer application, mulching and pruning are recommended to enhance coffee yield.

Key words: Pests, Diseases, Coffee farming system, Agricultural practices and Climate change adaptation.

DECLARATION

I, **Abel Petro,** do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Abel Petro — 20th April 2016

Name and signature of candidate — **Date**

The above declaration is confirmed

Prof Karoli N. Njau — 20th April 2016

Name and signature of supervisor — **Date**

Dr. Linus Munishi — 20 th April 2016

Name and signature of supervisor — **Date**

Dr. Laurence Jassogne — 20 th April, 2016

Name and signature of supervisor — **Date**

CERTIFICATION

The undersigned certify that they have read and hereby recommend for accepted by the Nelson Mandela African Institution of Science and Technology a dissertation entitled**;** ***Constraints and Opportunities for Coffee Productivity on the Slopes of Mt. Kilimanjaro in the Face of Climate Change***, in partial fulfilment of the requirements for the Degree of Master of Environmental Science and Engineering (ENSE) of the Nelson Mandela African Institution of Science and Technology Arusha, Tanzania (NM-AIST).

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Prof Karoli N. Njau — 20th April 2016

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Thank you all.

DEDICATION

I dedicate this work to my lovely parents Mr. and Mrs. Peter Mhina, my wife Maria Godfrey Mwabulwa and my children Hans, Nancy, Rosemary and Rogers for their prayers, care, inspiration and guidance have become a good support to my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Meaning
ANTESB	Antestia Bug
ASL	Above Sea Level
BES	Brown Eye Spot
CAP	Coffee Aphids
CBB	Coffee Berry Borer
CBD	Coffee Berry Disease
CBM	Coffee Berry Moth
CC	Coffee and Climate
CLM	Coffee Leaf Miner
CLR	Coffee Leaf Rust
CTP	Coffee Thrips
GAP	Good Agricultural Practices
GS	Green Scale
HRNS	Hans R. Neumann Stiftung
ICO	International Coffee Organization
ISA	International Society of Arboriculture
LMB	Leaf and Branch Mealy Bug
MT	Mount
N P K	Nitrogen, Phosphorous and Potassium
NCC	National Coffee Conference
RMB	Root Mealy Bug
RSM	Red Spider Mite
TACRI	Tanzania Coffee Research Institute
TCBR	Tanzania Coffee Baseline Report
TCCACR	Tanzania Climate Change Arabica Coffee R
TCIDS	Tanzania Coffee Industry Development Strategy
URT	United Republic of Tanzania

CHAPTER ONE

1.0 Introduction

This chapter describes the general introduction of the study. It mainly focuses on the background information of the problem, the problem statement and justification, the objectives of conducting the study and its significance.

1.1 Background Information

Coffee is an important cash crop in African countries such as Tanzania, Kenya, Rwanda, Uganda and Ethiopia for generating income for smallholder farmers (ICO, 2015). Coffee in Tanzania accounts for 5% of the total annual export value, 24% of traditional cash crop and generates export earnings averaging USD 100 million per annum over the past 30 years (1983-2013) (NCC, 2013). Coffee was introduced in Tanzania early in the 20th century as an estate crop, but later became a mainly smallholder crop (Baffes, 2004). Tanzania mainly produces two types of coffee; Robusta (*Coffea canephora*) and Arabica coffee (*Coffea arabica* L.). Arabica coffee accounts for 60% of total country production while robusta accounts for 40% of entire country production (TCIDS, 2012). Arabica coffee in Tanzania, is cultivated on Kilimanjaro, Arusha, Mbeya and Ruvuma regions (TCIDS, 2012; Craparo *et al.*, 2015), at an elevation between 1000 and 2300 m above sea level (A.S.L) (Craparo *et al.*, 2015). Robusta coffee is primarily cultivated in Kagera region (TCIDS, 2012) at an elevation between 800 and 900 m A.S.L (TCB). Both varieties of coffee in Tanzania are mostly produced by smallholder farmers in an intercropped system with bananas (TCIDS, 2012). Smallholder are farmers who own small farms of less than 2 ha and dominated developing countries (Zhou, 2010).

Tanzania, coffee production increase significantly before 1990s, when the price was more favourable (Baffes, 2004; Mhando *et al.*, 2013; Mkandya *et al.*, 2014) and farmers benefited from the provision of coffee input such as pesticides and fertilizer, coffee transportation, and coffee processing by government through the coffee board and corporative union (Baffes, 2004; Mhando *et al.*, 2013). The subsidy such as crop loan and coffee processing cost were later deducted after the coffee was sold, this enabled farmers to practice sustainable coffee farming since they did not participate directly in the cost of production (Baffes, 2004; Mhando *et al.*, 2013).

Coffee production substantially declined after 1990s due among other factors is the plummeting coffee prices caused by market liberalization implemented in 1990 by the gorvement of Tanzania (Baffes, 2004; Mhando *et al.*, 2013; Mkandya *et al.*, 2014). Prices published by (Baffles, 2004) fluctuated in the 1994/95 season in which producers received only 33% of the export price, in 1997/98, 16% and in 1998/99, 19%. Price fluctuation negatively affected farmers and consequently their coffee plots. In addition, Mhando *et al* (2013) reported burden of taxes to producers which include 0.75% of the auction, value-added tax (VAT), and tax to the district council also affected farmers. For example, between 1997/98 and 1998/99, producer prices for arabica declined by 24% but the tax as a percentage of the producer price rose by more than three per cent (Baffes, 2004). Misana 2003, have witnessed farmers replacing banana, tomatoes, onions and other vegetable for coffee in their farms (Misana *et al.*, 2003). A UNDP report established that farmers were cutting down the coffee trees without replacing them (Noe, 2014).

Despite the fluctuation in prices, coffee yields in Tanzania have been experiencing various other challenges associated with factors such as, incidence of pests and diseases, aging of coffee trees (TACRI, 2008), as well as climate change (Craparo *et al.*, 2015). Regardless of the fact that both types of coffee are sensitive to climate change and variability, arabica coffee is more responsive compared to robusta. For instance, under the current climate change where the global temperature is increasing, robusta coffee is likely to be favored because it is adapted to slight higher temperature as compared to arabica coffee (Haggar and Schepp, 2012). Arabica coffee production requires conducive optimal and absolute temperatures ranging from 14 to 28°C and 10 to 30°C respectively (Haggar and Schepp, 2011) and reliable and well distributed rainfall of about 1200 to 1800 mm per annum (DaMatta and Ramalho, 2006). High-temperature affect the physiological process of arabica coffee plants, hence reducing yields; temperatures above 23^{o}C accelerates the ripening of cherries whereas above 30^{o}C cause abnormalities such as yellowing of leaves (Haggar and Schepp, 2011).

Thus, understanding factors limiting farm yields provides the foundation for identifying agricultural management options and improved practices to close the coffee yield gap (Van Ittersum and Cassman, 2013). Hence, for sustainable intensification of agriculture, information about the sites specific constraints are highly needed (Van Ittersum and Cassman, 2013). Previous progress towards coffee yield improvement in Tanzania such as Hans Neumann Stiftung and

TACRI have focused mainly on crop protection and agronomy aspects of coffee production. Such constraints include, aging of coffee trees, poor agronomic practices, high density of intercropping, diseases, pests and lack or insufficient agricultural inputs such as fertilizer and pesticides (TCBR, 2005). Information on site-specific production constraints grounded on direct farm measurements is highly needed for sustainable intensification of coffee productivity along slopes of Mt. Kilimanjaro. The objectives of this study were to identify the effective present coffee farming systems, their major constraints and assessed adopted practices to mitigate rise in temperature at the plot level for sustainable intensification of coffee productivity.

1.2 Research problem and justification of the study

Most of the coffee farmers along the slopes of Mt. Kilimanjaro intercrop coffee with bananas, other intercrops such as shade trees. Productivity of arabica coffee at the plot level is facing threats of climatic change and variability (rainfall and temperature), pests, diseases, aging of coffee trees, inappropriate intercropping regimes, poor agronomic practices, lack or inefficient inputs, price fluctuations and access of resources such as land and credit. Since farmers are getting fertilizers, pesticides and training on good agricultural practices on demonstration plots, the study seeks to understand existing farming system and how fertilizers, crop protection and good agricultural practices can improve coffee yields. However, there is limited scientific information on site-specific production constraints based on farm measurement of incidence of pests and diseases and agricultural practices. Therefore, there was a need to assess challenges limiting coffee yield at the plot level for opportunities of improvement

1.3 Objectives

1.3.1 General objective

To identify major constraints and opportunities for coffee productivity on the slopes of Mt. Kilimanjaro in the context of climate change.

1.3.2 Specific objectives

i. Characterization of coffee farming system at plot level along an altitude gradient of Mt. Kilimanjaro and implication for livelihood.
ii. Determination of constraints limiting coffee yield for an opportunities of sustainable intensification.

iii. Identifying opportunities for sustainable intensification and for climate smart agriculture practices

1.4 Research questions

i. What are the existing coffee farming systems at plot level?
ii. What are the factors contributing to yield gap along in Hai, Siha and Moshi Rural districts?
iii. What are the potential adopted practices for climate smart agriculture practices on slopes Mt. Kilimanjaro?

1.5 Significance of the research

The results obtained from this study contribute knowledge to the society about the constraints limiting current coffee farm yields and improved practices to bridge the gap. This knowledge can help to increase productivity; as well as national export revenue and enhance coffee farmers' livelihoods. Information obtained from this study may enable farmers to improve farming system in responding to climate change particularly rainfall and temperature through mulching, irrigation, maintaining appropriate shade trees and proper use of inputs of pesticides and fertilizer for sustainable intensification of coffee productivity.

CHAPTER TWO

Characterization of Coffee farming system along the slopes of Mount Kilimanjaro

Abstract

Coffee is a valuable crop to the Tanzania economy and contributes 5% of annual revenue and consequently supporting the livelihoods of an estimated 2.4 million individuals. Coffee sector experiencing various challenges which include, increase in pests and diseases, climate change and variability, olds trees and high intercropping regimes This study was carried out to assess coffee farming system along gradient at an elevation between 1060 to 1760 m A.S.L. Household interview, field observations and measurements were used to collect data for two month from June, 2015 to August, 2015. The results of the analysis showed that, mixed coffee is common practiced system. Three commonly cropping systems were identified, 95.1% of farmers practice coffee intercrop with banana and shade trees, 2.1% practice coffee intercrop with banana and 2.8% practice coffee intercrop with shade trees The practiced system increases farmers' incomes and reduces the impacts of climate change associated with rise in temperature. Additionally results of the analysis showed that, shade covers increases with altitude and incidence of pests and diseases were distributed along the altitude in low =1000-1300 m A.S.L, medium = >1300-1500 m A.S.L, high = >1500-1800m A.S.L. It can be concluded, proper intercropped system in appropriate spacing between and within the rows and proper number of plants density per hectare are recommended to enhance coffee yield and households' income.

2.1 Introduction

Coffee is an important cash crop in Uganda, Kenya, Burundi, Democratic Republic of Congo and Tanzania (Van Asten *et al.*, 2011). Tanzania, cultivates both Arabica and Robusta coffee (TCBR, 2005; TCIDS, 2012). An average of 50,000 tons of coffee was produced each year in Tanzania for the past 30 years (1980-2010) (Haggar and Schepp, 2011; TCIDS, 2012). Declining arabica coffee yields in Tanzania have been influenced by factors such as, incidence of pests and diseases, aging of coffee trees (TACRI, 2008); as well as climate change and variability (Craparo *et al.*, 2015) and economic liberalization programs and reforms implemented in the 1990s (Baffes, 2004; Mhando *et al.*, 2013; Mkandya *et al.*, 2014). Implementation of good agricultural practices (GAP) was reported to improve productivity (DaMatta, 2004; Tittonell and Giller, 2013).

Farmers normally practice coffee-banana intercropping (TCBR, 2005). This intercropping system is more profitable than the mono-cropping system (Van Asten *et al.*, 2011; CIGAR, 2015). The system provides shade for the coffee tree and mulch which reduce environmental stress caused by extreme temperature (Beer *et al.*, 1998; DaMatta, 2004; Bote and Struik, 2011; Van Asten *et al.*, 2011; Jassogne *et al.*, 2013a; Jassogne *et al.*, 2013b). Studies by CIGAR, (2015) in Uganda showed that, shades from banana lower effects of coffee leaf rust and black coffee twing borer by 50% compared to other shaded system. Coffee-banana intercropping system, provides farmers with additional food and income through selling bananas (Jassogne *et al.*, 2013c; Wairegi *et al.*, 2014; CIGAR, 2015). Studies in Uganda showed that, intercrop system can produce more than 50% revenue compared to monocrop system (CIGAR, 2015). Despite the advantage of intercropping, can also lead to increase competition of water, nutrients and light if not well managed (Nzeyimana *et al.*, 2013; Wairegi *et al.*, 2014). Climate change increased some pest such as coffee leaf miner, mealy bugs and coffee leaf rust, the mitigation such shading system reduces the effects (CIGAR, 2015).

Currently, Tanzania coffee production is averaged 216 kg ha^{-1} (ICO, 2015) whereas in Kenya 412 kg ha^{-1}, Uganda 708 kg ha^{-1}, Burundi 281 kg ha^{-1}, Rwanda 385 kg ha^{-1} . Coffee production provides direct income to more than 400,000 farmers, and sustains the livelihoods of an estimated 2.4 million people (TCIDS, 2012). However, the production is far below the average coffee yields in other East African countries. Therefore, there is a need to increase productivity to enhance sustainability of coffee and farmer livelihoods. The best approach to increase productivity is to identify and mitigates constraints (Vanlauwe *et al.*, 2014). The study was carried out to assess the coffee farming system as a way of identifying constraints for opportunities of yield improvement.

2.2 Materials and Methods

2.2.1 Description of the study area

This study was conducted in Hai, Siha and Moshi rural districts in Kilimanjaro region from June, 2015 to August, 2015 (Fig.1). The plot site was located using a global positioning system (GPS) in which the northern and eastern parts were marked in each corner of the plot. These districts were selected because they lie within an altitude of ~1000 and 2300 m above sea level, where arabica coffee is cultivated in Tanzania (Craparo *et al.*, 2015). The plots occur at similar elevation range.

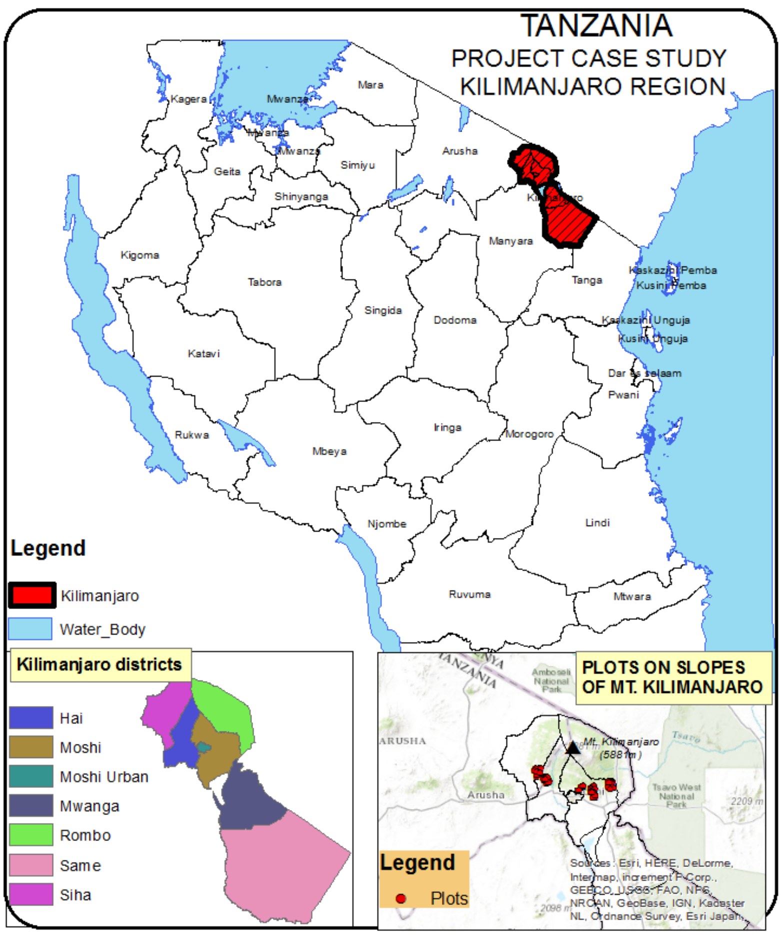

Figure 1: **Map of Tanzania showing surveyed sites**

2.2.2 Plot selection

A total of 144 plots were selected randomly from three districts Hai, Siha and Moshi Rural to represent the population of coffee plots in each district. Out of these 70 were demonstration and 74 control plots respectively. The purpose of the demonstration plots was to understand if fertilizers, crop protection and training can improve coffee yields as compared to control plots since farmers are empowered on the demonstrations plots the subsidy and inputs.

2.2.3 Data collection on plots characteristics

A total of 74 households were surveyed whereby one respondent from each household was interviewed using structured questionnaires Appendix 1). Head of the household was interviewed, when he/she is absent his spouse or child interviewed. Interview was conducted before measurements and observation in coffee plots. Households was asked to give the information income generating activities and recall of clean coffee yield in kilograms (The data of coffee yield was collected by the Researcher.

The plots altitude, northing and easting was located using GPS. The plots altitude was taken at the centre of the plots whereas the northings and easting was located at each corner of the coffee plot. Data on plants density was obtained by counting the number of coffee trees, banana trees and shade trees (Appendix 2). The intensity of shade produced by shade trees was measured by densitometer by randomly subdivided the plots ten portion and the measurements taken times around the ten portion of the plots and averaged.

2.2.4 Determination of yield

The annual coffee yield in parchment was obtained through dividing the cumulative yearly production per plot (kg year^{-1}) by plot size (ha) and expressed as kg ha^{-1}year^{-1}. Plot size was calculated by multiplying the area (m^{2}) and the conventional factor (0.0001). Observable outliers related to the extreme range were deleted. The yield above 1800 kg ha^{-1}year^{-1} was regarded as an outlier because it was above maximum African coffee yield (Wang *et al.*, 2015). The outlier were seven in demonstration plots while only three were observed in control plots.

2.2.5 Determination of plant density

The tree densities (trees ha^{-1}) were calculated by dividing the number of trees obtained per plot size in hectare. This method determine the banana mats per hectare, shade trees per hectare and coffee trees per hectare.

2.2.6 Evaluation of pests and diseases

Data on the incidence of pests and diseases in percent were evaluated by observation method. The proportions of affected coffee trees among the total coffee population in the plot from 10 randomly selected plant bushes were rated as a/b (a= observed pest or disease and b= total plant observed) and assessed as none=0/10, low=1/10 to 3/10, moderate 4/10 to 6/10 and severe7/10 to 10/10. The evaluation of pests and diseases was done by dividing the plots 10 times and evaluated ten times and ranked.

Diseases covered in this study were coffee berry disease (CBD), coffee leaf rust (CLR), brown eye spot (BES). Pests were also considered, which include: coffee berry borer (CBB), white stem borer (WSB), antestia bug (ANTSB), root mealy bug (RMB), coffee berry moth (CBM), green scale (GS), coffee leaf miner (CLM), red spider mite (RSM), coffee thrips (CTP), coffee aphids (CAP) and leaf and branch mealy bug (LMB).

2.2.7 Statistical analysis

Data were analyzed using SPSS version 21, Microsoft excel 2013 and graph pad prism statistical package. The SPSS were used to determine proportions, mean, standard deviation and sample size of variables, whereas Microsoft excel 2013 and graph pad prism were used to draw graphs and chart. P- value was computed by using online Graphpad QuickCalc t test calculator (http://graphpad.com/quickcalcs/ttest1.cfm) at confidence interval 95% aiming to get the relationship between variables.

2.3 Results

2.3.1 Description of coffee farming system

The proportions of the different coffee farming system are displayed in Table 1. The results of the analysis using SPSS version 21 indicated that coffee banana intercropping plus other shade trees accounts for 95.1% of plots, coffee banana system 2.1% and coffee intercrop with shade trees system 2.8%.

Table 1: **Coffee intercropping system adopted by farmers along slopes of Mt. Kilimanjaro**

Farming System	Frequency	Proportions (%)
Coffee/Banana/Shade trees	137	95.1
Coffee-Banana	3	2.1
Coffee-shade trees	4	2.8

2.3.2 Relationship between altitude and incidence of pest and disease

The relationship between infestation of pests, diseases and altitude is shown in (Appendix 3). Pests and diseases were observed to be distributed in all attitudes in low =1000-1300m A.S.L, medium = >1300-1500m A.S.L, high = >1500-1800m A.S.L in different proportions, with some exceptions in the demonstration and control plots. For example, there was no moderate and severe infestation of coffee berry disease at low altitude.

2.3.3 Banana mats and shade trees adopted by coffee farmers

Table 2 shows the average number of banana mats and shade trees per hectare. The results shows that, banana mats was on average of 823 treeha^{-1} and shade tree was on average of 335 treesha^{-1}. The total shade trees was 1157 treesha^{-1} per plot.

Table 2: Banana mats and shade trees adopted by farmers along the slopes of Mt. Kilimanjaro

Variables	N	Mean	Standard error
Banana mats	144	822.60	37.601
Shade tree	144	335.07	25.540
Total shade	144	1157.67	46.018

2.3.4 Households incomes generating activities

Figure 2 show the percentage of households' income. The results of the interview indicated that 31.3% of income generated are from banana, 18.3% from coffee, 15% from fruits and timber and 13.8% from maize etc. The common shade trees which are used for timber harvesting such as albizia, agricopper, gravelia and those which produce fruits mangoes trees, avocado trees and guava trees.

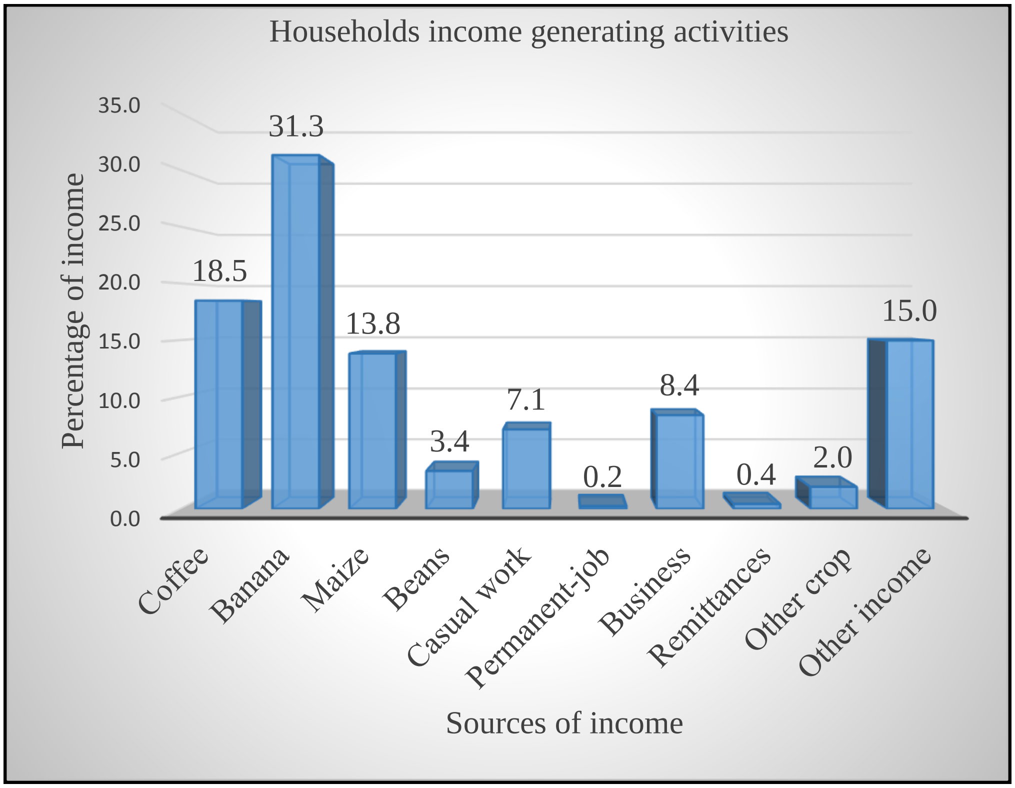

Figure 2: Household's incomes generating activities.

2.3.5 Average coffee yield in Hai, Siha and Moshi Rural Districts

The average coffee yields and range are displayed in Table 3. The average yields and range in demonstration plots were, Hai 1055 kg $ha^{-1}$and 126 to 1800 kg ha^{-1}, Moshi Rural 704 kg ha^{-1} and 68 to 1800 kg ha^{-1} and Siha 804 kg ha^{-1} and 35 to 1800 kg ha^{-1}. Likewise, the average yields and range in the control plots were, Hai 671 kg ha^{-1} and 27 to 1800 kg ha^{-1}, Moshi Rural 464 kg ha^{-1} and 29 to 1690 kg ha^{-1} and Siha 670 kg ha^{-1} and 18 to 1800 kg ha^{-1}. The mean coffee yield after each district is considered separate showed no significant variation between plots and district ($p > 0.05$).

Table 3: Average coffee yield in Hai, Siha and Moshi rural Districts

		Demonstration plots		Control plots		
Districts	N,N	Mean (SD)	Min-Max	Mean (SD)	Min-Max	P
Hai	13,15	1054.8 (726.5)	126 - 1800	670.7 (654.3)	27 - 1800	0.7002
M-Rural	31,36	704.1 (615.1)	68 - 1800	463.5 (428.6)	29 - 1690	0.7441
Siha	08,11	803.7 (509.6)	35 - 1800	670.4 (580.3)	18 - 1800	08711
P- (A&C)		0.8072		0.9997		
P- (A&B)		0.7429		0.7934		
P- (B&C)		0.9368		0.8069		

Note: Mean= Average yield (Kgha^{-1}), SD= Standard deviation, P-; significant values are when p <0.05; N, N = Sample size for demonstration and control plots respectively, Min = minimum yield, Max = maximum yield, M= Moshi, A=Hai, B=Moshi Rural, C=Siha

2.3.6 Coffee plant densities adopted by coffee farmers

The number of coffee plant per hectare (productive trees, pre-productive tree and old productive tree) is shown in Table 4. Data was analysed by using SPPS version 21. The analysis was done to get mean. Number of productive coffee trees was on average of 1132 treesha^{-1}, the number of pre-productive tree was on average of 295 treesha^{-1} and number of old coffee trees; whereas the total plant density was 1523 treesha$^{-1.}$.

Table 4 : **Coffee plant density adopted by farmers along the slopes of Mt. Kilimanjaro**

Variables	N	Mean	
Coffee trees	Statistic	Statistic	Standard error
Productive tree	143	1132.34	65.883
Pre-productive	141	295.40	43.819
Old trees	142	110.80	22.617
Total plant density	144	1522.98	84.390

Note: Pre= immature

2.3.7 Shade intensity produced by shade trees

Figure 3 show the average shade intensity in percentage produced by shade trees in coffee plots along the slopes of Mt.Kilimanjaro. The intensity of shade was on average of 50.76%. Most of the plots are over shaded, 75% of the plots show that 63.39% of shade intensity.

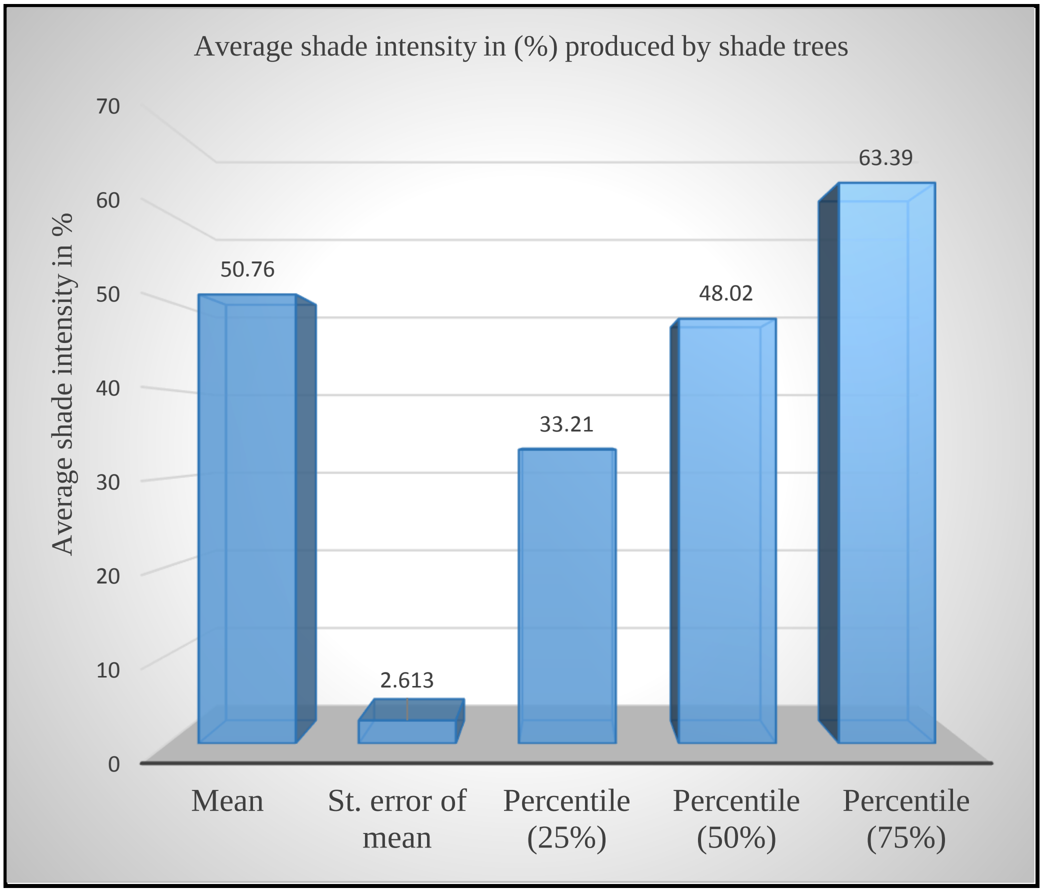

Figure 3: Shade management adopted by farmer along the slopes of Mt. Kilimanjaro.

2.3.8 Relationship between shade tree density and altitude

Figure 4 show the relationship between altitude and shade tree cover. The results of the analysis indicated shade cover increases with altitude. Plots located at high altitude have high number of shade trees density.

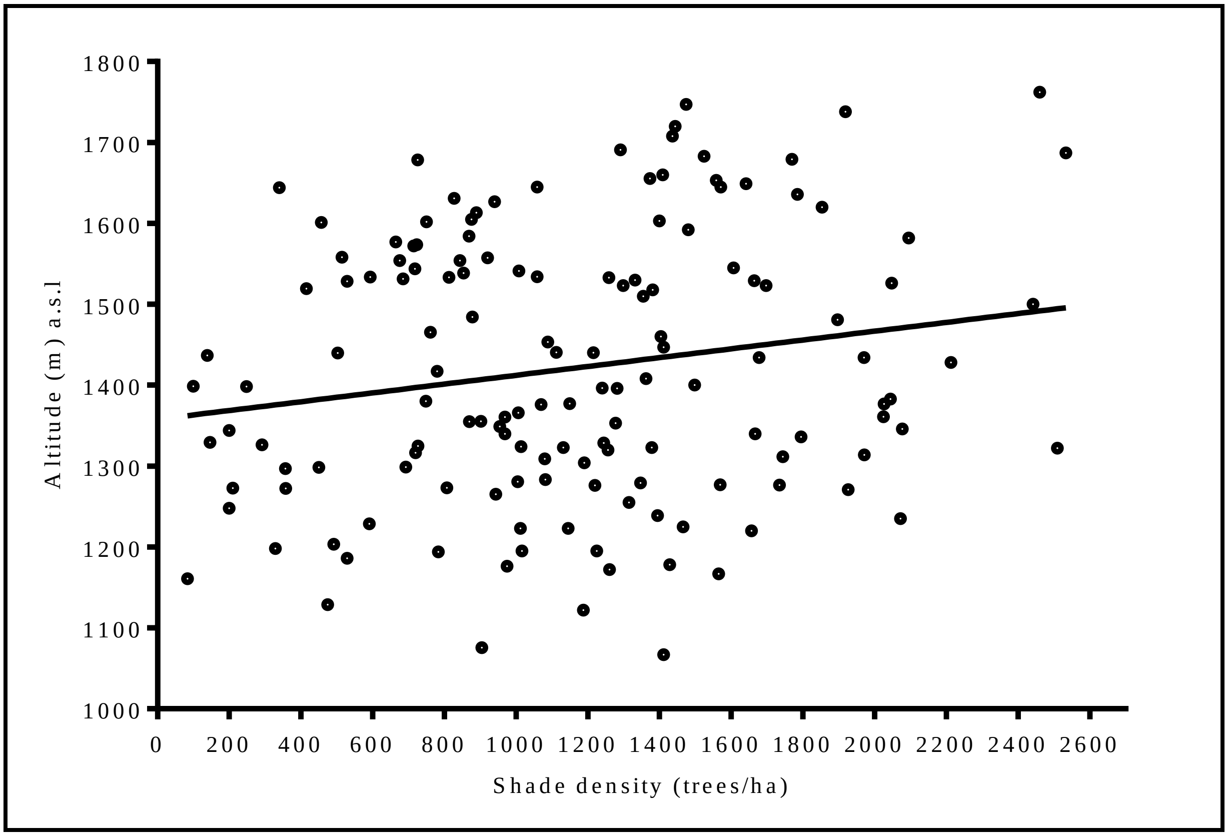

Figure 4: **Relationship between shade trees density and Altitude**

2.4 Discussion

2.4.1 Coffee farming system adopted by farmers

Coffee faming system identified in this study includes: coffee intercropped with banana and shade trees, coffee intercrop with banana and coffee intercrop with shade trees. It was realized that coffee intercrop with banana and shade trees is mostly practiced system. The observation from these studies is different from other documented reports that show in Kilimanjaro coffee-banana intercropping as most practiced (TACRI, 2008; TCIDS, 2012). This suggest that, farmers adopted increasing shades tree so as to earn more money as compared to previous years in which they were relying on coffee and banana system. The aforementioned practice coffee-banana intercrop and shade tree is the mostly used and was also reported as an intensive cultivation of coffee, bananas, fruits and shade trees (Agroforestry) (Misana et al., 2003).

Species of shade trees were observed in the field excluding banana and can be categorized based on economic value and use. Therefore, the common shade trees which are used for timber harvesting includes as albizia, agricopper, gravelia and those which produce fruits are mangoes tree, avocado tree and guava tree. Both of this timber and fruits are source of other income for smallholder farmers along the slopes Mt. Kilimanjaro and it was revealed to contribute 15% of household income. Studies in Uganda have shown that intercropping coffee banana system generates additional food and income for smallholder farmers. (Van Asten et al., 2011; Bongers et al., 2012; Jassogne et al., 2013c; Wairegi et al., 2014; CIGAR, 2015).

Banana and Shade trees provide shade to the coffee trees which reduces the adverse effects of the rise in temperature (DaMatta, 2004; Van Asten et al., 2011; Jassogne et al., 2013a; Wairegi et al., 2014; CIGAR, 2015; Wang et al., 2015). In this study the banana and shade trees provides shade intensity on average of 50.76%. This suggest that temperature is reduced by 50.76%. The shade cover was revealed to increases with altitude, hence the intensity of shade increased too. High-temperature affect the physiological processes of coffee plants, hence reducing yields; temperatures above 23^{o}C accelerates the ripening of cherries whereas above 30^{o}C cause abnormalities such as yellowing of leaves (Haggar and Schepp, 2011). Bananas also produce mulch during pruning which buffers the evaporation rate of soil water and increase nutrients available in the soil (Nzeyimana et al., 2013; CIGAR, 2015). In addition, Banana intercrop with coffee reduces the risk of coffee leaf rust and lowers the amount of carbon from the atmosphere (Campbell et al., 2014; CIGAR, 2015). Banana can store 15-30 tons of carbon in the soil (Campbell et al., 2014). Therefore, coffee intercrop with banana and shade trees when practiced in appropriate spacing reduce competition and is well managed can results in increasing households income, reduce amount of carbon and providing a buffer to microclimate effects.

2.4.2 Altitude and incidence of pests and diseases

Pests and diseases were observed in the field to affect across the altitudinal gradient (low, medium and high). It was revealed that coffee berry disease (*Colletotrichum caffeanum*) affected more plots at high altitude (Appendix 3). The observed results is similar to other prior research findings, which reported that coffee berry disease (*Colletotrichum caffeanum*) affected plots at high altitude (Hindorf and Omondi, 2011). This could therefore explain, the decreased of temperature and increased rainfall at the high-altitude increase the incidence of coffee berry disease (Bedimo *et al.*, 2009). Coffee berry disease is one of the serious diseases, and its incidence is directly linked to climate change (TACRI, 2008; Haggar and Schepp, 2012) as climate change leads to excessive rainfall which is favourable condition for coffee berry disease (Hindorf and Omondi, 2011).

2.4.3 Average coffee yield among districts

The average arabica coffee yield among the district did not show significant variation. This indicates that, Siha, Hai and Moshi rural district require similar treatments for yield improvement; because are affected equally.

2.4.4 Plant Density adopted by coffee farmers

Coffee plants density (trees ha^{-1}) was on average of 1523 trees per hectare, whereas shade trees density was on average of 1158 trees per hectare (banana mats 823 trees per hectare and shade trees 335 trees per hectare. Research conducted by the International Institute for Tropical Agriculture (IITA) and its partners shows that the best coffee banana performance is associated with 600-800 banana mats per hectare to 2000-2400 Arabica coffee trees per hectare (CIGAR, 2015). This study show that, banana mats is above the suggested number and the coffee trees is below the suggested number. Hence adoption of better intercropping system is recommended. The suggested intercropping of arabica are as follows spacing between rows 3m, within rows 1.5m and coffee tree per hectare 2222, banana spacing between row 3m, within rows 4.5cm and plant density 740 (CIGAR, 2015). The author suggest that, because along the slopes of Mt. Kilimanjaro 95% use coffee banana plus shade trees system, a study on performance is recommended.

2.5 Conclusion

Coffee banana intercropping with other shade tree system is the climate smart practiced along the slopes of Mt. Kilimanjaro. The practices has significant effects of increasing farmers' income and reduces the impacts of rise in temperature. Despite the fact that, this can be adaptation to climate change, the practices can lead negative effects of increasing completion of soil water, nutrients and light. Thus, instead appropriate space within and between rows and required plant density per plot is recommended for better yield, resilient to climate change and enhancing farmers' incomes.

CHAPTER THREE

Coffee yield gap in relation to management practices along the Slopes of Mount Kilimanjaro

Abstract

Incidences of pests, diseases and poor farming practices are among the factors limiting coffee productivity along the slopes of Mt. Kilimanjaro. Understanding the limiting factors to coffee productivity is a one way to identify opportunities for sustainable intensification and reducing the yield gap. This study assesses how the coffee yield gap was influenced by pests, diseases and agricultural practices. Data were collected through interviewing coffee farmers on yield, observation of pests and diseases and measurements of shade intensity and plant density. Data was analyzed using Logistic regression model. The yield gap was estimated as a difference between the maximum attainable yield and actual yields in the dataset. Demonstration plots yield was 19% higher than control plots suggesting improvement in management practices in demonstration plots. The large yield gap was partly attributed to the incidence of red spider mite (*Tetranychus urticae*) and interaction effects between coffee berry disease (*Colletotrichum caffeanum*) and coffee thrips (*Diarthrothrips coffeae*). Poor agricultural practices (especially in appropriate banana mats density and shade trees density, poor interaction effects of mulching and weeding and poor interaction effects of mulching and replanting of coffee trees contributed to the large yield gap. It is thus recommended that, for sustainability of coffee productivity, priorities such as improved management practices such mulching, weeding and replanting of coffee trees and integrated-pest-management should be accorded to bridge the existing yield gap through addressing the production constraints.

3.1 Introduction

Coffee is an important cash crop in Uganda and the highlands of East Africa of Kenya, Rwanda and Western Highlands of Ethiopia (Wang *et al.*, 2015). In Tanzania, coffee is grown mainly by the smallholder farmers in intercropped system with banana (TCIDS, 2012). Tanzania grows both Robusta and Arabica coffee (TCBR, 2005). Coffee in Tanzania is one of the sources of income and improves livelihoods of smallholder coffee farmers (TCBR, 2005; TCIDS, 2012). Production of coffee yield in Tanzania was on overage of 50,000 tons for the past 30 years (1980 to 2010) and yields continue to decrease (TCIDS, 2012; NCC, 2013). Decreased yields were associated with various reasons such as aging of coffee trees, poor agricultural practices, and high density of intercrops, diseases and lack or inefficient of fertilizer and pesticides as well as weather-related problems (TCBR, 2005). Pressure of pests and diseases, soil infertility and poor agricultural practices as well as climate change are often considered as the most important limiting factor for coffee yield for farmers to achieve maximum attainable yield (Wang *et al.*, 2015). Other studies have reported the importance of applying good agricultural practices to reduce the gap (DaMatta, 2004; Tittonell and Giller, 2013).

The gap between maximum attainable yield and actual yield might be reduced by implementing good agronomic practices such as appropriate shade trees and crop protection using pesticides (DaMatta, 2004; Tittonell and Giller, 2013; Wang *et al.*, 2015). In this study, the yield gap under the incidence of pests, diseases and agricultural management practices was analyzed. The yield gap was defined as the difference between the maximum attainable yield and the actual yield of the data set. This approach has also been used to assess coffee management options and the yield gap; an example is the yield gap assessment of biotic and abiotic constraints using boundary line analysis by (Wang et al., 2015).

However, in Tanzania, along the slopes of Mt. Kilimanjaro; no study has been conducted to determine the coffee yield gap. Hence, there is a need for yield gap analysis to determine major constraints limiting coffee productivity in order to enhance effective agronomic practices and reducing coffee yield gap. This study evaluated the yield gap under the incidence of pests; diseases and agronomic management practiced as the most important limiting factors for coffee yield along slopes of Mt. Kilimanjaro.

3.2 Materials and Methods

3.2.1 Description of the study area

The study was conducted in Hai district, Siha district and Moshi rural district over two months from June 2015 to August 2015 (Fig.1). The plots altitude ranges from 1176 to 1631 and 1235 to 1679 m A.S.L in Siha district, 1161 to 1437 and 1195 to 1440 m A.S.L in Hai district and 1076 to 1676 and 1067 to 1762m A.S.L in Moshi rural district respectively in the demonstration plots and control plots.

3.2.2 Data collection

The pilot study was conducted for three days in order to locate the plots site using a global positioning system (GPS) in which plot attitude was measured at the Centre of the plots. Data on recall of coffee yield and coffee age, perception of climate change and its effects related to climate change as perceived by farmers were collected through systematic interviews. 74 Head of the household was interviewed, when he/she is absent his spouse or child interviewed. (Appendix 4).

Data on agricultural practices and incidence of pests and diseases were obtained through field observation by researcher and trained team for a period of two month from June, 2015 to August, 2015. Data on incidence of the pests and diseases were assessed by estimating the proportion of affected coffee trees among the total coffee population in the plot in 10 randomly selected plant bushes. Diseases covered in this study were coffee berry disease (CBD), coffee leaf rust (CLR), brown eye spot (BES). Pests were also considered, which include: coffee berry borer (CBB), white stem borer (WSB), antestia bug (ANTSB), root mealy bug (RMB), coffee berry moth (CBM), green scale (GS), coffee leaf miner (CLM), red spider mite (RSM), coffee thrips (CTP), coffee aphids (CAP) and leaf and branch mealy bug (LMB). The value 0/10 represent absence of incidence of pests and diseases; 1/10 to 3/10 represent low incidence of pests and diseases; 4/10 to 6/10 represent moderate incidence of pests and diseases, and 7/10 to 10/10 represent severe incidence of pests and diseases.

Data on agricultural practices, example mulching, weeding, pruning, replanting of coffee trees, erosion control, shade management, nutrition and composting in coffee fields, were qualitatively assessed and rated as 1= adopted and 0= not adopted, except on shade management (Appendix 5). The intensity of shade trees in a plantation was measured using densitometer and then assessed the intensity produces from shade trees as adopted or not adopted.

Data on plants density was obtained by counting the number of coffee trees, banana trees and shade trees (Appendix 5**)**. The tree densities (trees ha^{-1}) were calculated by dividing the trees obtained per plot size in hectare. This method determine the banana mats per hectare, shade trees per hectare.

3.2.3 Yield determination

The annual coffee yield was obtained through dividing the cumulative yearly production per plot (kg $year^{-1}$) by plot size (ha^{-1}). Observable outliers related to the extreme range were deleted. The yield above 1800 kg $ha^{-1}year^{-1}$ was regarded as an outlier (Wang et al. 2015).

3.2.4 Determination of coffee yield and climatic factor perceived by farmers.

The coffee yield and climatic were tabulated for each group (demonstration plots and control plots). For example, tabulated yield versus lack of water and runs the data set to get the proportions. Then once the results have been obtained, p-value was computed to check the significant effect between demonstration and control plots by considering (N, n) for each climatic factor and was done using the online graph pad t test calculator.

3.2.5 Description of demonstration plots and control plots

Demonstration plots are plots in which farmers are receiving fertilizers, pesticides and training on good agricultural practices from coffee stake holder in Tanzania particularly Hans R. Neumann Stiftung (HRNS) project, whereas in control plots farmers are not empowered. In season 2014/15, each farmer was given, 200 grams of NPK 22:6:12, three mills of tracel BZ, 55 mills of tan copper and two mills of dasban /dasban FP (special case for Kirua) in the demonstration plots for 40 coffee trees. However, from 2013 to 2015, 896 training has been conducted. Farmers trained they know how to read and write. The training includes, weed control in coffee, compost and manure making, shade management, pruning, pest and disease control, nutrition, land preparation and planting; water requirement and erosion control management. The training was conducted by Agronomist, Assistant Agronomist, Field Facilitators and contact farmer.

3.2.6 Statistical analysis

Data were analyzed by using STATA and online Graphpad prism6 software (Lp, 2012); (http://graphpad.com/quickcalcs/ttest1.cfm).. The relationship between yield and the limiting factors, was done by using linear regression model by first generating the response variable from the yield ha^{-1} by categorizing, 1= demonstration, 0= controls plots.

Logistic regression does not make many of the key assumptions of linear regression and general linear models that are based on ordinary least squares algorithms – particularly regarding linearity, normality, homoscedasticity, and measurement level. Firstly, it does not need a linear relationship between the dependent and independent variables. Logistic regression can handle all sorts of relationships, because it applies a non-linear log transformation to the predicted odds ratio. Secondly, the independent variables do not need to be multivariate normal – although multivariate normality yields a more stable solution. Also the error terms (the residuals) do not need to be multivariate normally distributed. Thirdly, homoscedasticity is not needed. Logistic regression does not need variances to be heteroscedastic for each level of the independent variables. Lastly, it can handle ordinal and nominal data as independent variables. The independent variables do not need to be metric (interval or ratio scaled).

Thereafter, a logistic regression model was fitted to the data set to get regression coefficient (bl) of yield in response to incidence of pests and disease, agricultural practices, banana mats, shade trees and altitude. The results on the main factors, and their interaction which show negative coefficient and are significant were interpreted in terms of odds ratio (e^{bl}) as “if the odds ratio is less than one, the demonstration plots in terms of yield were performing better compared to control plots” and “if the odds ratio is above one, then the demonstration plots in terms of yield were performing much better under agricultural management practice, or else less affected under infestation of pests and diseases.

3.3 Results

3.3.1 Coffee Yield in Plots

Yield is the production of certain amount in a given single growing season. Results of the analysis are represented in Fig. 5. Yields ranged from 35 to 1800 kg $ha^{-1}year^{-1}$ and 18 to 1800 kg $ha^{-1}year^{-1}$ in demonstration plots and control plots respectively. The whiskers represent the minimum and maximum yield (Kg ha^{-1}), and 1st bar represents lower quartile (25% of the data less than this value); 2nd bar represents medium (50% of the data greater than this value; middle of the data set) and 3nd represent upper quartile (25% of the data greater than this value).

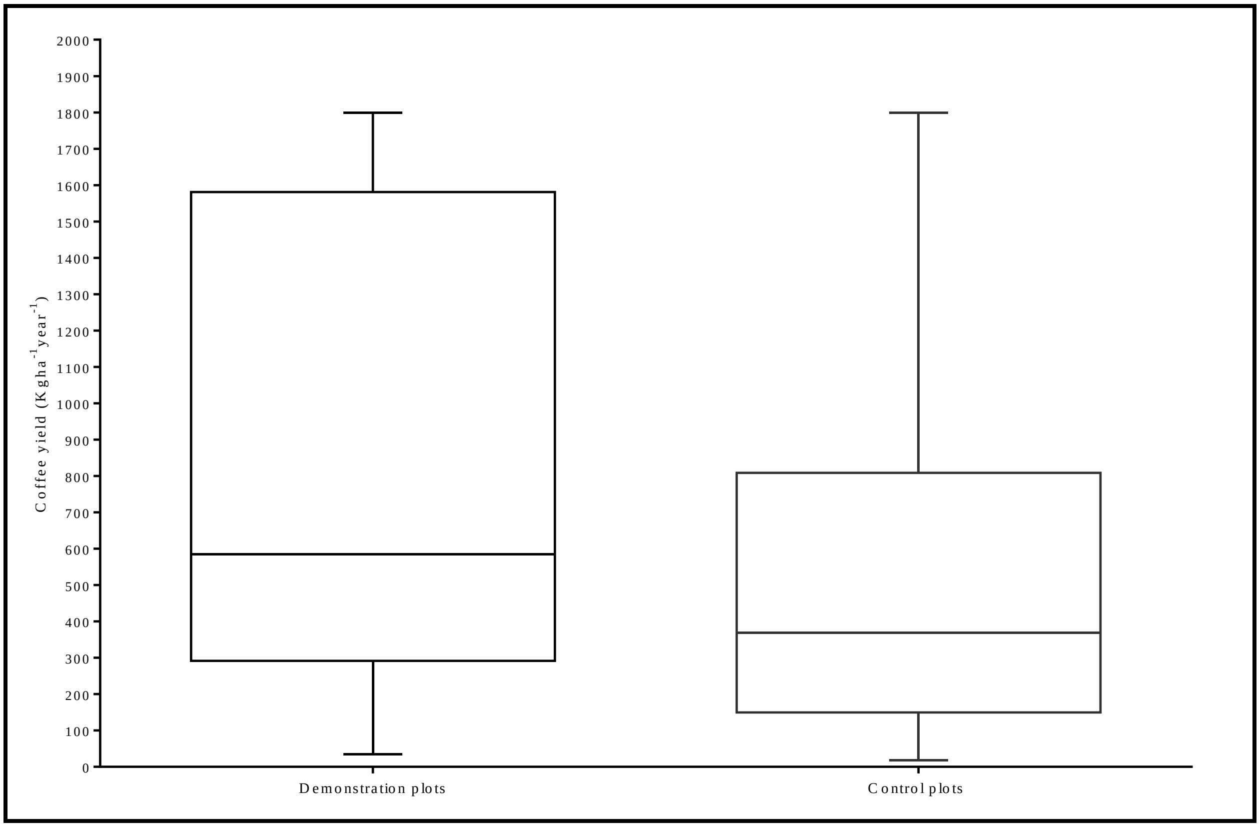

Figure 5: Actual coffee yields in demonstration plots and control plots

3.3.2 Average coffee yield in demonstration plots and control plots

The average coffee yield in the demonstration plots and control plots was analysed using SPPS version 21. Whereas the relationship between the plots was computed using online graph pad t-test calculator ([http://graphpad.com/quickcalcs/ttest1.cfm)](http://graphpad.com/quickcalcs/ttest1.cfm). Results of the analysis are presented in Figure 6. The average of coffee yield was 807.10 kg ha^{-1} and 550.32 kg ha^{-1} for the demonstration plots and control plots respectively, and the mean were significantly different ($P < 0.05$).

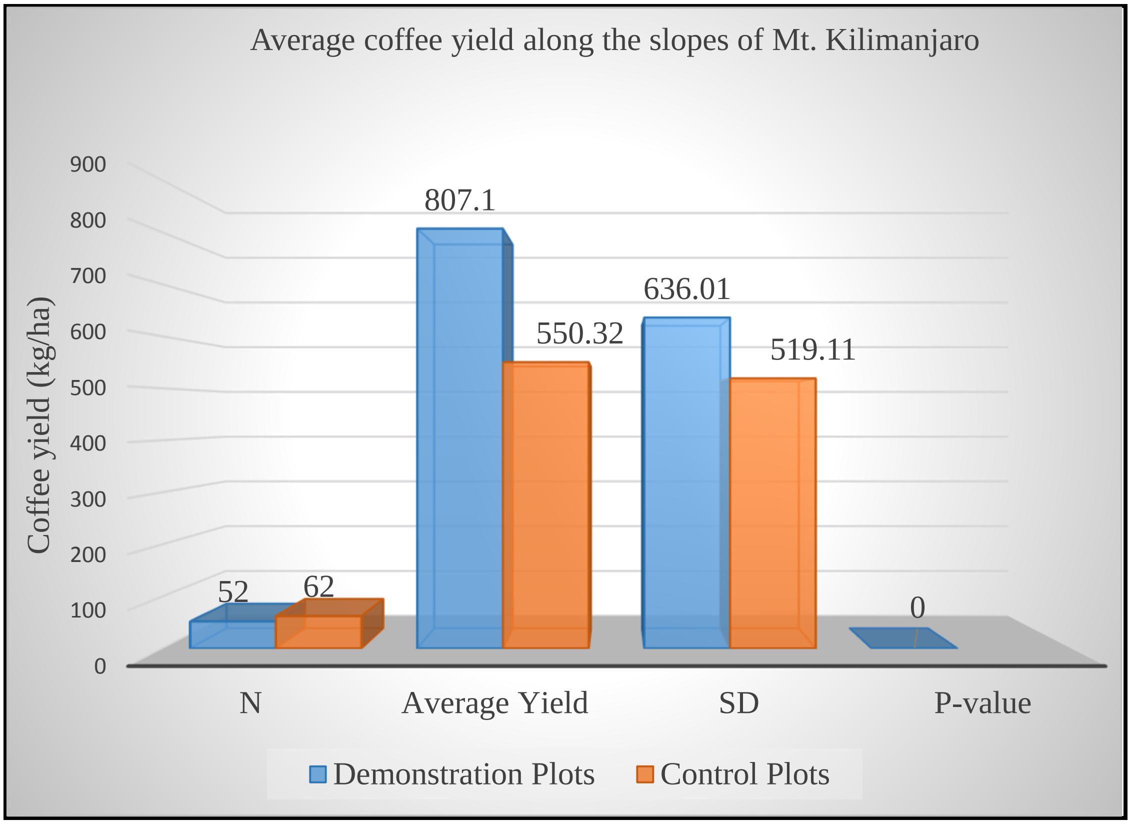

Figure 6: Average coffee yield in the demonstration plots and control plots

Note: N= Sample size of the demonstration plots and control plots respectively, SD= Standard deviation and P-value, is significance are when $p<0.05$

3.3.3 Local perception on relation between climate change and yield reduction

Table 5 indicates the perception of farmers in relation to yield decline and climate change for season 2014/15. The data on perception were analysed using SPPS version 21. These are proportions of respondents. 41.9% of farmers thought drought was responsible for the yield decline; 2.7% of farmers thought excessive rainfall, 16.2% of farmer's thoughts frost, and 39.2% of farmer's thoughts increased pests and diseases.

Table 5: Proportion (%) of climatic factor responsible for yield reduction

Climatic factor	Frequency	Proportion (%)
Drought	31	41.9
Excessive rainfall	02	02.7
Frost	12	16.2
Increase Pest and disease	29	39.2

3.3.4 Effects related to climate change perceived by farmers

Table 6 displays the proportions of effects of coffee yield caused by climate change. The results indicate that the coffee yield was affected equally in the demonstration plots and control plots by climate change (P> 0.05).

Table 6: Proportion (%) of climatic change effects as perceived by farmers to affects coffee yield

		Demonstration plots	Control plots	
Climate change effects	N,N	Proportion (n)	Proportion (n)	P-value
Lack of water	69.73	36.23 (25)	36.99 (27)	1
Pests incidence	70,72	80.88 (25)	81.94 (59)	0.5382
Disease incidence	68,73	79.71 (55)	80.82 (59)	1
Flower abortion	69.73	52.17 (36)	52.05 (38)	1
Reduce bean size	69,73	52.07 (38)	54.79 (40)	1
Sediments	69,73	-	-	-
Water logging	69,73	-	-	-
Reduced flower	69,73	52.17 (36)	52.05 (38)	1
Soil erosion	69,73	1.45 (1)	1.37 (1)	1
Others	69,73	5.80 (4)	6.85 (5)	1

Note: N= sample size in the demonstration plots and control plots respectively, n=frequency, P-value, significance are when p<0.05, Proportion (%)

3.3.5 Incidence of pests and diseases

Table 7 shows relationships of coffee yield and incidence of pests and disease. Diseases observed in the field were coffee berry disease (*Colletotrichum caffeanum*), coffee leaf rust (*Hemileia vastatrix*) and brown eye spot (*Cercospora coffeicola*). Pests identified included coffee berry borer (*Hypothenemus hampei*), white stem borer (*Xylotrechus quadripes*), antestia bug (*Antestiopsis lineaticolis*), root mealy bug (*Planococcus lilacinus*), coffee berry moth (*Prophantis smaragdina)*, green scale (*Coccus viridis*), coffee leaf miner (*Leucoptera coffeella*), red spider mite (*Tetranychus urticae*), coffee thrips (*Diarthrothrips coffeae*), aphids (*Toxoptera aurantii*) and leaf and branch mealy bug (*Plannococcus lilacinus cockerell)*. The regression coefficients (bl) of coffee yields against incidence of pests and diseases were determined using logistic regression model (Yield in demonstration plots or control plots) = Intercept + bl_1*cbd*ctp + bl_2*rsm). Logistic regression model was assumed because the response variable was either 1 or 0 and interpreted in terms of odds ratio (e^{bl}). The results of the analysis show that, the odds ratio of yield reduction attributed by red spider mite (*Tetranychus urticae*) was 0.2 in demonstration plots as compared to control plots. Whereas odds ratio of yield reduction caused by the interaction effects between coffee berry disease (*Colletotrichum caffeanum*) and coffee thrips (*Diarthrothrips coffeae*) was 0.1 in the demonstration plots as compared to control plots.

Table 7: Relationship between coffee yield and incidence of pest and disease

Variables	Regression coefficients (SD)	Odd ratio (e^{bl})	P-value
Intercept	1.73 (1.23)	6	0.159
CBD	-1.66 (0.91)	0.2	0.067
RSM	-1.88 (0.67)	0.2	0.005*
CTP	2.81 (4.22)	17	0.506
WSB	-0.40 (1.28)	0.7	0.757
CBD-RSM	0.56 (0.26)	2	0.033*
CBD-CTP	-2.43 (1.15)	0.1	0.034*
WSB-RSM	0.68(0.33)	2	0.039*

Note: SD=Standard deviation, P-value (*); significant values are when p <0.05, bl = regression coefficient

3.3.6 Agricultural management practices

Table 8 shows the influence/relationship of agricultural practices on coffee yield. Regression coefficients (bl) of coffee yields against agricultural practices were determined using logistic regression model (Yield in demonstration plots or control plots) = intercept + bl_1*mulching+ bl_2 *weeding +....etc.). Logistic regression model was assumed because the response variable was either 1 or 0 and interpreted in terms of the odds ratio (e^{bl}). The results show that, the odds ratio of yield reduction caused by the interactive effects of mulching and weeding were 0.003 in the demonstration plots as compared to control plots. The odds of yield reduction caused by the interaction effects of weeding and replanting of the coffee tree were 0.002 in the demonstration plots as compared to control plots.

Table 8: **Relationship between coffee yield and agricultural management practices**

Variables	Regression coefficients (SD)	Odds ratio (e^{bl})	P-value
Intercept	-0.42 (0 .86)	0.7	0.623
Mulching	-1.64 (1.64)	0.2	0.318
Weeding	5.20 (2.67)	I81	0.052
Replanting	1.05 (1.11)	3	0.566
Shade management	1.65 (1.53)	5	0.281
Mulching and weeding	-5.75 (2.39)	0.003	0.016 *
Mulching & shade management	6.45 (2.47)	633	0.009 *
Weeding and replanting	-6.50 (1.82)	0.002	<.0001*

Note: SD=standard deviation, P-value (*); significantly values are when $p < 0.05$, bl= regression coefficient

3.3.7 Banana mats, shade trees and altitude

Table 9 shows the relationship between coffee yield and number of banana mats per ha, number of shade trees per ha and altitude. Regression coefficients (bl) of coffee yields against banana mats, shade trees and altitude were determined using logistic regression model (Yield (demonstration plots or control plots) = intercept + bl_1*banana mats + bl_2*shade trees + bl_3.*altitude, assumed a logistic regression because the response was either 1 or 0) and interpreted in terms of the odds ratio (e^{bl}). The results indicated that, the odds ratio of coffee yield reduction due to banana mats were 0.9 in the demonstration plots as compared to control plots. The odds of yield reduction due to number of shade trees were 0.5 in the demonstration plots as compared to control plots.

Table 9: **Relationship between coffee yield and Banana mats, shade trees and altitude**

Variable	Regression Coefficients (SD)	Odd ratio (e^{bl})	P-value
Intercept	2.74 (1.70)	16	0.108
Banana mats	-0.07 (.017)	0.9	<.0001*
Shade trees	-.0.80 (.030)	0.5	0.008 *
Altitude	1.52 (1.70)	5	0.014 *

Note: SD=standards deviation, P-value (*); significant values are when p <0.05, bl= regression coefficient

3.3.8 Description of coffee ages at plot level

The proportion of coffee ages recalled from farmers during the interview was analyzed using SPSS version 21. The results of the analysis of coffee age data obtained from farmer recall indicated that 33.3% of coffee trees accounted for the age greater and equal 35 years, 7.6% age of greater or equal to 20 and less than 35 years; 26.5% less than 20 and greater to two, and 32.6% two years and less (Table 10).

Table 10: **Proportion of coffee age**

Coffee Age (Years)	Frequency	Proportion (%)
≥35	48	33.3
35 < and ≥20	11	07.6
20 < and > 2	38	26.5
2 and less	47	32,6

Note: > mean greater than, < means less than, ≥ means greater than and equal to, % means percentage

3.4 Discussion

3.4.1 Actual Coffee yield and yield gap

In this research, average arabica coffee yield in demonstration plots and control plots was 807.10 kg ha^{-1} and 550.32 kg ha^{-1} respectively. The yields in the demonstration plots were significantly higher as compared to control plots. Hence, the yield gap was 14% higher in control plots as compared to demonstration plots. The large yield gap illustrates challenges facing farmers in Hai, Siha and Moshi rural districts. The observed better performance of yield in demonstration plots was due to good agricultural practices of application of interaction effects of mulching and weeding and weeding and replanting of coffee trees, banana mats density and shade trees density. However, crop protection of the red spider mite (*Tetranychus urticae*) and interaction effects of coffee berry disease (*Colletotrichum caffeanum*) and coffee thrips (*Diarthrothrips coffeae*) contributed to better performance in the demonstration plots.

More education on coffee production to the local farmer based on how to intercrop, replanting coffee trees, crop protection, mulching, weeding and removing the old coffee trees are needed in order to improve productivity. However, in comparison of observation studies made from part of East African countries for period 2010/11 to 2013/14 in the small-scale coffee plots and low inputs, showed that, the average yields in Uganda were 708 kg ha^{-1}, Rwanda 500 kg ha^{-1}, Kenya 412 kg $ha^{-1}$and Burundi 281 kg ha^{-1} (ICO, 2015).

3.4.2 Farmers' perception on climate variability with yield decline

In this study, most farmers believed that the low production of coffee yield in season 2014/15, were due to drought, excessive rainfall, frost and increase pests and diseases. Other studies in the Pacific region in Nicaragua showed that drought and excessive rainfall results to the decline of coffee yield by 29% and 43% respectively (Lara-Estrada *et al.*, 2012). The strategy to reduce the risk of drought have already been adapted locally by some farmers through various practices such as irrigation, mulching and planting or keeping shade trees while excessive rainfall was adopted through making trenches to harvest water. In addition, the effect of extreme rainfall enforces farmers to increase crop protection against coffee berry disease since the incidence of the disease is linked to excess rainfall (Haggar and Schepp, 2012). Frost is not the common disaster in

Tanzania (URT, 2002/3). Nowadays, the effects of frost are intervened by the rise in temperature (Haggar and Schepp, 2012), so that the disaster do not impact the production.

Mulching has the advantage of retaining water and improving nutrient recycling (Van Asten *et al.*, 2011; Nzeyimana *et al.*, 2013; Wang *et al.*, 2015), whereas shade trees provide shade, which buffers against increases in temperature (DaMatta, 2004; Van Asten *et al.*, 2011; Jassogne *et al.*, 2013a; Wairegi *et al.*, 2014; Wang *et al.*, 2015). The study done in Tanzania by (Tibanyenda, 1987) shows that mulching improves soil, conserves water and increases organic matter and nutrients in the soil. Likewise, irrigation reduces water stress to the coffee plant (DaMatta and Ramalho, 2006). Generally, whether the coffee is grown in the demonstration plots or control plots, they are affected in the same way by the climatic change. Therefore, for yield improvement under the climate change as perceived by farmers, there is a need for sustainable intensification and climate smart agriculture practices.

3.4.3 Pests and diseases as causes yield decrease.

Pressure of pests and diseases is perceived by farmers and researchers to be among the factors contributing to the decline of coffee yield in East Africa (Jaramillo *et al.*, 2009; Wang *et al.*, 2015). Also studies by (TACRI, 2008) shows that the pressure of pests and diseases contributes to the decline of coffee yields. In this study, it was realized that the reduction of coffee yield to the current level of production was due to the incidence of red spider mite (*Tetranychus urticae*). The odds ratio to yield decrease was 0.2 and was affecting more the control plots as compared with the demonstration plots. This suggests that farmer did control better the incidence of red spider mite (*Tetranychus urticae*) in the demonstration plots compared to control plots. Other pests and diseases did not appear to be constraints, however, their interactions effects appear to be significant constraints. For instance, in Table 7 it was realized that, interaction effects of coffee berry disease (*Colletotrichum caffeanum*) and coffee thrips (*Diarthrothrips coffeae*) lead to yielding reduction at the current level of production. Odds of reduction of coffee yield were 0.1 and were affecting more the control plots compared to the demonstration plots. This also suggests that farmer control better the interaction effects of coffee berry disease (*Colletotrichum caffeanum*) and coffee thrips (*Diarthrothrips coffeae*) in the demonstration plots compared to control plots.

The better performance of yields in the demonstration plots, might be possible because farmers are practicing good agricultural practice and crop protection empowered by HRNS-Tanzania. Studies show that, good agronomic practices (GAP) with balanced crop nutrition, especially nitrogen, phosphorus and potassium (N:P:K) inputs can reduces the incidence of pests and diseases (Mugo *et al.*, 2012). Therefore, a detailed study is needed to monitor these interactions and come up with a tangible output.

However, data for this study was taken for only two months, so the among of data is insignificant to make a reasonable conclusion on pests and diseases. During the interview, farmers reported that, pests kept on increasing because neighbor plots are abandoned, thus pests production increased and migrates to the plots. This suggests that the impacts of pests should be controlled by using integrated pest management (IPM) over a wide range instead of relying merely on pesticides on specific plots. IPM brings all possible tactics and maintains population levels of pests below economic injury (Dent and Elliott, 1995).

3.4.4 Agronomic management practices

Agricultural practices gave similar information in the demonstration plots and control plots when it stands alone except when there are interaction effects of mulching and weeding practices and weeding and replanting of coffee trees practices. The interaction effects of mulching and weeding practices and also weeding and replanting of coffee trees were poorly practiced at the current level of production. This is suggested by the reduction to coffee yield. It was realized that, the odds of yield reduction was 0.003 and 0.002 respectively for the interactions effects of mulching and weeding practices, and weeding and replanting of coffee trees practices. The demonstration plots were performing better compared to control plots.

Markedly performance under the demonstration plots indicate that, farmers whoever trained by HRNS did good agricultural practices. Furthermore, the significant yield difference of 256.78 kg ha^{-1} between demonstration plots and control plots reveals that farmers have the opportunities of improving yield through adopting GAP. This study suggests that HRNS-Tanzania has to innovate the way to bridge this gap to attain a higher yield difference; this will motivate farmers who abandoned their plots to renew it. Most of the farmers who abandoned their plots have been waiting the results of plots empowered by HRNS-Tanzania to renew their plots.

3.4.5 Banana mats and shade trees

In this study, it was realized that, yield reduction at the current level of production was due to decrease in banana mats density and shade trees density. The odds of reduction in yield in the demonstration plots as compared to the control plots is 0.9 with decrease in the banana mats. The odds of reduction in yield in the demonstration plots as compared to the control plots is 0.5 with decrease in the shade trees. This suggest that, yield is reduced due to decrease in shade trees and banana mats. The decrease in banana mats and shade trees might affect yield because shades from banana lower effects of coffee leaf rust and black coffee twing borer by 50% compared to other shaded system (CIGAR, 2015) and increasing shades trees have a significant role in reducing adverse effects associated with the rise in temperature (Van Asten *et al.*, 2011; Wairegi *et al.*, 2014). Shade intensity of about 50% is an ideal for sustainability (CIGAR, 2015). Hence, appropriate increasing shade trees and banana mats density and spacing between and within row is recommended.

3.5 Conclusion

Large yield gap obtained and compared with the attainable yield indicates that there is a need to improve coffee farming and management practices. The yield gap was partly contributed by the red spider mites and interaction effects of coffee berry disease and coffee thrips. Poor agricultural management practices attributed to yield decrease were inappropriate banana mats and shade trees, poor interaction effects of mulching and weeding and also weeding and replanting of coffee trees. The result of this study is useful for coffee growing region in Tanzania and other parts of East Africa as a basis for reducing the coffee yield gap.

CHAPTER FOUR

Climate change adaptation by coffee farmers along the slopes of Mount Kilimanjaro

Abstract

Variation of rainfall and temperature as a result of climate change will continue to decrease coffee yield along slopes of Mt. Kilimanjaro. Recent studies in Tanzania shows that for every 1°C increase in minimum temperature results in annual yield losses of 137±16.87 kg ha^{-1} of Arabica coffee. Hence, there was a need to develop enhanced agricultural practices that will reduce stress of climate change and variability. Data on climate change adaptation practices were collected through interview, shade management and mulching thickness was collected through measurements methods whereas mulching practices was collected through observation methods in the coffee field. The results of the analysis showed that, mulching, irrigation and shade management practices are adopted by farmers to reduce effects of climate change. Farmers have opportunities for increasing coffee yield under the current situation of global warming. Such management practices shade management, proper mulching and mulching thickness and proper irrigation need to be done to be done in a way that will not reduce the effective yield of coffee and should be adopted based on recommendations from standard practices.

4.1 Introduction

Arabica coffee is an important cash crop in Tanzania. Productivity of coffee decreased due to among other factors, climate change (Haggar and Schepp, 2011; Haggar and Schepp, 2012; Craparo *et al.*, 2015). The reduction of yield from 1961 to 2012 was due to the increase in minimum temperatures (Craparo *et al.*, 2015). Every rise of 1°C night time minimum temperature resulted to in annual yield losses of 137±16.87 kg ha^{-1} (Craparo *et al.*, 2015). It was projected that by Craparo 2015 that, without immediately adaptation strategy yield will drop to 145±41 kg ha^{-1} by 2060. Hence, there is a need to improve coffee farming and agricultural practices to adapt to the changing climate. Rising in temperature and decreased rainfall appears to be the most important weather parameter affecting arabica coffee yield across the world (Haggar and Schepp, 2011; Jassogne *et al.*, 2013a). Studies show that, increasing shade trees and proper mulching have a significant role in reducing adverse effects associated with the rise in temperature (Van Asten *et al.*, 2011; Wairegi *et al.*, 2014). Shade intensity of 50% is an ideal for sustainability (CIGAR, 2015).

However, under the current rise in temperature studies show that coffee-banana plus other shade trees system buffers rise in temperature (Van Asten *et al.*, 2011; Wairegi *et al.*, 2014). In addition, mulching practices reduce the evaporation rate of soil water and increase nutrients available in the soil (Nzeyimana *et al.*, 2013). Production of arabica coffee requires conducive optimal and absolute temperatures ranging from 14 to 28°C and 10 to 30°C respectively (Haggar and Schepp, 2011) and reliable well distributed rainfall of about 1200 to 1800 mm per annum (DaMatta and Ramalho, 2006). Then, any change poses negative productivity (Camargo, 2010; Haggar and Schepp, 2011; Craparo *et al.*, 2015) due to its sensitivity to climate change (Haggar and Schepp, 2011). Thus, future coffee production depends on how we improve intercropping system, mulching and irrigation. There are several efforts from coffee stakeholder such as HRNS-Tanzania and TACRI empowering farmers to overcome challenges of the rise in temperature through training on increasing shades trees, shade management, mulching and irrigation. The emphasis of reducing challenges of should be laid on minimizing environmental impacts and enhancement of yield (Campbell *et al.*, 2014). Therefore, the best approach is to interlink sustainable intensification (SI) and climate smart agricultural practices (CSA) in order to decreasing the consequence of climate and improve productivity to support household income (Campbell *et al.*, 2014. The present study were carried out to assess climate change adaptation practices as implemented by the coffee farmers on the slopes of Mount Kilimanjaro.

4.2 Material and Methods

4.2.1 Description of study area

The study was conducted in Hai, Siha and Moshi rural districts in Kilimanjaro region from June 2015 to August, 2015 (Fig 1). The plots site was located using a global positioning system (GPS) in which the northern and eastern parts were marked in each corner of the plot. These districts were selected because they lie within an altitude between 1000 and 2300 m above sea level, where arabica coffee is cultivated in Tanzania (Craparo *et al.*, 2015).

4.2.2 Data collection process

Data on mulching thickness, shade management and mulching practices were collected through observation and measurements methods in coffee fields. Data on irrigation was obtained through interviewing the head of household. Mulch thickness measurements were taken at 1 m interval along the tape measure by inserting a meter ruler and read the thickness three times resulting in a total of 30 readings, subsequently the 30 readings were averaged and get mulch thickness in centimetre (cm). The intensity of shade trees in a plantation was measured using densitometer and then assessed as adopted or not adopted. Shade intensity covering less than 20% of the farm or heavy shade over more than 40% of the farm was rated as not adopted whereas established shade trees covering at least 20-40% of the farm rated adopted. Mulching was rated adopted when there is partial or old mulch under the tree canopy or farm fully mulched, under and between the trees whereas was rated not adopted when the soil is clean with no mulch at all.

4.2.3 Statistical analysis

Data was analyzed by using SPSS version 21. The analysis of mulching practice, shade management, irrigation practice and mulch thickness was merely descriptive for understanding the proportions of the practices in two categories, adopted or not adopted; except for mulch thickness in which was analyzed to get the average thickness in centimeter (cm).

4.3 Results

4.3.1 Mulching practices and thickness adapted by farmers along slopes of Mt. Kilimanjaro.

The assessment of mulching practiced and thickness are shown in figure 7. The results of the analysis using SPSS show that 71.4% of the farmers adopted mulching practices in the demonstration plots whereas 60.8% of farmers adopted the practice in the control plots whereas average mulch thickness was on average of 2cm in both plots.

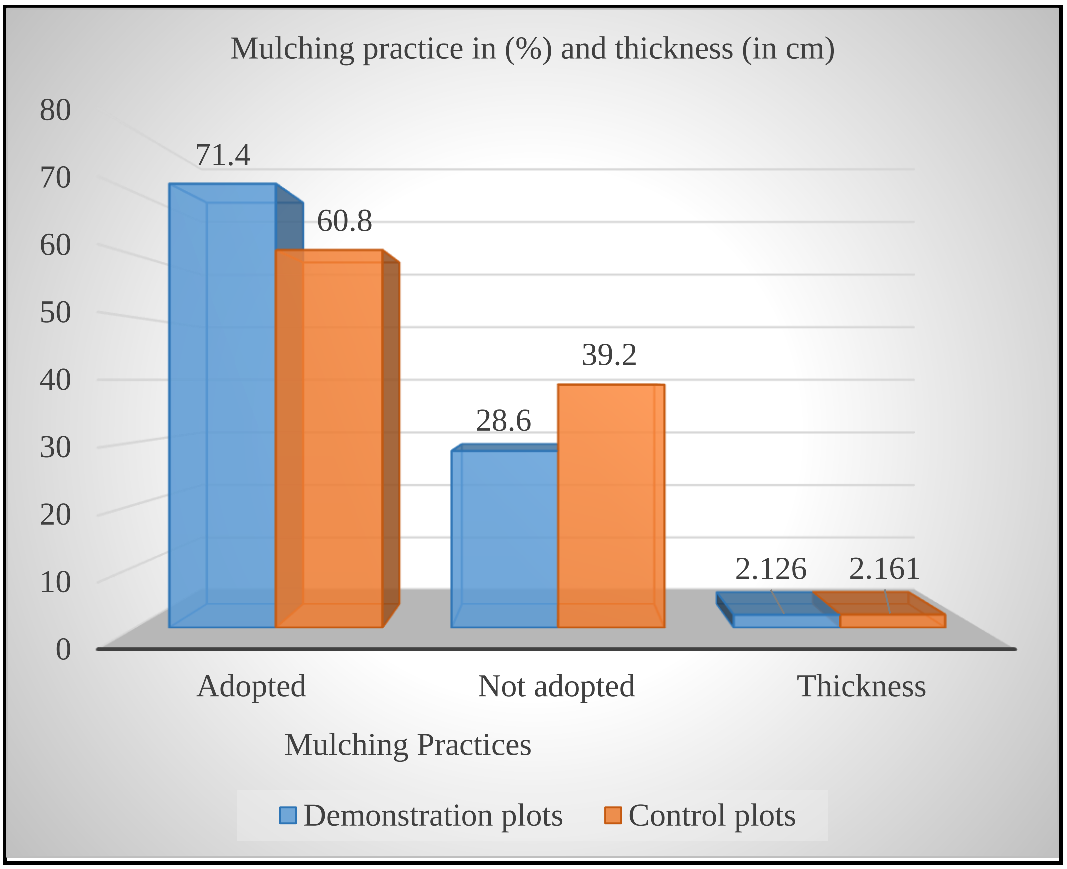

Figure 7: Mulching practices and thickness adopted by coffee farmers along the slopes of Mt. Kilimanjaro

4.3.2 Irrigation practice adapted by farmers along slopes of Mt. Kilimanjaro

Figure 8 shows the proportion of respondents of farmers in relation to irrigation practices. These are proportions of respondents; 35.1% of farmers did apply irrigation during dry season and 64.9% of farmers did not apply irrigation during the dry season.

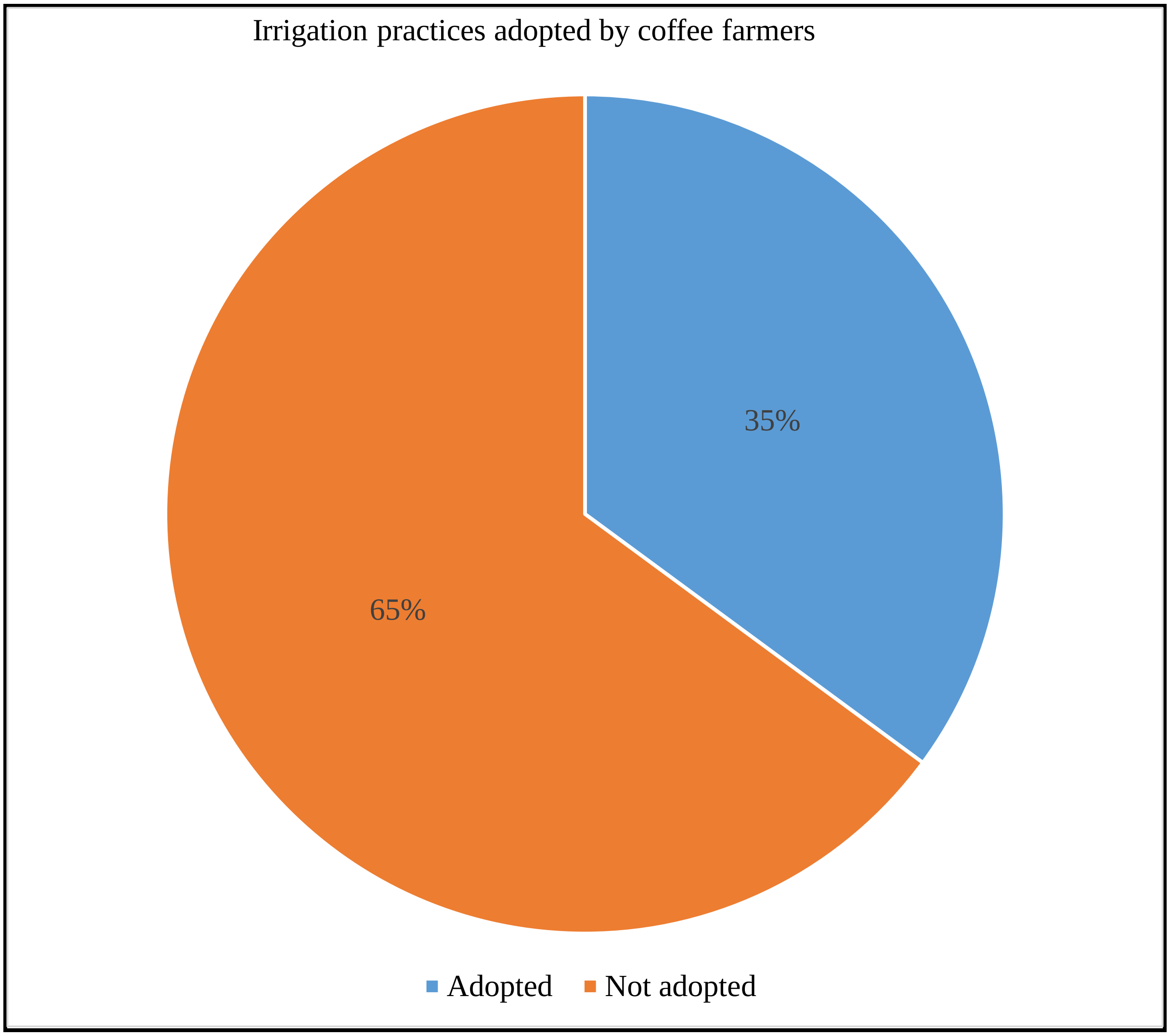

Figure 8: Proportion of coffee farmers adopted irrigation practices

4.3.4 Shade management adapted by farmers along the slopes of Mt. Kilimanjaro

Figure 9 shows the assessment of shade management. The results of the analysis using SPSS version 21 shows that, 40% of the farmer adopted shade management in the demonstration plots whereas 20.3% managed well shade trees in control plots.

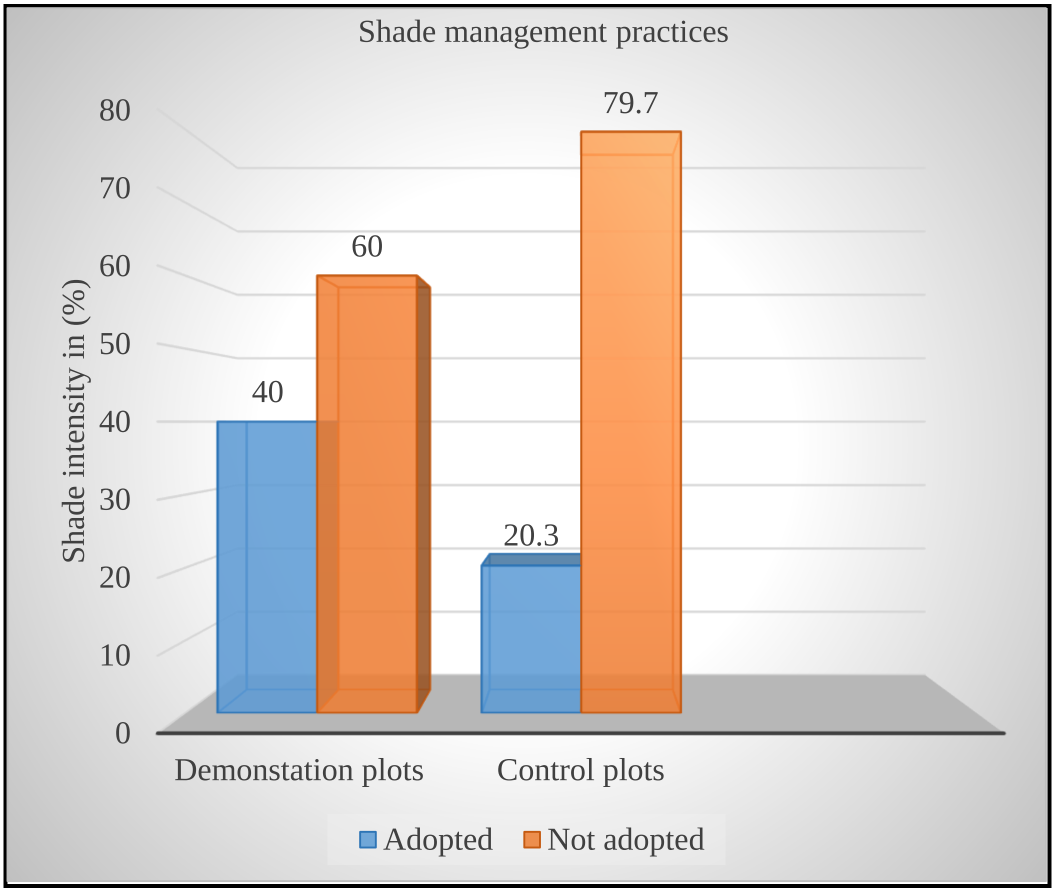

Figure 9: Shade management adopted by coffee farmers along the slopes of Mt.Kilimanjaro.

4.4 Discussion

4.4.1 Mulching practices adapted as mitigation to climate change.

Coffee farmers along slopes have started mitigating climate change through mulching practices. The proportion of adoption is higher in the demonstration plots as compared to control plots. This indicate that farmers trained by HRNS did good mulching practices. Mulching reduced the evaporation rate of soil water and increase nutrients available in the soil ((Nzeyimana *et al.*, 2013; WOCAT, 2014) and improve yield (Nzeyimana *et al.*, 2013).. In this study the average mulch thickness observed was on average of 2cm, hence an increase is thickness is recommended. The ideal thickness for mulching is of about 15cm and recommended to applied before the onset of rain August to September (WOCAT, 2014).

4.4.2 Irrigation practices adapted as mitigation measure to climate change

In this study farmers practiced irrigation, it was revealed that only 35.1% of farmers did the practices and the rest did not practiced due some reasons such as to cost and lack water. During the study coffee farmers having reliable source of water was observed irrigating by allowing water to enter in the farm from the stream. The author suggest the use of dripping irrigation to be practiced. Studies reported that, dripping irrigation techniques saves water and increases water-use efficiency (Narayanamoorthy, 2006).

4.4.3 Shade management adapted by coffee farmers along the slopes of Mt. Kilimanjaro

Coffee farmers along the slopes of Mt. Kilimanjaro practiced intercrops system**.** This system have advantage of reducing environmental stress caused by extreme temperature when it is well managed (Beer *et al.*, 1998; Bote and Struik, 2011; Van Asten *et al.*, 2011). High temperature affects the yields by reducing the growth since it increases evaporation rates of soil water and evapotranspiration rates of plants (Mary and Majule, 2009). In addition, it affects coffee quality by quickly accelerating the ripening of cherries and cause abnormalities such as yellowing of leaves and abortion of flowers (Haggar and Schepp, 2011). In this study shade management was poorly managed in both plots by less than 50%. Hence shade management is recommended.

4.5 Conclusion

Sustainable intensification (SI) and climate smart agriculture (CSA) as a useful approach for increasing productivity in a way that lower environmental impacts. Farmers along slopes of Mt. Kilimanjaro have adapted to the rise in temperature through mulching, irrigation and keeping and increasing shade trees. Despite the fact that farmers have adopted as means of reducing effects of climate change, there was no scientific evidence to what extent mulching practices and thickness, shade management and irrigation is adopted. Thus, it can be concluded that, enhanced irrigation practices, mulching practice and thickness and shade management are among best mitigation measure under the current global warming.

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CHAPTER FIVE

5.1 General Discussion

Arabica coffee productivity in Hai, Siha and Moshi rural districts experienced various challenges, which lead to declining trend of coffee yields. This study show that there is no possibility of expansion of plots because of limited land, instead is to increase the number of productive coffee tree in plots by replacing the old coffee trees using improved varieties, shade management, increasing number of shade trees and banana mats, adapting and mitigation to the challenges of climate change, good agricultural practices proper crop protection against pests and diseases. Incidence of pests and diseases and poor agricultural practices as well as climate change were major constraints limiting coffee yield at the current level of production along the slopes of Mt. Kilimanjaro. Most farmers has begun to overcome challenges associated with the yield decline by increased shade trees and practices mulching and irrigation. The techniques used to adapt to the current rise temperature have several advantages such as shades and mulch which, buffers environmental stress associated with a rise in temperature, mulch apart from reducing evaporation from the soil it also increases nutrient availabilities in the soil. In addition, banana tree is capable of storing 15 -20 tons of carbon per ha in the soil (Campbell *et al.*, 2014).

The coffee-banana inter crops and other shade trees system, mulching practices, irrigation have good implication for the sustainability of coffee yield when well managed. Currently, these practices are implemented locally. Therefore, training farmers on adopting appropriate irrigation, appropriate spacing when intercrops, shade management, mulch thickness are still needed. Although in this study, decrease shade tree density and banana mats density revealed to decreased yield but what is needed is to increase the number of banana mats and shade trees as recommended because high inter crop also is associated with increased competition of light ,water and nutrients (Nzeyimana *et al.*, 2013; Wairegi *et al.*, 2014).

This study has further shows that many of the pests and disease were distributed across the altitudinal gradient, coffee berry disease was affecting more plots located at high altitude. The result is similar to the finding in Kenya that coffee berry disease affects plots located at high altitude (Hindorf and Omondi, 2011). This could therefore explain that the decreased of temperature and increased rainfall at high altitude favour the incidence of coffee berry disease

(Bedimo *et al.*, 2009). This suggests that, farmers with plots at high altitude above 1600 m above sea level have needs more awareness of coffee berry disease, because their plots are likely to be affected and the incidence of CBD can lead to loss of yield of about 60%-80% (Bedimo *et al.*, 2009).

Generally, coffee banana intercropped with other shade trees with well managed shade and have the benefit of increasing yield by reducing environmental impact associated with rise in temperature. However, incidence of red spider mite, interaction effects of coffee berry disease and coffee thrips whereas poor agricultural practices decreased banana mats density and shade trees density, interaction effects of mulching and weeding and interaction effects of mulching and replanting of coffee trees are the major constraints limiting current level of coffee productivity. Farmers have already locally adopted practices in reducing effects of climate change through mulching and irrigation and increasing shade trees, hence, enhanced irrigation practices, mulching practice and thickness and shade management are among best mitigation measure.

5.2 Conclusion

This study assesses how coffee yield gap was influenced by pests, diseases, coffee farming system and agricultural management practices and the opportunities of improving yield in the context of climate change. Logistic regression analysis, STATA, SPSS version 21 and graph pad prism 6 were used. The large yield gap was more control plots as compared demonstration plots. This indicates that there is significant need to improve coffee productivity across the slopes of Mt. Kilimanjaro. Yield gaps were due to the incidence of pests and diseases, poor farming and management practices.

Generally, common pests and diseases were red spider mite and interaction effects of coffee berry disease and coffee thrips. Poor agricultural practices such as in appropriate banana mats and shade trees regimes, interaction effects mulching, and weeding and also weeding and replanting of coffee trees affected yield. Despite the extensive effort of Tanzanian coffee stakeholder, in particular, HRNS-Tanzania of empowering farmers on crop protection against pests and diseases and training on agricultural practices little research has been conducted to study the effectiveness of their efforts. The results can be useful for large-scale and other parts of Tanzania and beyond Tanzania where coffee arabica are cultivated. The constraints illustrated in this study are a basis for the development management strategies to reduce the coffee yield gap. Farmers have the opportunities for yield improvement in a sustainable manner using enhanced practices.

5.3 Recommendation

- Proper intercropped system in appropriate spacing and plant density is recommended
- Good agricultural practices and crop protection are recommended for reduced constraints limiting coffee productivity
- Enhanced irrigation, proper mulch thickness and shade management are ideal for mitigating current rise of temperature.

REFERENCES

Baffes, J. (2004). Tanzania's coffee sector: Constraints and challenges in a global environment.

Bedimo, J.M., Bieysse, D., Cilas, C. and Nottéghem, J. (Ed.) (2009). Effect of temperature and rainfall variations on coffee berry disease (Colletotrichum kahawae). *In: 22nd International Conference on Coffee Science, ASIC 2008, Campinas, SP, Brazil, 14-19 September, 2008. Association Scientifique Internationale du Café (ASIC)*, pp. 1439-1442, 2009.

Beer, J., Muschler, R., Kass, D. and Somarriba, E. (1998). Shade management in coffee and cacao plantations, Directions in Tropical Agroforestry Research. Springer, pp. 139-164.

Bongers, G., Jassogne, L., Wanyama, I., Nibasumba, A., Mukasa, D. and van Asten, P. (Ed.) (2012). Understanding and exploring the evolution of coffee-banana farming systems in Uganda. *In: Proceedings of the tenth European IFSA Symposiums*, pp. 1-4, 2012.

Bote, A.D. and Struik, P.C. (2011). Effects of shade on growth, production and quality of coffee (Coffea arabica) in Ethiopia. *J. Hortic. For*. **3**(336-341.

Camargo, M.B.P.d. (2010). The impact of climatic variability and climate change on arabic coffee crop in Brazil. *Bragantia*. **69**(1): 239-247.

Campbell, B.M., Thornton, P., Zougmoré, R., Van Asten, P. and Lipper, L. (2014). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability*. **8**(39-43.

CIGAR (2015). Coffee-banana intercropping: Implimentation guidance for plicy makers and investor. https://cgspace.cgiar.org/bitstream/handle/.../CCAFSpbCoffee-Banana.pd. Accessed on February 5, 2016, 2015.

Craparo, A., Van Asten, P., Läderach, P., Jassogne, L. and Grab, S. (2015). Coffea arabica yields decline in Tanzania due to climate change: Global implications. *Agricultural and Forest Meteorology*. **207**(1-10.

DaMatta, F.M. (2004). Ecophysiological constraints on the production of shaded and unshaded coffee: a review. *Field Crops Research*. **86**(2): 99-114.

DaMatta, F.M. and Ramalho, J.D.C. (2006). Impacts of drought and temperature stress on coffee physiology and production: a review. *Brazilian Journal of Plant Physiology*. **18**(1): 55-81.

Dent, D. and Elliott, N. (1995). Integrated pest management. Springer Science & Business Mediapp.

Haggar, J. and Schepp, K. (2011). Coffee and climate change. *Desk study: impacts of climate change in four pilot countries of the coffee and climate initiative. Hamburg: Coffee and Climate*.

Haggar, J. and Schepp, K. (2012). Coffee and climate change: Impacts and options for adaptation in Brazil, Guatemala, Tanzania and Vietnam. Climate Change, Agriculture and Natural Resources Working Paper Series, No. 4. London: Natural Resources Institute, University of Greenwich.

Hindorf, H. and Omondi, C.O. (2011). A review of three major fungal diseases of Coffea arabica L. in the rainforests of Ethiopia and progress in breeding for resistance in Kenya. *Journal of Advanced Research*. **2**(2): 109-120.

ICO (2015). International Coffee organization. http://www.ico.org.documents/cy2014-15/icc-114-5e-overview-coffee-sector-africa.pdf (Accessed on October 20, 2015).

Jaramillo, J., Chabi-Olaye, A., Kamonjo, C., Jaramillo, A., Vega, F.E., Poehling, H.-M. and Borgemeister, C. (2009). Thermal tolerance of the coffee berry borer Hypothenemus hampei: predictions of climate change impact on a tropical insect pest. *PLoS One*. **4**(8): e6487.

Jassogne, L., Lderach, P. and van Asten, P. (2013a). The Impact of Climate Change on Coffee in Uganda: Lessons from a case study in the Rwenzori Mountains. *Oxfam Policy and Practice: Climate Change and Resilience*. **9**(1): 51-66.

Jassogne, L., Nibasumba, A., Wairegi, L., Baret, P., Deraeck, J., Mukasa, D., Wanyama, I., Bongers, G. and van Asten, P. (2013b). 18 Coffee/Banana Intercropping as an Opportunity for Smallholder Coffee Farmers in Uganda, Rwanda and Burundi. *Banana Systems in the Humid Highlands of Sub-Saharan Africa*: 144.

Jassogne, L., van Asten, P.J., Wanyama, I. and Baret, P.V. (2013c). Perceptions and outlook on intercropping coffee with banana as an opportunity for smallholder coffee farmers in Uganda. *International Journal of Agricultural Sustainability*. **11**(2): 144-158.

Lara-Estrada, L.D., Haggar, J., Stoian, D. and Rapidel, B. (Ed.) (2012). Coffee yield variations and their relations to rainfall events in Nicaragua. *In: 24th International Conference on Coffeee Science*, 2012.

Lp, S. (2012). Stata/IC 12.1 for Windows. Revision.

Mary, A. and Majule, A. (2009). Impacts of climate change, variability and adaptation strategies on agriculture in semi arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania. *African Journal of Environmental Science and Technology*. **3**(8): 206-218.

Mhando, D.G., HALLER, T., MBEYALE, G. and LUDI, E. (2013). Adaptation to changes in the coffee value chain and the price of coffee among coffee producers in two villages in Kilimanjaro, Tanzania.

Misana, S.B., Majule, A.E., Lyaruu, H.V. and Change, L.U. (2003). Linkages between changes in land use, biodiversity and land degradation on the slopes of Mount Kilimanjaro, Tanzania. LUCID Project, International Livestock Research Institutepp.

Mkandya, E., Kilima, F., Lazaro, E. and Makindara, J. (2014). The Impact of Market Reform Programmes on Coffee Prices in Tanzania. *Tanzania Journal of Agricultural Sciences*. **10**(1).

Mugo, H., Irungu, L. and Ndegwa, P. (2012). Population dynamics of predacious phytoseiid mites, Euseius kenyae and coffee thrips, Diarthrothrips coffeae and their Interactions in coffee agro ecosystems in Kenya.

NCC (2013). National Coffee Conference. http://www.coffeeboard.or.tz/News_publications/2013-2014/4th_NCC_REPORT_ENGLISH.pd (Accessed on July 10, 2015).

Noe, C. (2014). Reducing Land Degradation on the Highlands of Kilimanjaro Region: A Biogeographical Perspective. *Open Journal of Soil Science*. **4**(13): 437.

Nzeyimana, I., Hartemink, A.E. and de Graaff, J. (2013). Coffee farming and soil management in Rwanda. *Outlook on AGRICULTURE*. **42**(1): 47-52.

Romero-Alvarado, Y., Soto-Pinto, L., Garcia-Barrios, L. and Barrera-Gaytán, J. (2002). Coffee yields and soil nutrients under the shades of Inga sp. vs. multiple species in Chiapas, Mexico. *Agroforestry Systems*. **54**(3): 215-224.

TACRI (2008). Tanzania Coffee Research Institute. www.tacri.org/uploads/media/TACRI_Annual_Report_2008.pdf (Accessed on January 20, 2016).

TCB http://www.coffeeboard.or.tz/tzcoffee_%20profile.php. Accessed on.(March 10 , 2016).

TCBR (2005). Tanzania Coffee Baseline Report. http://www.tacri.org/fileadmin/Documents/TaCRI.documents/COFFEE_BASELINE_SURVEY.pdf (Accessed on May 25, 2015).

TCCACR (2012). Tanzania Climate Change Arabica Coffee Report. http://www.coffeeandclimate.org/reports_studies.html%3Ffile%3Dtl_files/CoffeeAndClimate/Future%2520C (Accessed on June 20, 2015).

TCIDS (2012). Tanzania Coffee Industry Development Strategy. http://www.coffeeboard.or.tz/News_publications/startegy_english.pd (Accessed on May 24, 2015).

Tibanyenda, C. (Ed.) (1987). Mulching as traditionally applied by small scale coffee growers in Tanzania. *In: INTERNATIONAL Workshop on the application of meteorology to agroforestry systems planning and management. Nairobi, February 9-13, 1987. Proceedings*.. 1987.

Tittonell, P. and Giller, K.E. (2013). When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*. **143**(76-90.

URT (2007). Managing Risk and Reducing Vulnerability of Agricultural Systems under Variable and Changing Climate

Van Asten, P., Wairegi, L., Mukasa, D. and Uringi, N. (2011). Agronomic and economic benefits of coffee–banana intercropping in Uganda's smallholder farming systems. *Agricultural systems*. **104**(4): 326-334.

Van der Vossen, H. (2005). A critical analysis of the agronomic and economic sustainability of organic coffee production. *Experimental Agriculture*. **41**(04): 449-473.

Van Ittersum, M. and Cassman, K. (2013). Yield gap analysis—Rationale, methods and applications—Introduction to the Special Issue. *Field Crops Research*. **143**(1-3.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M. and Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*. **8**(15-22.

Wairegi, L., van Asten, P., Giller, K. and Fairhurst, T. (2014). Banana-coffee system cropping guide. *Africa Soil Health Consortium, Nairobi*.

Wang, N., Jassogne, L., van Asten, P., Mukasa, D., Wanyama, I., Kagezi, G. and Giller, K. (2015). Evaluating coffee yield gaps and important biotic, abiotic, and management factors limiting coffee production in Uganda. *European Journal of Agronomy*. **63**(1-11.

WOCAT (2014). www.fao.org/3/a-au294e.pdfFood and Agriculture Organization. Accessed on, April 4 , 2016.

Zhou, Y. (2010). Smallholder agriculture, sustainability and the Syngenta Foundation. Syngenta Foundation for Sustainable Agriculture: 1-15.

APPENDICES

Appendix 1: Households Generating Incomes and recall of coffee yields

Confirm name head of the household

1. Is the respondent head of household/family (exercises more power in binding family decisions more than any other member): If no, the questions below should refer to the head of household and yes if not respondent No (continue with question 2)

2. Name of the respondent:

2. Relationship to head of household? (Spouse, child, sibling, others specify)

3. What are your households' income generating activities and relative proportions?
(Distribute 10 points according to income generating activity)

i. Coffee
ii. Banana
iii. Maize
iv. Beans
v. Casual work
vi. Permanent Job
vii. Business
viii. Remittances
ix. Other crop
x. Other income (specify)

4. How much coffee did you harvest from the plot of interest in the last season (2014/15) in kg?

i. Total harvest in kg of parchment
ii. Total harvest in kg of fresh cherry
iii. Total harvest in kg of green bean

Appendix 2: Measurements of altitude, northing easting, shade cover and plant density

Record the plot altitude at the Centre of the farm and measure northing and easting of the corners of the whole farm

	Northing	Easting
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Plant density

- Count number of productive coffee trees
- Number of pre-productive coffee trees (young)
- Number of post-productive trees (old)
- Number of banana mats
- Number of banana stumps
- Number of shade trees by species
- Percentage of shade using densitometer

Appendix 3: Proportion (%) of incidence of pests and diseases across the altitude gradient

		Demonstration plot			Control plot		
Incidence	Altitude	Proportion			Proportion		
		Low	Medium	High	Low	medium	High
CBD	Absence	38.5	38.5	23.1	46.2	41.0	12.8
	Low	38.9	33.3	27.8	36.8	26.3	36.8
	Moderate	-	25.0	75.0		25.0	75.0
	Severe	-	20.0	80.0	-	16.7	16.7
CLR	Absence	50.0	37.5	12.5	53.9	23.1	23.1
	Low	33.3	26.7	40.0	40.0	30.0	30.0
	Moderate	26.7	20.0	53.3	40.0	33.3	26.7
	Severe	20.0	44.0	36.0	22.2	36.1	41.7
BES	Absence	33.3	33.3	33.3	38.9	38.9	22.2
	Low	30.4	26.1	43.5	41.7	25.0	33.3
	Moderate	25.0	37.5	37.5	13.3	26.7	60.0
	Severe	36.4	45.5	18.2	35.3	41.2	23.5
CBB	Absence	35.3	35.3	29.4	35.3	41.2	23.5
	Low	27.3	36.4	36.4	48.3	20.7	31.0
	Moderate	21.1	42.1	36.8	10.5	47.4	42.1
	Severe	46.2	15.4	38.5	33.3	22.2	44.4
WSB	Absence	32.1	39.3	28.6	26.7	43.3	30.0
	Low	31.4	28.6	40.0	38.7	25.8	35.5

		Demonstration plot			Control plot		
Incidence	Altitude	Proportion			Proportion		
	Moderate	-	40.0	60.0	33.3	22.2	44.4
	Severe	66.7	33.3	-	50.0	25.0	25.0
ANSTB	Absence	26.2	40.5	33.3	29.2	39.6	31.3
	Low	41.7	20.8	37.5	40.0	20.0	40.0
	Moderate	20.0	40.0	40.0	-	-	-
	Severe	-	-	-	100.0	-	-
RMB	Absence	32.7	30.9	36.4	30.6	34.7	34.7
	Low	33.3	33.3	33.3	36.4	27.3	36.4
	Moderate	-	-	100	50.00	50.0	-
	Severe	-	100.0	-	100.0	-	-
CBM	Absence	21.7	30.4	47.8	38.5	26.9	34.6
	Low	35.0	35.0	30.0	27.3	36.4	36.4
	Moderate	33.3	33.3	33.3	30.0	35.0	35.0
	Severe	38.5	38.5	23.1	50.0	33.3	16.7
GS	Absence	28.9	33.3	37.8	36.6	26.8	36.6
	Low	35.0	30.0	35.0	31.8	27.3	40.9
	Moderate	25.0	75.0	-	40.0	40.0	20.0
	Severe	50.0	-	50.0	16.7	83.3	-
CLM	Absence	66.7	16.7	16.7	80.0	20.0	-
	Low	33.3	33.3	33.3	20.0	50.0	30.0

		Demonstration plot			Control plot		
Incidence	Altitude	Proportion			Proportion		
	Moderate	43.8	37.5	18.8	21.4	35.7	42.9
	Severe	20.0	35.0	45.0	35.6	28.9	35.6
RSM	Absence	24.0	28.0	48.0	26.7	36.7	36.7
	Low	18.8	43.8	37.5	5.9	41.2	52.9
	Moderate	50.0	7.1	42.9	53.9	7.7	38.5
	Severe	37.5	56.3	6.3	64.3	35.7	-
CTP	Absence	30.5	35.6 (21)	33.9 (20)	36.5 (23)	31.8 (20)	31.8 (20)
	Low	27.3 (3)	27.3 (3)	45.5 (5)	10.0 (1)	40.0 (4)	50.0 (5)
	Moderate	100.0	-	-	100.0	-	-
	Severe	-	-	-	-	-	-
CAP	Absence	32.4	43.2	24.3	43.2	35.1	21.6
	Low	35.7	42.9	21.4	20.0	50.0	30.0
	Moderate	30.0	-	70.0	33.3	16.7	50.0
	Severe	20.0	20.0	60.0	20.0	26.7	53.3
LMB	Absence	28.9	35.6	35.6	29.6	31.8	38.6
	Low	31.6	31.6	36.8	38.1	23.8	23.8
	Moderate	50.0	-	50.0	50.0	50.0	-
	Severe	33.3	66.7	-	-	100.0	-

Appendix 4: Coffee yield, coffee age and perception to climate change and its effects related effects

A. Is the respondent head of household/family (exercises more power in binding family decisions more than any other member): If no, the questions below should refer to the head of household and yes if not respondent No (continue with question 2)

B. Name of the respondent:

C. Relationship to head of household? (Spouse, child, sibling, others specify)

1. How much coffee did you harvest from the plot of interest in the last season (2014/15) in kg?

i. Total harvest in kg of parchment
ii. Total harvest in kg of fresh cherry
iii. Total harvest in kg of green bean

2. Plant density and age

How many coffee trees does the plot of interest has currently?	A. Number of productive trees	Year planted
	B. Number of past-productive trees (old)	Year planted
	C. Number of pre-productive trees (younger than 2 years)	Year planted

3. Perception of Climate change

In the last year, which climate factor(s) affected your coffee yield?

i. Drought
ii. Excessive rain
iii. Frost
iv. Others

4. Which negative effects on coffee production did you observe? (Several answers possible)

i. Yield decline due to lack of water
ii. Yield decline due to more pests
iii. Yield decline due to more diseases
iv. Yield decline due to flowering abortion
v. Quality reduction due to reduced bean size
vi. Yield decline due to sediments
vii. Yield decline due to waterlogging
viii. Yield decline due to reduced flowering
ix. Soil erosion
x. Others, specify

5. What do you do in the case of drought to mitigate its effect on your coffee production?

6. What do you do in the case of excessive rain to mitigate its effect on your coffee production?

7. Have you ever thought about changing from coffee to other crops because of climate change

Yes No

Appendix 5: Observation of agriculture management practices

Indicate whether the following practices are applied on the plot (score 0 or 1)

A: Mulching Practice

0-Clean soil with no mulch at all

1-Either one of the following:

1. Partial or old mulch under the tree canopy

2. Farm fully mulched, under and between the trees

B: Weeding Practice

0-Either of the following:

1. Established weeds under the tree canopy 2. The whole farm was weeded by plowing.

1-Weeds are managed by:

1. Mulching, slashing, herbicides or cover crop (e.g. beans).

2. Weeding under the tree canopy by hand

C: Pruning Practice

1-All of the following 3 have been done:

1. Dead and unwanted branches removed,

2. Branches touching the ground removed and

3. Unwanted suckers removed

0-If any of the above has not been done

D: Replanting and Rejuvenation

0-No systematic (a defined pattern by the farmer) rejuvenation or replanting of coffee trees is seen on the farm, more than 90% of trees with 1-3 old main stems have 10 years or more)

1-Rejuvenation (that is stumping of trees) happened in the last few years, more than 10% of trees with 1-3 main stems have less than 10 years old And/or Replanted coffee trees (systematic planting of seedlings is seen and young trees of age 1 to 3 years old seen on the farm) using improved or traditional varieties And/or Rejuvenation not necessary since trees are younger than 15 years

E: Erosion Control

0-No erosion control method being used

1-At least 1 method of erosion control used: terraces, grasses, mulch, water traps, Physical barriers (e.g. Rocks) or the land is plain (no slope) and do not require any erosion control measures.

F: Shade Management

0-Shade trees covering less than 20% of the farm or heavy shade over more than 40% of the farm

1 Established shade trees covering at least 20-40% of the farm

All options apart from 20-40% should be coded as ‘0’

G: Composting

0-No compost heap (at any stage) around a farmer’s and no sign of compost having been applied

1- Compost heap with mixed materials present or compost applied to trees