AGROFORESTRY AS A RESILIENT STRATEGY TO CLIMATE CHANGE IN MWANGA DISTRICT, KILIMANJARO REGION, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN MANAGEMENT OF NATURAL RESOURCES FOR SUSTAINABLE AGRICULTURE OF SOKOINE UNIVERSITY OF AGRICULTURE, MOROGORO, TANZANIA.

2015

ABSTRACT

Agroforestry is a climate-smart production system that sustainably diversifies environmental and socio-economic benefits to subsistence farmers, and is therefore considered more resilient than monocropping to increased intensity of extreme weather events. This study was conducted to assess the potential of agroforestry (AF) in buffering smallholder farmers against climate variability and mitigating CO_2 emissions through carbon sequestration in Mwanga District, Kilimanjaro Region, Tanzania. Research methodologies used included literature review, questionnaire, and ecological survey. A sample of 54 plots with a size ranging from 0.04 Ha to one Ha and 103 households engaged in AF and non-AF were selected randomly from three villages for ecological study which involved an inventory of on farm trees and questionnaire survey for collecting socio-economic data respectively. SPSS computer program was used to analyse socio-economic data and allometric equations were used for estimation aboveground biomass and carbon. The diversity of benefits in AF practices such as food (59.2%), fodder (58.2%), selling livestock (71%), fruits (54.4%), timber (27.2%) and fuelwood (45.7%) increased farmer`s resilience during environmental extremes and climate variability. AF practitioners were richer than non practitioners with an extra income of TAS 988 042 (USD 618) annually. Furthermore, agroforestry systems (AFs) such as parklands, homegardens and woodlots stored substantial aboveground carbon stock (10.7 to 57.1 Mg C ha^{-1} with an average of 19.4 Mg C ha^{-1}), and the difference in carbon stock among AFs was statistically significant at $p<0.001$. Integration of crops and diversity in AFs were among the resilient features which reduced farmer's risk from total crop failure. Further increased income as a result of the diversity of products from the AFs enhanced the resilience of AF practitioners. Therefore, vigorous efforts are needed to provide knowledge on the AF products

value-addition innovation, promoting rich carbon land use, understanding and addressing competing claims on natural resources.

DECLARATION

I, Richard Lufunda Charles, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted in any other institution.

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The above declaration confirmed

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ACKNOWLEDGEMENTS

I wish to express my sincere thanks to my supervisors, Prof. P. K. T. Munishi (Department of Forest Biology) and Dr. E. F. Nzunda (of the Department of Forest Mensuration and Management) for their advice, tireless, constant and consistent comments, constructive criticisms, commitment, encouragement and patience which were wonderful, hence have led to successful completion of this study.

I would like to extend my gratitude to the Local Knowledge Climate Change and Adaptation Project (LKCCAP) for financial support and Misungwi District for granting permission to me to undertake this MSc. Programme.

My sincere thanks should go to Mwanga District Executive Director for allowing me to conduct the research in the district. Thanks also should go to Village Executive Officers, Village Chairmen, Extension Officers and the local communities for their participation and willingness during the interview and field survey. Prof. Tomas Smucker, Prof. Ben Wisner, Prof. Adolfo Mascarenhas and LKCCAP members are also acknowledged for their supportive and creative ideas contributed during my study.

I am indebted also to my wife Khadija and children Godlove, Irene and Beatrice. Their understanding, love, patience and prayers were a source of strength and inspiration, which enabled me to accomplish this academic endeavour. I thank my father, may the Lord God bless you all. AMEN.

DEDICATION

This dissertation is dedicated to my family for their tolerance for the whole period of the study.

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LIST OF ABBREVIATION AND SYMBOLS

AF	Agroforestry
AFs	Agroforestry Systems
AGB	Aboveground biomass
BA	Basal area
DBH	Diameter at breast height
FAO	Food and Agriculture Organization of the United Nations
GHGs	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
LKCCAP	Local Knowledge climate change and adaptation project
MDG	Millennium Development Goals
Mg	Megagramme (equivalent to one million grams or one tone)
NAPA	National Adaptation Programme of Action
NWFP	Non -wood forest products
REDD+	Reduced Emissions from Deforestation and Forest Degradation
SPSS	Statistical Package for Social Science computer programme

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Global warming, or the increase in temperature of the earth's near surface air and ocean in recent decades, is brought about primarily by the increase in atmospheric concentrations of greenhouse gases (GHGs) of which carbon dioxide is a major GHG (IPCC, 2007). According to its fourth assessment report, the Intergovernmental Panel on Climate Change (IPCC) emphasized that climate change is one of the most challenging problems presently facing humankind (IPCC, 2007). Poor agricultural practices including, shifting cultivation and extensive pastoralism are also among the major causes of deforestation, hence reducing carbon sinks. Long-term changes in the patterns of temperature and precipitation that are part of climate change are expected to shift production seasons, pest and disease patterns, and modify productive land and other resources, prices, incomes and ultimately, socio-economic activity (FAO, 2010).

Tropical agriculture is a human enterprise that is less resilient to climate change (Lin, 2011). Literature has shown that crop yield is very sensitive to changes in temperature, precipitation, especially during flowering and fruit development stages. Temperature fluctuations, as well as seasonal shifts, can have large effects on crop growth, production and quality (FAO, 2010). In order to stabilize output, ecosystem and income, production systems must become more resilient, i.e. more capable of performing well in the face of destructive events and perturbation (Eriksen and O`Brien, 2007; Roy *et al*., 2011). IPCC (2007) defines `resilience` as the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the ability to adapt to stress or change.

Agroforestry practices are an example of socio-ecological system that increases resilience and boosts carbon dioxide removals (Ulsrud *et al*., 2008; Zomer *et al*., 2009; Ajayi *et al*., 2011). They also protect crops and animals from extreme weather events such as heavy rains, drought and wind storms, in which high rainfall intensity and hurricane winds can cause land slide, flooding, premature fruit drop from crop plants (Nair, 2008; Smith, 2010; Berrang-Ford *et al*., 2011). According to Nair *et al*. (2009); Akinnifesi *et al*. (2010) and FAO (2010), the use of trees and shrubs in agricultural systems help to tackle the triple challenge of food security, mitigation and reducing vulnerability and increasing adaptive capacity of agricultural systems to climate changes. Trees on farm can increase farm incomes and serve to diversify production and thus spread risk against agricultural production or market failures.

Agroforestry is therefore important for both climate change mitigation as well as adaptation through reducing farmers` vulnerability, diversifying income sources and building the capacity of smallholders to adapt to climate change (FAO, 2010). The risk of losses from environmental hazards is spread among many species and varied land use practices (Lin, 2011). Smith (2010); Kabebew and Urgessa (2011) argued that AFs are more resilient and less risky than other agricultural options because of the effective and efficient use of natural resources for production. This includes soil fertility improvement and soil moisture retention through increasing soil organic matter and nitrogen-fixing by leguminous trees and shrubs. Second, they prevent erosion; stabilize soils, increase infiltration rates, and arrest land degradation through increasing soil cover, soil porosity and reducing runoff. Therefore, agroforestry is a promising area of interest for scientists, policy-makers and practitioners. However, efforts and strategies are needed for intensifying management and governance efforts to generate products and services in AFs, through integrating trees in agricultural landscapes, cultural landscapes, watersheds and adjacent natural forests in order to restore ecosystems (Smith, 2010; Angelsen *et al*., 2012).

1.2 Problem Statement and Justification

With increased climate variability, changes in temperature and precipitation patterns are likely to affect agricultural processes. Such effects include changes in nutrient cycling, production, type of crops and soil moisture, as well as health problems to both livestock and plants (Berrang-Ford *et al*., 2011; Lin, 2011; Nakashima *et al*., 2012).

Although adapting to changes in long-term averages may be feasible through technology and germplasm transfer, increased climate variability with concomitant increased frequencies of extreme events poses a greater challenge, particularly in the semi-arid tropics (IPCC, 2007). The existence of complex land tenure, land use conflict, environmental factors, trees and crops preferences, management and type of AFs which are shaped by the configuration of the Eastern Arc Mountains (North

Pare Mountains), river valleys, plateaux and the plains dipping into the Pangani Valley in Mwanga District (Sheridan, 2009), is adding another challenge that could have different socio-economic influence on AF practitioners in adapting to climate change and variability.

Furthermore, the suitability of different agroforestry products under changing climate and other biotic and abiotic stresses will be exceeded due to some adaptation practices or coping strategies like shifting cultivation, overgrazing and overstocking (Eriksen *et al*., 2008;Haggar *et al*., 2011; Rahman *et al*., 2011; Hewitt and Mehta, 2012).

Therefore, understanding the roles played by AF in supplying household needs would contribute to further understanding of the role played by AF in increasing farmers` resilience to climate variability and mitigating CO_2 in the study area. The finding of this study are expected to promote the recognition of the roles played by AFs; contribute to the achievement of the National Adaptation Programme of Action (NAPA), National Strategy for Reduced Emissions from Deforestation and Forest Degradation (REDD+), Millennium Development Goals (MDGs) and National Poverty Reduction by 2015 and 2025 respectively.

1.3 Objective

1.3.1 Overall objective

The overall objective of this study was to assess the potential role of agroforestry in buffering smallholder farmers against climate variability and mitigating CO_2 emission through C sequestration in Mwanga District, Tanzania.

1.3.2 Specific objectives

Specifically, the study sought to achieve the following specific objectives:

i. To determine tree species uses that enhance farmers resilience to climate variability;

ii. To analyse and compare various AF and non-AF products, production and practices that enhance farmer's resilience against changing climate;

iii. To determine the contribution of AF products to total annual households cash income;

iv. Examine the potential of tree components of AF in mitigating CO_2 emission.

1.3.3 Research questions

This study was guided by the following research questions:

a) What type of tree species that is preferred and tree species functions, uses and benefits that increase farmer's resilience to climate variability?

b) What roles do AF products, benefits and practices play to enhance farmer`s resilience to climate change and variability?

c) Are the products and benefits accrued from AF practitioners differing from those of non-AF practitioners?

d) Could the contribution of income accrued from AF and non-AF to the total annual households’ cash income differ among farmers of different attitudes?

e) Could the trees above- and belowground biomass and carbon stock of AF differ among AFs and from the lowlands to the highlands?

1.3.4 Conceptual framework

The conceptual framework for this study was based on the assumption that climate change and variability have direct impacts on crops, animal production and resource management due to fluctuations of temperature and precipitation. Consequently, the impacts were expected to compel farmers to develop coping strategies such as adopting AF or not adopting-AF. Coping and adaptation strategies or practices might enable farmers’ resilience to changing environmental conditions by supplying various products such as food, fodder, ecosystems goods and services throughout the year as shown in Fig. 1.

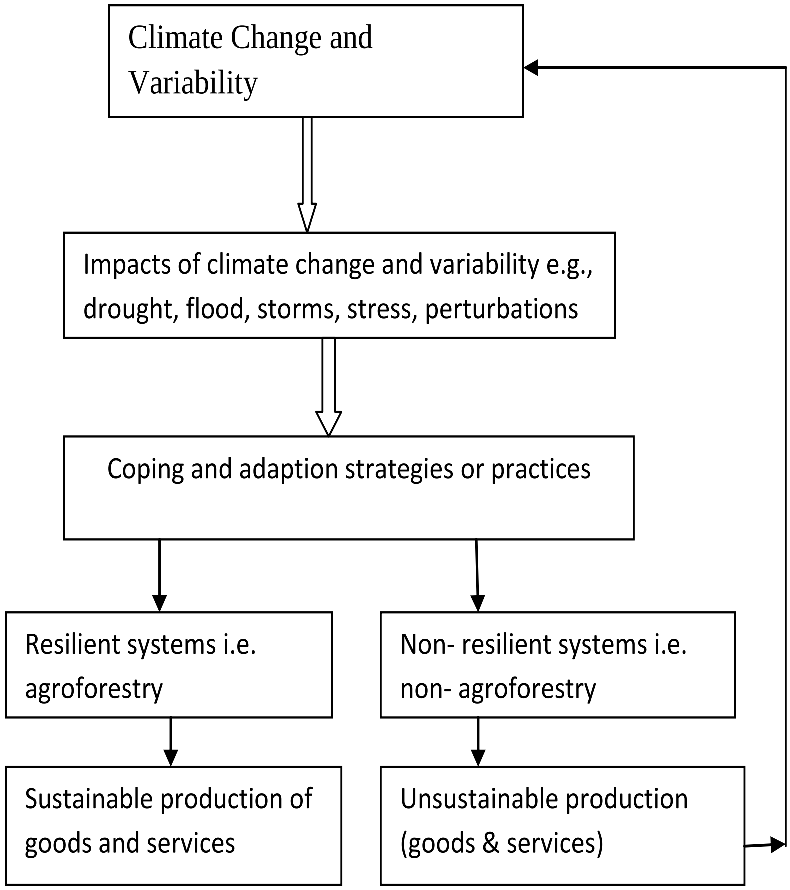

Figure 1: Conceptual framework showing AF as resilience to climate changes.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General Overview

Human activities have an increasing impact on the integrity of the complex natural ecosystems that provide essential support for human well-being and economic activities (Lin, 2011). The capacity of ecosystems to cope with disturbance like climate change is determined by the characteristics such as species genetic variability within the populations, species diversity within and among functional groups, variability and connectedness of habitats (Thomas *et al*., 2011; Nakashima *et al*., 2012).

In this dissertation, resilience is used in the context of climate change and variability, and for a system to be resilient, it must be able to continue to thrive and reproduce, and compete for space and resources in face of perturbation. According to Hughes *et al*. (2005); Lin (2011) and Thomas *et al*. (2011), resilience refers to the ability of a system to maintain key functions and processes in the face of stresses or pressures by resisting, adapting or mitigating change. Key forest ecosystem functions include: production (soil and nutrient management), ecological services (carbon sequestration), social services and protection functions (water-use efficiency, pest and disease control). In a resilient socio-ecological system, events such as disturbance can create opportunities for development and innovation. In a vulnerable socio-ecological system, even a small event may be devastating. Lundberg and Moberg (2003); Lin (2011) and Nakashima *et al*. (2012) reported that a system with high adaptive capacity have the ability to sustain the combined system of human and nature in a desirable state, along a desirable trajectory, in response to changing climate event.

In this dissertation agroforestry is used as resilient systems, and loss of resilience (non-resilience) implies that a small disturbance may be devastating or loss of resilience means vulnerability of AF structures and functions that are crucial for buffering disturbance, mitigating change and maintaining the capacity of AF to produce goods and services (FAO, 2010; Lin, 2011 and Roy *et al*., 2011). Thus, loss of resilience or increased vulnerability implies loss of opportunities for redevelopment.

2.2 Tree Products in Increasing Farmer's Resilience to Climate Variability

Several studies have proved the potential of trees in increasing resilience of subsistence farmers against environmental extremes by modifying temperatures, providing shade, shelter and by acting as alternative feed resources during periods of drought (Rao *et al*., 2007; Abebe *et al*., 2010). Trees can reduce surface runoff, increase infiltration and soil water holding capacity. Furthermore, AFs reduce the risk of flash flooding following periods of heavy rainfall, with the tree roots and trunks acting as permeable barriers to reduce sediment and debris loading into rivers following floods (Snelder *et al*., 2007; Zomer *et al*., 2009; Nair *et al*., 2009). In semi-arid climates, soil water content under tree canopies was reported to be higher than in open pasture due to reduced evapotranspiration under the tree shade out-weighing water uptake by plants (Smith, 2010).

A number of factors motivate farmers to plant trees, although the factors varied from site to site based on ecological and socio-economic circumstances (Kumar, 2006; Abebe *et al*., 2010; Moges, 2010; Fifanou *et al*., 2011). For example, in Ethiopia it has been reported that most common factors for planting *Eucalyptus* species are wood scarcity both for construction and fuel wood and thus the need to satisfy household subsistence demand and to generate income. Another important contribution of this tree has been security of tenure. For example, tree based systems have proved to be the most important guarantors for farmers who wanted to maintain ownership of their rural land while living in urban areas. For example, Bucagu *et al*. (2012) reported that farmers preferred *Grevellia robusta* due to its fast growing and being less competitive and may be grown with other crops, while *Eucalyptus* planting in Rwanda was preferred as collateral for loans.

However, trees preferences differ between individuals, groups, institutions, societies and cultures due to socio-economic need, management and environmental factors (Snelder *et al*., 2007; Abebe *et al*., 2010; Ajayi *et al*., 2011; de Souza *et al*., 2012; Bucagu *et al*., 2012). In Benin, tree density was directly related to the size of land holding and local perception of the species abundance in the wild. Small land holdings and inherited farm supported more tree species (Fifanou *et al*., 2011). Further tree preference and use played an important role in responding to climate change, both in terms of mitigation of GHGs emissions such as CO_2 sequestration and resilience to changing climate conditions.

Literature showed that while men focus on timber productivity, women often preferred trees with multiple uses because these trees offer more domestic and supplementary value such as fuel, fodder, fruits and shade (Djoudi and Brockhaus, 2011). This difference is relevant in managing AFs as resilience to climate change

(Ajayi *et al*., 2011). Women's activities are strongly interlinked with the services provided by local ecological systems. The reliance on natural resources increases women's ability to acquire and disseminate knowledge, information about ecosystems, sustainable practices and conservation techniques (Snelder *et al*., 2007).

2.3 Agroforestry Products that Increase Farmer's Resilience

Agroforestry systems enhance smallholder farmers resilience to climate variability by supporting them with the diversity of products or benefits: food (arable crops, vegetables, animal products, fruit, mushrooms, oils, nuts, and leaves), fuel (charcoal and fire wood) (Bucagu *et al*., 2012). Others include fodder and forage, fibre, timber (construction and furniture making), gums and resins, thatching and hedging materials (binders and stakes), gardening materials (pea sticks, beans poles, fencing, hurdles), medicinal products, craft products (natural dyes, floral arrangements) and ecological services (Ndayambanje and Mohren, 2011; de Souza *et al*., 2012).

Numerous and diverse AFs are found in the tropics partly because of their favourable climatic conditions and partly because of the socio-economic factors such as human-population pressure, multiple-benefits, smaller land-holding size, complex land tenure, and markets (Garrity, 2004; Nair *et al*., 2009; Fifanuo *et al*., 2011 and Roy *et al*., 2011). According to Kalaba *et al*. (2010); Smith (2010) and Folega *et al*. (2011), integrating trees into the agricultural landscape had potential to affect the local economy through increasing economic stability, diversification of local products and economies, diversification of rural skills, improving food and fuel security, improvements to the environment and landscape diversification.

Unlike the environmental emphasis of AFs in the tropics, economic studies of AFs have shown that financial benefits are the consequence of increasing diversity and productivity of the systems which are influenced by market and price fluctuations of timber, livestock and crops (Garrity, 2004; Smith, 2010; Singh and Pandey, 2011). Further, higher yield potentials of AF and product diversification increased the potential for economic profits by providing annual and periodic revenues from multiple outputs throughout the rotation and reducing the risks associated with farming single commodities (Rahman *et al*., 2011; Hewitt and Mehta, 2012). Agroforest practitioners were able to recoup initial costs more quickly due to the income generated from the AF component compared to conventional agricultural (Smith, 2010; Ajayi *et al*., 2011; Thorlakson, 2011). Tree products are also used on the farm for windbreak, fence posts, fodder or bio-energy and this substituted synthetic agricultural inputs and increased the 'eco-efficiency' of the farming system as discussed earlier (Sileshi *et al*., 2007 ; Ulsrud *et al*., 2008).

2.3.1 Agroforestry systems in moderating microclimate and animal welfare

Trees in AFs increase farmer`s resilience to climate variability by modifying microclimatic conditions including temperature, humidity and wind speed (Rao *et al*., 2007). A study from India revealed that during the monsoon season, the soil temperature just beneath the tree cover was lower by as much as 10°C to 16°C in the top soil zone and 4°C to 5°C at 30 cm depth when compared to open field conditions, thereby indicating better soil-thermal regime (Roy *et al*., 2011). While wind speed reduction prevented crop loss due to flower or fruits drop, the resultant decline in wind erosion effects had multiple benefits for crops including increased growth rate and quality, due to moisture management and soil protection (Smith, 2010; Roy *et al*., 2011).

Agroforestry systems are multifunctional in provisioning of services to animals like provision of shelter from rain, wind, shade, feed and fodder, cover from predators and a diversity of foraging resources. Farm animals such as chicken and ducks have forest-dwelling ancestors and therefore prefer to range in tree and thicket cover (Ulsrud *et al*., 2008; Smith, 2010). Ulsrud *et al*. (2008) argued that if livelihoods including feeding of animals, depend more on bushes and trees and less on grasses and annual grain crops, the risk of losses during floods and drought becomes less, because trees are more resilient to such weather than other plants.

2.3.2 Agroforestry in controlling pest and disease

Studies have reported reduced pest problems in AFs due to greater niche diversity and complexity than in monocultural systems. This is attributed to a number of mechanisms: Variable distribution of host plants makes it more difficult for pests to find the plants. A plant species which is highly attractive to pests, can act as a 'trap-crop', protecting nearby economically valuable species from herbivore attack (Pandey, 2007 and Smith, 2010). Singh and Pandey (2011) argued that plant species which is repellent to pest herbivores increased inter-specific competition between pest and non-pest species hence limits the spread of pests. In Philippines, root extract from *Leucaena leucocephala* as more effective against nematode eggs hatching and infestation. The performance of this root extract was comparable to that of chemically based nematicides (Adekunle and Akinlua, 2007; Adekunle and Aderogba, 2008). In addition, leaf extract or bulb extract from garlic (*Allium sativa*) and onion (*Allium alia*) were more effective against nematode (de Waele and Davide, 1998; Masamha *et al*., 2010).

2.3.3 Agroforestry in enhancing rain water use and soil fertility

Water is a scarce resource and the impact of climate change is expected to make the situation worse. Climate change has both direct and indirect impacts on water availability. The direct impacts include changes in precipitation pattern, while indirect ones are increase in losses through runoff and evapotranspiration (Roy *et al*., 2011). There are several mechanisms whereby AF may use available water more effectively than monoculture. First, agroforestry increase productivity of rain water by capturing large proportion of the annual rainfall by reducing runoff and by using water stored in deep layers. Secondly, changes in microclimate reduce the evaporative demand and make more water available for transpiration (Smith, 2010). Several studies revealed that rainfall interception is positively correlated with canopy cover (Roy *et al*., 2011), and the percentage of annual runoff and soil erosion is very low in AFs in comparison to non-AF. Thus, the presence of woody species in AFs improved farmers' resilience to climate variability.

Soil fertility is a limited resource and the impact of climate change is expected to make soil productivity worse due to nutrient mining from continuous cropping without adequate fertilization or fallowing the land (Ajayi *et al*., 2011). Agroforestry practices have attracted considerable attention as an attractive and sustainable pathway to improve soil fertility.

2.4 Income from Agroforestry in Increasing Farmer's Resilience

Integration of trees and shrubs with animals or annual crops production is an age old management system practiced by farmers to provide shade, steady supply of food and or income throughout the year, arrest degradation and maintain soil fertility and provide regular employment (Garrity, 2004; Smit and Wandel, 2006; Verchot *et al*., 2007; Rao *et al*., 2007; Lin, 2011). For instance, household income from intercropped rice field in Central India provided an illuminating economics and accounted for nearly 10% of the annual farm income-distributed uniformly throughout the year than in rice monoculture (Pandey, 2007). According to Maduka (2007), AF practitioners earned an extra income of US$ 760 in semi arid areas of Misungwi, Tanzania. The income obtained from AF in Kenya was lower. For example, lower Nyando farmers involved in AF project had an average income of between US$ 19 and137 (Thorlakson, 2011). In northeast India, an average net monetary benefit acquired from guava based AFs was US$ 448 and US$ 300 to Assam lemon based agrihorticultural AFs per hectare (Singh and Pandey, 2011). However, introduction of coffee varieties that are sun tolerant and low price of coffee from world market, shifting cultivation, higher demand of wood products and population pressure, favour canopy opening through cutting down tree or removal of coffee. This brought another challenges for enhancing subsistence farmers' resilience to climate change (Sheridan, 2009).

2.5 Agroforestry in Mitigating CO_2 Emission through C Sequestration

The great role of AF in relation to climate change resilience is perhaps in mitigating the emission of CO_2. With adequate management of trees in cultivated land and pasture, significant fraction of the atmospheric CO_2 could be captured and stored in biomass and in soils (Jose, 2009; Nair *et al*., 2009; Smith, 2010; Singh and Pandey, 2011; Nair, 2011). Albrecht and Kandji (2003) reported C sequestration of 12-228 Mg C ha^{-1} that could be removed from the atmosphere if AFs were implemented on a global scale in the tropics. Similarly, other literature revealed that tree component of agroforestry can be a significant sink of carbon in land devoted to agriculture (Roshetko *et al*., 2002; Kirby and Potvin, 2007; Rao *et al*., 2007; Yadava, 2010; Kumar, 2011; Wardah *et al*., 2011). It is estimated that an increase of one tonne of soil carbon of degraded cropland soils may increase crop yield by 20 to 40 kg ha^{-1} for wheat, 10 to 20 kg ha^{-1} for maize and 0.5 to 1 kg ha^{-1} for cowpeas. Therefore, better quantification of carbon stock is required with regard to the productivity of agricultural crops (Nair, 2008; Nair *et al*., 2009).

Montagnini and Nair (2004) and Verchort *et al*. (2007) reported that carbon stock potential of tropical AF ranged between 50 to 75 Mg C ha^{-1} in semiarid and 9 to 63 Mg C ha^{-1} in sub humid, humid and temperate areas. According to Montagnini and Nair (2004); Sileshi *et al*. (2007); Nair (2008); Singh and Pandey (2011), agroforestry can also have indirect effects on carbon sequestration when it helps to decrease pressure on natural forests which are the natural sinks of terrestrial carbon. Although pure forests sequester higher amounts of carbon per unit land area and contribute more to mitigate climate change, the opportunity cost in terms of food production of initiatives that take land out completely for forestation for many years may be high in some southern African countries that experience seasonal food deficit (Angelsen *et al*., 2012). However, there are trade-offs when considering smallholder farmers in countries where the average land holding per household is less than one hectare (Kalaba *et al*., 2010).

The aforementioned studies and several others indicated that tree based systems are important carbon sinks as reported by (Walsh *et al*., 2008; Nair 2011; Brakas and Aune 2011; Kimaro *et al*., 2011; Ajayi *et al*., 2011; Udawatta and Jose, 2011; Mosquera-Losada *et al*., 2011), even if variations of carbon stock in AFs depend upon several factors as described above. Sileshi *et al*. (2007); Adekunle and Akinlua (2007); Ulsrud *et al*. (2008); Adekunle and Aderogba (2008); Masamha *et al*. (2010); Smith (2010) reported the potential of AF to offset 5-360 t ha^{-1} of GHGs through energy substitution, up to 100 t ha^{-1} through material substitution, and 1-5 t ha^{-1} through reduction of fertilizer and pesticides inputs by increasing eco-efficiency. In the tropics, AF is estimated to regain 35% of original carbon stock of the cleared forest compared to only 12% by crop land and pasture through restoring degraded croplands and pastures consequently storing C in the soil (Kumar, 2006 ; Nair, 2008). It also improves land cover in agricultural fields through providing C inputs (root biomass, manure deposit, litter and pruning) to the soil (Ajayi *et al*., 2011; Udawatta and Jose, 2011). This has often reduced soil erosion, which is a cardinal process in the soil C dynamics (Albrecht and Kandji, 2003; Sileshi *et al*., 2007 Folega *et al*., 2011).

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Study Area Description and Geographical Location

The study was conducted in Mwanga District (37°25′-37°58′ E; 3°25′-3°55′ S), one of the seven districts council of Kilimanjaro Region, Tanzania. The district covers a total area of 2641 km^2, including 2,558.6 km^2 of land area and 82.4 km^2 area covered by water. The district has the semi-arid zone (lowlands) in the east and west with an altitude between 550-700 meters above sea level. The highlands have an altitude that ranges from 700-2500 meters above sea level with homegardens as main agroforestry systems. Population density as per year ,2012 Population and Households Census was 142,990 (69,175 Male and 73,815 Female), with an average annual growth rate of 1.2 %

Climatic condition

Rainfall patterns in the district is bimodal and unreliable, mean annual rainfall range between 400- 600 mm per in the lowland and between 800-1250 mm in the highlands. There are two distinct rainy seasons, short rains from October to December and long rains from March to June. The highlands enjoy both short and long rainy seasons. The district also experiences strong and dry winds blowing normally from the East to the West. Temperatures range between 14°C during June-July and 32°C, usually in January.

Land use and socio-economic activities

The main land use in the lowlands is pastoralism and simple agroforestry systems (Parklands).Vegetation cover includes shrubs of *Acacia* in both the eastern and western lowlands and rain forest reserve (7,806Ha) around the Eastern Arc Mountain, in the highlands. Rain-fed agriculture, including coffee production, maize, paddy, legumes, banana, fruits, agroforestry and livestock production are the main socio-economic activities practiced in highlands and lowlands, whilst the lowland or semi-arid areas depend almost entirely on irrigation systems. Large herds of cattle, goats and sheep are kept in both Western and Eastern lowlands. The District estimated that there were 51,010 cattle out of which 12,260 are improved breed, 6,449 goats out which 410 are improved bread, 22,240 sheep and 98,726 poultry. However the district is characterized by land degradation, unreliable rainfall, repeated water shortages, periodic famine, overgrazing, dry land cultivation in the marginal areas and heavy competition for limited biomass between farmers and cattle.

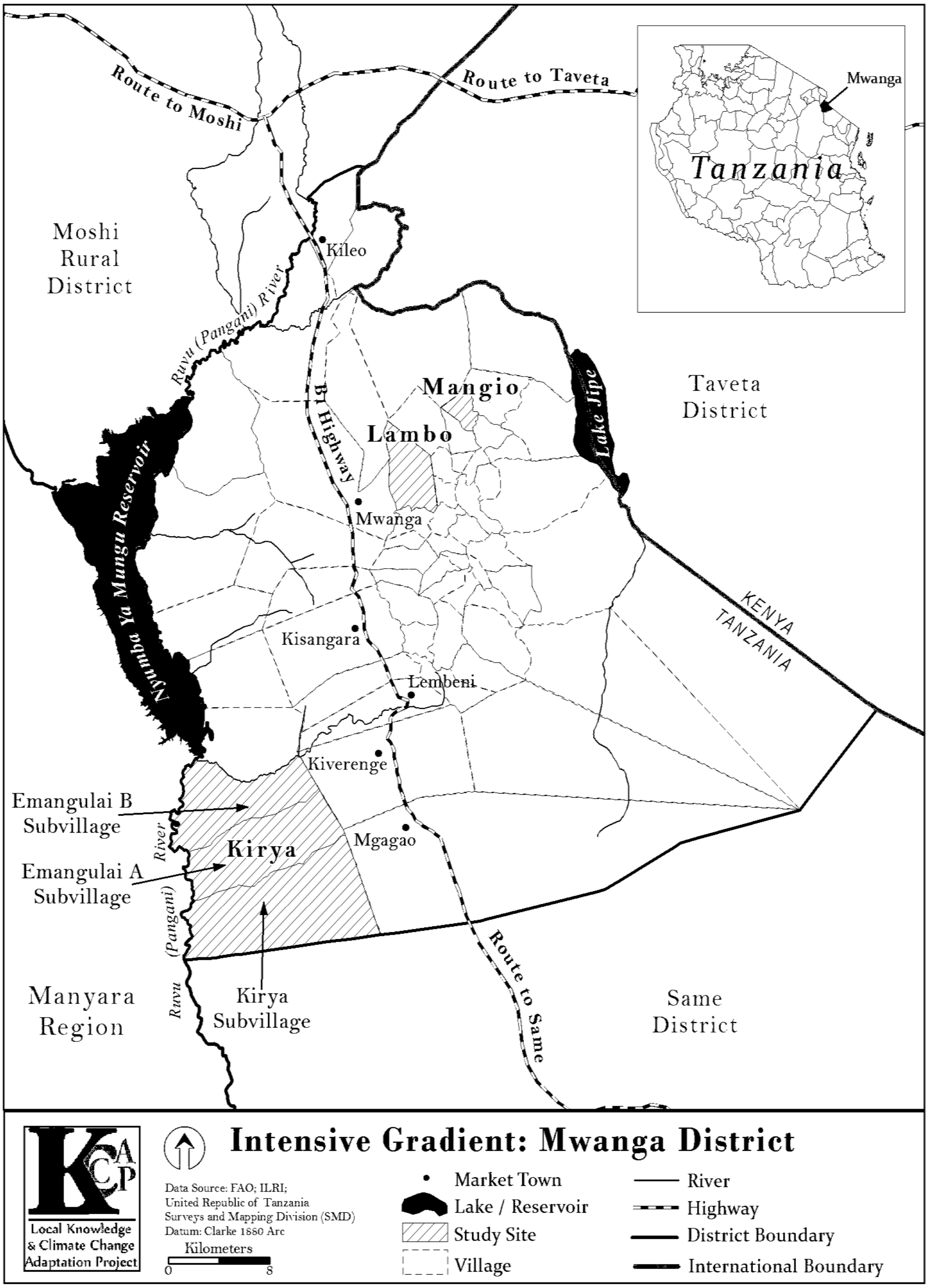

Figure 2: Map of Mwanga District, Kilimanjaro Region (LKCCAP, 2012)

3.2 Data Collection Methods

3.2.1 Research design

Prior to the main survey, villages under the study were visited for self introduction to the village leaders and to be acquainted with the villages` environment. A multi-stage sampling technique was used, in which three wards (Mwaniko, Shighatini and Kirya) in the district were purposively selected. From each of the wards, one village were selected purposively (Mangio, Lambo and Kirya) based on altitudinal range (Fig. 2). The sampling units of the study included households that were selected randomly based on AF and non-AF participation. According to Mbeyale (2007), a sample size of at least 30 units (households) is sufficient irrespective of population size. Based on the randomly sampling process, a total of 103 households (93 AF practitioners and 10 non-AF practitioners) were interviewed.

3.2.2 Socio-economic data collection

Questionnaire surveys and transect walk

In order to solicit socio-economic information, a household survey was undertaken using a structured questionnaire that included both open ended and closed questions underlying AF and non-AF practices i.e. existing household size, practices, land size, number of planted trees, species name and use, AF products, income from AF and non-AF and factors hindering the sustainability of AF (Appendices 1 and 2). In addition, focused group discussion, involving 10 key informants were conducted. The key informants included representatives from each village and district who were familiar with the village and knew well the district historical background. In order to get an overview of the adoption trend, production, market potential and sustainability of AF practices, a checklist was used (Appendix 3).

3.2.3 Ecological survey

Sampling design and plot shape and size

The District was stratified based on administrative areas. Three villages were selected purposively based on altitudinal range (Low altitude, medium altitude and high altitude) characterized by semi-arid, semi-humid and humid climatic conditions respectively. A total of fifty-four (54) agroforestry plots were randomly selected to cover as much variation in tree species diversity as possible. At least five sample plots were established in each AF. A rectangular plot, with a size of 0.04 ha for *Eucalyptus* woodlots and 0.125ha (10 m ×125 m) or 1 ha for home garden and parkland systems were adopted (MacDicken, 1997), in order to collect ecological information such as tree diameter, tree species name, abundance and stocking. Whenever a plot size for homegarden and parkland was smaller than a hectare, the whole farm was considered to be a sample plot. One sample plot was established in each selected AF field.

Ecological data collection

An inventory form (Appendix 4) was used to capture field information such as tree species names, tree species abundance and tree diameter at the breast height (DBH) ≥5cm, in each plot. In total, 777 individual trees were measured from 54 AF sample plots.

3.2.4 Secondary data

Secondary data collection was done through literature search from previous studies, , books, journals, websites, and reports from the study area, including reports on weather and demographic data. Collection of secondary data was also done by contacting different District officers.

3.3 Data Analysis

3.3.1 Ecological data analysis

All trees DBH ≥5cm in each plot were coded and converted into aboveground biomass (AGB), using general allometric equations (equations 1 and 2), developed based on climatic conditions (Brown, 1997) and the results expressed as tons (Mg) per hectare. Belowground biomass (root) was estimated by multiplying ABG by 0.3. The total biomass was estimated as the sum of AGB and belowground biomass. On the other hand, the total carbon was estimated assuming that the carbon content of total biomass is 50% (MacDicken, 1997), and summed by plot. Results were then scaled Mg C $plot^{-1}$ to Mg C ha^{-1}.

Allometric equation used

Dry (<900mm) $Y = \exp\{-1.996 + 2.32 \ln(D)\}$ $R^2 = 0.89$ (Eq.1)

Moist (1500-4000mm) $Y = \exp\{-2.134 + 2.530 \ln(D)\}$ $R^2 = 0.97$ (Eq.2)

Where: Y = Aboveground biomass (Kg) and D = diameter at breast height (1.3 m).

The use of this general equations rather species specific equations was deemed acceptable for the purpose of this study (Eq. 1 was used in estimating carbon in lowlands and Eq. 2 was used to estimate carbon in highlands), since reliable allometric equations for most of the species do not currently exist and the objective was merely to estimate the likely biomass storage and carbon sequestration where (1 C= 3.67 CO_2). One way Analysis of Variance (ANOVA) was used to test the quality of the means. Since the tests indicated significant difference among land-use types, means were contrasted with “Post hoc Scheffe tests”. Basal area (BA) of individual tree were calculated using Eq. 3 below, also were used to estimate the degree of stem crowding in a stand or stand density. The following formula was used to calculate basal area:

$$BA = \pi \times DBH^2/4 \qquad \text{(Eq. 3)}$$

3.3.2 Socio-economic data analysis

The qualitative and quantitative data were analysed using computer software, Statistical Package for Social Sciences (SPSS 16), in which frequency tables and charts of tree preference, tree uses, AF products, carbon stock and tree species abundance were obtained upon interpretation of the results.

Linear regression analysis

By using SPSS, inferential analysis was also carried out to predict whether or not the dependent and independent variable was significantly related using linear regression model.

(i) The linear regression model and hypothesis tested

Defining the dependent and independent variables was important for developing the linear regression and hypothesis testing. The dependent and independent variables were defined as follows:

(ii) The dependent variable

THHI=The annual total Household income. This was termed the dependent variable because it was hypothesized to be influenced by coping strategies. The more household will have higher income (economic position) enhance resilience to perturbation and other related stress.

(iii) The independent variables (Coping strategy or practices) were taken to be

VCI= Species or type of crops integrated. This was termed independent variable because it was hypothesized that the more type or species of crops planted on farm, the more they could avoid total loss hence spend for household use and sell hence contribute to total income.

NTB= Number of tree uses/ benefits. This was termed independent variable because it was hypothesized that the more benefits obtained on farm, the more they could avoid total loss hence spend for household use and sell hence contribute total income.

NLP= Number of livestock products/benefits. This was termed independent variable because it was hypothesized that the more products/benefits obtained from livestock, the more they could use for household needs and sell hence contribute total income.

IGI=Irrigation intervention. This was termed independent variable because it was hypothesized that irrigation practices on farm could increase productivity. Hence household become food secure and possibility of increasing income through selling extra crops is also high.

(iv) The hypothesis tested was

HO: THHI $\neq$ f (VCI, NLP, NTB, IGI)

Implying that the regression coefficient β_1-β_4 = 0

HI: THHI=f (VCI, NLP, NTB, IGI)

Implying that the regression coefficient β_1-$\beta_4 \neq 0$

Using a two tailed t-test at 0.05 probability level of significant, Null hypothesis would only to be rejected when $P < 0.05$.

Multiple linear regressions were constructed to show the relationship between the dependent and independent variables. These dependent and independent variables are denoted by `X` and `Y` respectively.

A multiple Linear Regression Model was described as

$Y_1=\beta_0+\beta_1X_1 +\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_nX_k +E_i$

Where Y_1= Dependent variable in this case THHI

β_0 = Constant/ Y- intercept

β_1 - β_n = Regression coefficients

X_1-X_n = these are independent variables

E_i = error/ residual term

When a model is used in hypothesis testing, inference is made from the regression coefficients (β_1 - β_n). To assess the goodness or fit of the linear relationship in the multiple linear regression, coefficient of determination (R^2) is used, the higher the R^2 the better the model in terms of independent variables accurately influencing the dependent variables.

(v) Test for multicollinearity

Before testing the above model, multicollinearity between the independent variables was tested. Multicollinearity typically occurs when two or more variables measure essentially the same thing. It is best to remove excess variables to eliminate multicollinearity. Multicollinearity was identified using a tolerant measure. In this test, the tolerant values lie between zero and one. The value close to zero indicates that a variable is almost in linear combination of the other independent values and that if the value is included in the model, it will have no significant impact and its standard error will tend to be large. Therefore, the acceptable tolerant value for independent variable that is acceptable in the linear regression model should be above 0.4.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the findings of the study. The first part gives the socio - economic characteristics of the sample population that include age, sex, marital status, education, land size and occupation. The second part presents tree species preferences and use as resilience to climate variability, while the third part compares information on AF and non-AF products and production in increasing farmer's resilience to climate variability. The fourth part presents annual income from AF and its role in improving household resilience to climate variability. The last part provides information on the role of tree component of AF in Co_2 sequestration.

4.1 Social-economic Characteristics of the Respondents

Farmers' willingness to grow trees on their farms was reported to be a function of their sociological, cultural and economical characteristics. At household level, human capital was a function of knowledge, health, the quality and quantity of available labour and relevant skills.

4.1.1 Age group, gender and marital status of the respondents

Table 1 summarizes the socio-economic information on age, gender and marital status of the respondents. Among the 103 farmers who were interviewed, the middle age class seemed to be dominant. This was made up of respondents whose age ranged from 18-39 and 40-59 years, representing 22.3% and 72.8% of the sampled population, respectively. The old people above 60 years comprised 4.9% of the sampled population. The results showed that about 75% of AF practitioners were old people, which is a challenge for sustainable development. The survey also found that 76.7% and 23.3% of the household heads were males and female respectively and those who were married constituted 98% of the respondents, as shown in Table 1.

Table 1: Comparison of Age group, gender and marital status of respondents

Characteristics	Variables	Frequency	Percentage
Age groups	18-39 years	23	22.3
	40-59 years	75	72.8
	60 and above	5	4.9
Sex	Male	79	76.7
	Female	24	23.3
Marital status	Married	100	97.1
	Single	3	2.9

4.1.2 Respondents education levels and occupation

The survey also revealed that 53.7% of the population had at least acquired primary education, implying that the farmers were capable of accessing useful skills through reading, listening and witnessing. The occupation status of the respondents in the study area revealed that 90.4% of the respondents practiced AF as the main economic activity.

4.1.3 Households size, farm sizes and land acquisition

The results revealed that the average households` size was six persons, with a range of 4 to 6 persons (87.4%) as shown in Table 2. The results also revealed that 86.4% of the respondents owned land of the size between 0.4-1.2 hectares. While 3.9% owned less than 0.4 hectare, 7.8% owned 1.6-2 hectares and 1.9% owned 2 hectares and above. On the other hand, the land tenure system and management regime was an important factor which determined the farmers' choice to plant trees (Table 2). In the case of home gardens of Pare Mountains, farmers cultivated various kinds of crops such as horticultural crops, cereal crops, trees, spices and root crops. With regards to land acquisition, it was revealed that 58.3% of the respondents acquired land through inheritance, whereby 31.1% of the respondents were given by Village Governments, and 1.9% bought the land from others and 8.7% of respondents hired the land from others, as indicated in Table 2. According to customary land tenure, it was revealed that home gardens belonged to respective clans in Pare Mountains. When a man from a given clan becomes independent from his parents, the father allocates a portion of home garden to her/him and the allocated land is not supposed to be sold.

Table 2: Comparison of household size, land size and Land acquisition

Characteristic	Variable	Frequency	Percentage
Household size	1-3 persons	4	3.9
	4-6 persons	90	87.4
	7 and above persons	9	8.7
Land size	Less than 0.4 hectare	4	3.9
	0.4 - 1.2 hectares	89	86.4
	1.2 - 2 hectares	8	7.8
	Above 2 hectares	2	1.9
Land ownership	Inherited	60	58.3
	Given by Government	32	31.1
	Bought	2	1.9
	Lend	9	8.7

4.2 Tree Species Uses and Functions that Enhance Farmer's Resilience

In the study area, AF practices involved agrosilviculture (growing trees with crops), agrosilvopastoral (growing trees with pastures), agrohorticultural (growing tree with vegetables), shifting cultivation, parklands (scattered trees on agricultural farms) and homegardens (management of trees, crops and animals). These were the main forms of traditional AFs. The most frequent method of growing trees (except exotic trees and coconut) was through deliberate retention and management of naturally regenerating tree seedlings. The respondents were able to speculate about types of tree species that are resilient to climate variability (Figure 3). The results also revealed that most of the trees regenerated naturally. For example, *Cordia africana*, *Croton macrostachyus*, *Markhamia* species,*Acacia species* and *Albizia schimperana. Eucalyptus saligna* was reported among the tree species with higher return and low cost of management due to its sprouting and coppicing characteristics. *Eucalyptus* species were grown along steep slopes, infertile land and away from water sources and were also reported to take 5-6 years to be due to their products such as poles and firewood.

However, farmers' willingness to grow trees on their farms was a function of their institutions, rules, management regime, socio-economic, environmental and cultural factors. For example, farmers ignored trees that reduce adaptability of other arable crops such as *Cedrella odorata* and *Acrocarpus fraxinifolius*. Farmers' perceptions correlated with positive outcomes of tree planting (Table 3). For example, farmers preferred to plant trees on their farms as capital for future generations and security of land.

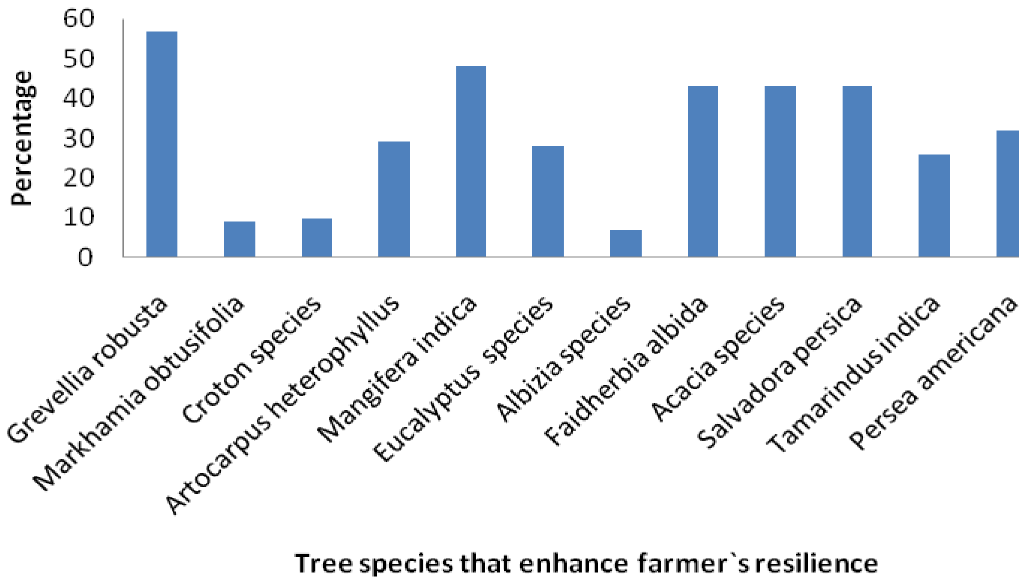

Figure 3: Tree species that enhance farmer`s resilient to climate variability.

This study revealed that most of the trees in AF were used for fuel wood, timber and poles. Other tree products and functions included, fodder, shade, windbreak, fruits, shelter, soil improvement and supporting climbing crops (Table 3). *Acacia* species was reported to be a source of fodder for livestock. In addition, it was observed that pastoralists retained *Acacia species*, *Balanites aegyptiaca*, *Salvadora persica* and *Faidherbia albida* near cattle sheds or homesteads in order to provide shelter from rain and wind, shade from the sun and cover from predators.

These trees were also retained to protect new born lambs, injured, old or sick animals. It was observed that tree planting/retention was a function of gender. For example, females preferred multipurpose trees for resilience to climate variability. The most important reasons were tree products contribution to food, fruits, and shade during farm activities, fuel wood, soil fertility improvement and fodder. These trees included *Faidherbia albida*, *Cordia africana*, *Markhamia obtusifolia* and *Persea americana*, while males preferred trees that provide construction material and income.

The results showed that most tree species in the study area were useful for fuel wood, hence protecting natural forests e.g. the Eastern Arc Mountains from overexploitation. However, not all AF satisfied firewood for household, hence most of the respondents reported that they bought firewood from farmers with *Eucalyptus* species woodlots in order to satisfy their household needs. They paid an average of TAS 10 000 (6.3US$) per cubic meter and normally a household of six people in the study area used an average of 6 m^3 per year.

Table 3: List of AF trees species, uses and functions that enhance resilience to climate variability

Species name	Uses/Functions
Grevellia robusta	Timber, shade, firewood, add organic matter
Cordia africana	Timber, shade, firewood, soil improvement, fodder
Tamarindus indica	Timber, Fruits, firewood, add organic matter
Syzigium cordatum	Timber, fruits, firewood, add organic matter, shade
Balanites aegyptica	Timber, firewood, organic matter
Markhamia obtusifolia	Firewood, Fodder, soil improvement, shade
Croton macrostachyus	Firewood, Fodder, add organic matter, shade
Kigelia africana	Fruits, shade, organic matter
Eucalyptus saligna	Poles, firewood, wind break, erosion control
Acacia species	Firewood, Fodder, Nitrogen fixation, shade
Salvadora persica	Firewood, Fodder, soil improvement, shade
Cordia sinensis	Firewood, organic matter, shade
Ficus species	Firewood, shade, windbreak, control soil erosion
Albizia schimperana	Timber, firewood, nitrogen fixation, fodder
Faidherbia albida	Firewood, nitrogen fixation, fodder, shade
Commiphora eminii	Firewood, fodder, shade, organic matter, support climber
Artocarpus heterophyllus	Fruits, shade, control soil erosion
Persea americana	Fruits, Firewood, shade, soil improvement
Mangifera indica	Fruit, erosion control, windbreak, firewood
Anona muricata	Fruits, shade, live fence
Anona squamosa	Fruit, shade
Croton megalocarpus	Firewood, shade, organic matter, control soil erosion
Syzigium guineense	Timber, firewood, shade, soil improvement
Azadirachta indica	Firewood, shade, windbreak, control soil erosion
Psidium guajava	fruits, support climbers, firewood
Cocos nucifera	Fruits, windbreak
Rauvolfa caffra	Shade

4.3 Agroforestry Products and Practices that Increase Farmer's Resilience

This study revealed that livestock products included organic manure, meat and milk. Nevertheless, some respondents claimed that cattle manure have the best effect on banana, coffee and maize growth. Farmers placed first priority on manure rather than meat or milk in the highland areas. One respondent claimed to use sheep dung (fresh) in controlling banana nematodes. From the household interviews, 33% of the respondents depended on Desmodium (*Desmodium species)* and elephant grass

(*Pennisetum purpureum*) to feed their livestock, 25.2% depended on elephant grass only; and 22.3% depended on shrubs. Furthermore, AF farmers were more resilient than non-AF farmer`s because they acquired additional money through selling poles and fuel wood and also saved time that could be used for searching for fuel wood and fodder.

Cardamom and sunflower were among the new cash crops found to be grown in the highland replacing coffee. Respondents reported to prefer *Elettaria cardamomum* (Cardamom) because of its good price. It was revealed that the price of one kilogram ranged between TAS 14 000 to 25 000, and a stem of Cardamom could produce between 0.25kg to 3kg per season depending on management practices. The household surveys revealed that majority of the respondents were not engaged in coffee production as a cash crop. The most important reasons given included drought, low price for the past decade, labour and unavailability of agricultural subsidies. Furthermore, other respondents cultivated horticultural crops such as tomato, pepper, watermelon and sweet melon due to their contribution to household income and availability of irrigation infrastructures as indicated in Table 4. Further this study reported 59.2% of the respondents to depend on root crops such as yams, cassava and sweet potato as their main source of food during drought in the highlands compared to less adapted cereal crops and banana.

Farmers were interviewed to identify their coping strategies during 2008 drought and 1997 floods. Results revealed that the first strategy involved was selling their livestock as reported by 71.8% of the respondents in order to meet their basic needs, 54.4% of the respondents reported to depend on AF products such as fruits and 27.2% of the respondents reported to depend on selling wood products such as timber and 45.7% selling fuel wood. Another coping strategy in the highlands and lowland was brick making and charcoal making as reported by 3.9% and 31.1%, respectively. In general, the role of AF products as a resilient strategy during the time of crops loss were higher compared to other sources of income and food such as fishing which was 9.7% in the lowland, labour work was 56.3%, remittances was 11.7% and food for work was 21.4%.

Table 4: Agroforestry products: food, spice, horticultural and cash crops

Crop type	Respondent	Frequency	Percentage
Cash crops	Not involved	65	63.1
	Coffee	26	25.2
	Paddy	12	11.7
Food crops	Banana	30	29.1
	Maize	73	70.9
	Paddy	16	15.5
	Yams	16	15.5
	Cassava	32	31.1
	Not involved	39	37.9
Spice crops	Not involved	78	75.7
	Cardamom	25	24.3
Horticultural crops	Not involved	39	37.9
	Sweet melon	6	5.8
	Tomato	27	26.2
	Pepper	25	24.3
	Water melon	6	5.8

The Data is from multiple responses

The household surveys revealed that 98% of households were involved in livestock keeping. Among the animals frequently kept included goats *(Capra hircus)*, indigenous/local chicken *(Gallus domesticus)*, cattle *(Bos indicus)*, sheep *(Ovis aries)* and donkey *(Equus asinus)*. Goats were reported to be preferred by 60.2% because of their drought endurance followed by indigenous/local chicken by 39.8%. Respondents argued that browsing behaviour enabled goats' survival during shortage of grasses as compared to cattle and sheep, which are grazers. However, most respondents reported to be less interested with hybrid breed cows because of their susceptibility to diseases and pests. Being a heavy feeder, labour intensive and fodder selective were among reasons that discouraged farmers to keep hybrid cattle. However, the majority of the sampled households failed to reveal admit the number of livestock they owned. One respondent claimed that they hide this information in order to avoid tax put by government.

4.3.2 Correlation of practices/ coping strategies that enhance farmers resilience

The following multiple linear regression equation was developed:

THHI= -845700.9 + 1.9 IGI + 165919.9 NTB + 31575.5VCI- 317554.7NLP

R^2=0.52 implied that independent variables were able to explain about 52% variation in dependent variable. The remaining 48% variations were due to other variables than identified ones. Further, the model revealed that small and medium scale irrigation intervention (IGI) was statistically significant at $p< 0.001$ and positively correlated with the total income (Table 5). The type of species or crops integrated (VCI) and number of tree benefits (NTB) were not significant but positive, indicating positive influence to the total households income. It implied the increase of VCI and NTB at one unit will influence total households income increase with the magnitude explained by their respective coefficients when other factors were held constant. On other hand livestock product (NLP) was statistically significant at $p<0.01$ but influenced the total household's income negatively. This implies that increasing this variable at one unit will decrease total households income (resilience) as indicated with magnitudes of its coefficient.

Table 5: Regression model

Model	Unstandardized Coefficients		Standardized Coefficient		$R^2=51.6$
	B	Std.error	Beta (β)	t	Sig.
Constant	-845700.9	1.2		-0.699	0.487ns
IGI	1.9	219162.7	0.74	8.951	0.000***
NTB	165919.9	261537.7	0.052	0.634	0.527ns
VCI	31575.5	135204.5	0.021	0.234	0.816ns
NLP	-317554.7	109212.4	-0.234	-2.908	0.005**

Not significant (ns) at P<0.05; Significant at **=P<0.01 *** =P< 0.001

From the regression equation, the null hypothesis that, THHI ≠ f (VCI, NLP, NTB, IGI) was rejected in favour of alternative hypothesis that, THHI = f (VCI, NLP, NTB, IGI) because none of the coefficient in the equations was equal to zero. These imply that these factors were important in explaining the household's resilience (income).

4.4 Income from Agroforestry as Farmer's Resilience to Climate Variability

Agroforestry practices were reported to improve household income through sale of timber, firewood, poles, fruits and non-wood products. Farmers were interviewed on the amount of cash they could earn through sale of AF products. Comparable average of income and percentages of contribution for each product both AF and non AF practitioners are summarized in Table 6.

Results from this survey indicated that 93 (90.2%) of the surveyed AF participants in Mwanga District on average had extra income than 10 (9.8%) of the surveyed non-AF participants of TAS 988 042.3 (US$ 617.5) annually. The contributions of each item to total cash household income or village are shown in Tables 6 and 7. The survey further revealed that, in the lowland (Kirya village), AF practitioners earn an average income of TAS 1 342 663.60 (US$ 839.2) annually, which was higher than in the highland (Table 7).

Table 6: Income generated from AF and non AF (1 US$=1600TAS)

Products	Minimum	Maximum	Average	Percentage
AF income in (TAS)				
Selling tree for Timber	100000	200000	150000	1.7
Fruits from tree	30000	200000	90483.3	1.0
Coffee	35000	84000	59500	0.7
Banana	105000	2100000	731484	8.3
Rice	450000	2070000	1130625	12.8
Maize	30000	6000000	985714	11.2
Spice(Cardamom)	60000	300000	154772	1.8
Milk	146000	2920000	382176	4.3
Tomato	1000000	3200000	2145833	24.4
Sweet melon	1600000	4400000	2980000	33.8
Sum	**3556000**	**21474000**	**8810587.3**	
Non AF participant income (TAS)				
Maize	900000	4080000	1914545	24.5
Rice	1080000	1710000	1404000	17.9
Tomato	2300000	3200000	2840000	36.3
Sweet melon	1040000	2400000	1664000	21.3
Sum	**5320000**	**11390000**	**7822545**	

Table 7: Cash income of agroforestry and non-agroforestry from three villages

Village	Minimum	Maximum	Average	St.Dev	Sum	N
AF income (TAS)						
Mangio	635000	3002000	1465866.7	607981.7	43976000	30
Lambo	616000	1192000	943173.3	153132.8	28295200	30
Kirya	1190000	5810000	3072969.7	1342663.6	101408000	33
Non AF income (TAS)						
Mangio	0	0	0	0	0	0
Lambo	0	0	0	0	0	0
Kirya	2520000	4700000	3185000	760471.3	31850000	10

Village	Minimum	Maximum	Average	St.Dev	Sum
AF income (TAS)					
Mangio	635000	3002000	1465867	607981.7	43976000
Lambo	616000	1192000	943173	153132.8	28295200
Kirya	1190000	5810000	3072970	1342663.6	101408000
Non AF income					
Mangio	-	-	-	-	-
Lambo	-	-	-	-	-
Kirya	2520000	4700000	3185000	760471.3	31850000

Crops grown in the study area included paddy, maize and horticultural crops which fetched high price. Arable crops contributed 92.9% for AF household incomes while livestock products (milk) contributed 4.3% for AF household income. Nevertheless, no attempts in this study were made to quantify the amount of income contributed by selling livestock. Since most people were not willing to admit the number of livestock they have, hence it will be meaningless to try to quantify the income generated from selling their livestock.

Furthermore, AFs in the study areas faced different challenges such as uncontrolled grazing, poor institution arrangement, and shifting cultivation in the lowland. This implies that land is still open access to most of farmers and pastoralists. Others were increased surface temperature, changes in rainfall pattern, fluctuation of river flows, land degradation and drought. This study showed that 76.7% of the respondents reported drought to affect soil moisture and water sources and 23.4% of the respondents reported increases in surface or soil temperature. In addition, the impact of drought was reported to increase pests and diseases in crops as reported by 64.1% of the respondents. Further 20.4% of the respondents reported the impact of drought in reducing crops yield and weight, while 15.5% of the respondents reported drought to cause wilting of the crops. Other impacts of drought were reported by livestock keepers; 65% reported drought to cause shortage of fodder and water; 11.7% reported drought to increase livestocks vulnerability to pests and diseases, while 4.9% reported loss of body weight due to drought. All farmers interviewed reported root-knot nematodes (*Meloidogyne species*) and mites to affect banana, coffee and horticultural crops production. In addition, field observation revealed that soil erosion and salinization were major challenges to AF in the highlands and lowlands respectively, since larger number of farmers ignored terraces in highlands.

4.5 Tree Component of Agroforestry in Mitigating Carbon Dioxide Emissions

The variation in AF carbon stocks from different altitudinal ranges ranged from 10.7 to 57.1 Mg C ha^{-1} (Fig. 4).

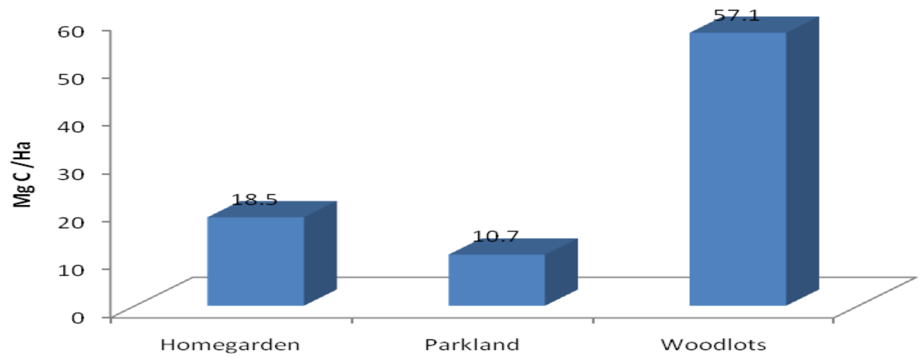

Figure 4: Comparison of carbon stocks (Mg C ha^{-1}) from different AF practices

In general average carbon stock of AFs ranged from 5.3 to 45 Mg C ha^{-1} (Table 8), while aboveground carbon stock reported in lowlands characterised by parkland were lower compared to that of the highlands which were characterised with homegardens and woodlots. Parkland system refers to the landscapes were mature trees occur scattered in cultivated or recently fallowed field. Carbon stock of the systems showed high significant variation (F=131; P< 0.0001; Table 9). Management practices, tree density, species diversity and socio-economic factors were among the factors that contributed to carbon stock variation. For example, farmers grew crops around and underneath of the trees selectively left or regenerated by farmers because of the variety of functions (mostly non-timber). Parkland systems were dominated by one or few tree species. Common tree species included *Acacia species, Balanites aegyptiaca*, *Faidherbia albida*, *Salvadora persica*, *Azadirachta indica*, *Tamarindus indica* and *Kigelia africana*. High density of *Eucalyptus* species were reported in woodlots both in the highlands and the medium altitude.

Table 8: Comparison of carbon stock from different agroforestry practices

	Carbon stock (Mg C ha^{-1})					
Agroforestry systems	**N**	**Minimum**	**Maximum**	**Mean**	**St.Dev**	**CV**
Woodlots	5	36.8	57.1	45	7.8	17.3%
Homegardens	34	1.6	23.3	8	5.4	67.5%
Parkland	15	3	10.7	5.3	2.1	39.6%

Table 9: Comparisons of significant differences in carbon stock among AFS (F=131; p<0.0001) (W= woodlot; H= Homegarden; P= Parklands)

	Carbon stock Mg C Ha^{-1}		
Agroforestry systems	**Means differences**	**S.E**	**Scheffe`s Post hoc**
Woodlots Vs Homegarden	37.1	2.4	W > H > P
Woodlots Vs Parklands	39.7	2.5	W > H > P
Homegarden Vs Parklands	2.6	1.5	W > H > P

Homegardens had higher density of coffee and banana plants in the highland compared to the medium altitude. Tree species composition in homegardens and land size were among the factors that contributed to carbon dynamics. For example, tree richness was higher in high altitude, followed by medium altitude. Similarly, tree dominance varied from highland to medium altitude for example *Mangifera indica*, *Cordia africana* and *Grevellia robusta* were dominant in medium altitude and *Coffea arabica*, *Grevellia robusta*, *Cordia africana* and *Persea americana* in the highlands homegarden.

Table 10 summarizes 40 different tree species identified in AFs. *Eucalyptus saligna* was top ranked species in the study area; others species observed were *Mangifera indica*, *Grevellia robusta*, *Cordia africana* and *Coffea arabica*. Apart from socio-economic importance in the study area also were a sinks for CO_2 through the process of photosynthesis, which accumulate C in tree biomass. Fruits tree such as Mango (*Mangifera indica*), Avocado (*Persea americana*) and Jackfruits (*Artocarpus heterophyllus*) were also top ranked. Their abundance and other multiple benefits such as carbon sinks exemplify the significance and potential of the trees species if used in reforestation projects for C storage.

Table 10: Trees species abundance sampled in the 54 agroforestry farms

Species name	Frequency	Percentage
Grevellia robusta	79	10.2
Cordia africana	72	9.3
Tamarindus indica	11	1.4
Syzigium cordatum	8	1
Balanites aegyptiaca	3	0.4
Markhamia obtusifolia	17	2.2
Croton macrostachyus	5	0.5
Kigelia africana	9	1.2
Eucalyptus saligna	124	15.9
Acacia tortilis	7	0.9
Salvadora persica	13	1.7
Cordia sinensis	2	0.3
Ficus thonningii	4	0.5
Albizia schimperana	8	1
Faidherbia albida	49	6.3
Commiphora eminii	11	1.4
Artocarpus heterophyllus	46	6
Persea americana	36	4.6
Mangifera indica	123	15.8
Anona muricata	16	2.1
Anona squamosa	11	1.4
Croton megalocarpus	3	0.4
Syzigium guineense	8	1
Azadirachta indica	12	1.6
Psidium guajava	3	0.4
Cocos nucifera	2	0.3
Cinamomum zeylanicum	1	0.1
Acrocarpus fraxinifolius	8	1
Rauvolfia caffra	1	0.1
Eucalyptus globulus	1	0.1
Coffea arabica	60	7.7
Pinus species	3	0.4
Citrus species	1	0.1
Cedrella odorata	2	0.3
Acacia polyacantha	7	0.9
Albizia gummifera	8	1
Milicia excelsa	1	0.1
Borassus aethiopum	1	0.1
Ficus sycomorus	2	0.3
Carica papaya	1	0.1

CHAPTER FIVE

5.0 DISCUSION

5.1 Tree uses that Increase Farmer's Resilience to Climate Variability

This study has revealed that trees help to buffer subsistence farmers against environmental extremes by modifying temperatures, providing shade and shelter and acting as alternative sources of food and feed during the period of drought. This observation is consistent with other studies on the multifunctional role of trees by sustaining production during wetter and dry season (Smith, 2010; Fifanou *et al*., 2011; Folega *et al*., 2011). According to Snelder *et al*. (2007); Zomer *et al*. (2009); Akinnifesi *et al*. (2010), tree products and uses played an important role in mitigating CO_2 emissions and buffering subsistence farmers against crops and animals loss. For example, Nair (2008); Fifanou *et al*. (2011); Ajayi *et al*. (2011) realized that multipurpose trees and shrubs were the mainstay of most traditional AFs, and its contributions reported to be grouped under two broad categories: production of commodities and ecosystems services. Similarly, Smith (2010) and Bucagu *et al*. (2012) reported the multifunctional role of trees in their provision of resources for animals' in Elm Farm. Other studies also revealed that if fodder for livestock will depend more on bushes or trees and less on grasses and annual grain crops, the risk of losses during floods, drought and landslides would be less, because trees are more resilient to such weather conditions than non perennial plants (Ulsrud *et al*., 2008).

Farmers' resilience to environmental changes often seem to be constrained by prolonged drought and land degradation that can jeopardize land productivity and threaten adaptive capacity of subsistence farmers (Rahman *et al*., 2011; Hewitt and

Mehta, 2012). This is exemplified by low productivity of land due to soil erosion, decline in soil fertility and increased salinity of the soil. However, Hines and Eckman (1993) and Kumar (2006) reported that trees such as *Acacia nilotica*, *Dalbergia sissoo*, *Terminalia arjuna* and *Salvadora persica* offer a cost effective and promising options (phytoremediation) to reclaim large tracts of salt affected soil respectively. Certainly farmers are taking adapting measures with less understanding of the aforementioned benefits of tree products. Zomer *et al*. (2009); Abebe *et al*. (2010); Ajayi *et al*. (2011); Djoudi and Brockhaus (2011); Fifanou *et al*. (2011); de Souza *et al*. (2012); Irshad *et al*. (2011) argued that tree planting or retention on farm were mostly associated with compatibility with other crops, land tenure, customs, institutions arrangement in place, easiness to manage, higher income from off-farm employment opportunities and high level of awareness/understanding of the importance of tree planting. Proximity to town favoured trees with higher return such as fruits trees, timber and poles. Competition with other crops discouraged farmers from planting *Cedrella odorata* and *Acrocarpus fraxinifolius* (Zomer *et al*., 2009; Irshad *et al*., 2011; Roy *et al*., 2011). Experience has shown that avocado (*Persea americana*) and mango trees do well during drought, hence people depended on their fruits during drought periods.

5.2 Agroforestry Products and Practices that Increase Farmers` Resilience

A variety of benefits of AF products found in this study are similar to those reported in other studies (Akinnifesi *et al*., 2010; Ndayambanje and Mohren, 2011; de Souza *et al*., 2012). However, in this study farmers seemed to put more emphasis on the benefits of shade, livestock manure, food, fodder, ecosystem services and wood products. Sileshi *et al*. (2007) ; Masamha *et al*. (2010); Singh and Pandey (2011) argued that the major role of AF in increasing farmer’s resilience to changing climatic conditions was through supporting production of wide range of products including food, fuel wood, fodder and forage, timber, shade, gardening material, medicine, biological control and ecological services.

Nair (2008) and Smith (2010) argued that AFs are useful in maintaining production during wetter and drier years. A central hypothesis in AF is that productivity is higher in AFs compared to monocultural systems due to complementarities in resource-capture i.e. trees acquire resources that the crops alone would not. Based on the ecological theory of niche differentiation; different species obtain resources from different parts of the environment, such as, *Grevellia robusta* are fast growing and less competitive, while tree roots of *Persea americana* and *Syzigium species* are reported to extend deeper than crop roots and are therefore able to access soil nutrients and water unavailable to crops, as well as absorbing nutrients leached from the crop rhizosphere (Pandey, 2007; Smith, 2010; Bucagu *et al*., 2012). In drought-prone environments, such as Rajasthan, as a risk aversion and coping strategy, farmers maintain AFs to avoid long-term vulnerability by keeping trees as an insurance against drought, insect pest outbreaks and other threats, instead of a yield-maximizing strategy aiming at short-term monetary benefits (Singh and Pandey, 2011; Rigueiro-Rodríguez *et al*., 2011).

The finding of this study agree with other studies that suggested multi-sectoral or products diversification in improving farmer`s resilience (Garrity, 2004 and Abebe *et al.,* 2010; Thorlakson, 2011; Hewitt and Mehta, 2012). Various methods of improving farmers adaptive capacity to climate variability have been suggested to include strengthening strategies that people developed, providing off-farm sources of income, improving farm productivity, raising drought resistance crops, improved irrigation infrastructure, improving institutional arrangement and access to markets (Garrity, 2004; Vincent, 2007; Lin, 2011). For instance, Hines and Eckman (1993) reported that *Salvadora persica* leaves and bark contain an alkaloid and its seeds are rich in oil and contain organic acids, which have a potential for making soaps and candles, thus using it will provide off-farm source of income in the study area. Similarly, Waele and Davide (1998); Adekunle and Akinlua (2007); Adekunle and Aderogba (2008); Ulsrud *et al*. (2008); Masamha *et al*. (2010) reported that extract from *Leucaena leucocephala*, root and leaf or bulb from *Allium sativum* (garlic) and *Allium alia* (onion) to be used in controlling nematodes hence can substitute synthetic pesticides with bio-pesticides. Moreover in this study there were unproved claims that sheep dung (fresh dung) was highly effective against banana nematodes.

Nevertheless, findings from this study revealed products diversification did not guarantee farmer`s resilience in terms of securing basic needs under changing climatic condition (Vincent, 2007; Eriksen and O`Brien, 2007), since the results revealed most households have inadequate skills, labour, capital and access to information necessary for such specializations and institution support. Agroforestry has been proposed as potential strategy for helping subsistence farmers' resilience to climate change through intentional use of trees in agricultural systems to increase farm productivity, diversify income sources and improve environmental services (Smit and Wandel, 2006; Verchot *et al.,* 2007; Folega *et al*.,2011; de Souza *et al*., 2012).

According to Singh and Pandey (2011), even trees that do not fix nitrogen can enhance physical, chemical and biological properties of the soils by adding significant amount of organic matter. In addition, trees also reduce soil erosion by providing long- term vegetation cover. Maintenance and enhancement of soil fertility is vital for farm productivity and environmental sustainability (Ajayi *et al*., 2011). Irrespective of motivation for adaptation, both purposeful and unintentional adaptations may generate short- term or long- term benefits, whilst what appears successful in the short term turn out to be less successful in the long term like shifting cultivation (slash and burn) and uncontrolled grazing (Smit and Wandel, 2006; Rao *et al*., 2007; Smith, 2010; Kalaba *et al*., 2010). Aforementioned finding highlights the need of place-based studies that will assess which specific AF practices and productions will be more effective in increasing farmers' resilience under variation of climate hazard.

Trade-offs such as competition, incompatibility, natural resources access and uses, are increasingly acute, with subsistence farmers becoming more vulnerable to adverse outcomes in the study area. Giller *et al*. (2008) suggested competing claim approach as a more equitable management option that will reduce rural vulnerability. The approach will enable communities to address competing claims on natural resources that involve complex situations where uncertainty is high and where different values and interests are at stake. The approach in this sense can be useful in three ways it enable better understanding of today's challenges of resources access and use, unsustainable resource exploitation, land degradation and vulnerability. Secondly, the approach offers a management tool to make the competing claims of stakeholders visible, manage emerging conflicts better by not neglecting stakeholder's power dynamics. Thirdly, is a tool to trigger innovation in resources use and production such as finding new ways to reduce subsistence farmers` vulnerability to climate change and variability.

5.3 Role of Income from Agroforestry in Increasing Farmer's Resilience

Studies on AFs have shown that financial benefits are the results of increasing diversity and productivity of the systems which are influenced by market and price fluctuations of wood products, livestock and annual crops (Abebe *et al*., 2010; Kalaba *et al*., 2010; Smith, 2010). For instance, source of cash income of AF practitioners in Mwanga District were more diversified and on average had extra income than non-AF participants of TAS 988 042 (US$ 617.5) annually. This amount was slightly higher than that reported by (Maduka, 2007) of TAS 954 611 (US$ 596.6) in Misungwi, Tanzania. Moreover, income reported from Kenya was lower; for example, lower Nyando farmers involved in AF project had an average, between US$ 19-137 (Thorlakson, 2011). These differences in incomes between farmers from semi-arid areas and highland areas may be contributed by factors like AFs and practices adopted, number or type of trees species and crops established and sold, markets price of agroforestry products, land size, age of the trees and bargain power of farmers (Abebe *et al*., 2010).

Garrity (2004) argued that enhanced tree based system and improved tree products marketing have a potential to increase farmers resilience to climate variability. In contrast, rural poor households are further disadvantaged by poor market price transparency, absence of processing techniques to add value to AF products like horticultural crops and perishable tree products like fruits. This study revealed the potential of non-timber forest products in improving resilience of subsistence farmers against climate variability but vigorous efforts are needed to provide knowledge on the value addition innovation (Abebe *et al*., 2010; Smith, 2010). For instance, Oduol *et al*. (2006) reported that processing of both exotic and indigenous fruits enabled 85% of women in Tabora, Tanzania to generate income through processing and selling juice, jam and wine. Women earned average of US$ 9 per week through selling juice, US$ 13 through selling wine and 17% of women from Shinyanga, Tanzania earned average of US$ 7 per week through selling jam. The most used tree species included *Vitex species*, *Adansonia digitata*, *Syzygium guineense, Psidium guajava, Carica papaya ,Mangifera indica* and *Passiflora edulis.* The extra money earned was used for meeting other basic needs such as education, buying food and other assets. Similarly, Garrity (2004); Rao *et al*. (2007); Adger *et al*. (2010); Ndayambanje and Mohren (2011) argued that AFs if supported by appropriate cultivation, processing and marketing methods, AF products could make major contribution to economic development of millions of poor farmers by meeting their basic needs for food, fuel wood and income.

This study revealed a great income variation from different geographical location; for example AF practitioners in lowland earned higher income of TAS 1 342 663.60 (US$ 839.2) annually. It is not surprising that farmers from the highlands villages have not improved their wealthy through AF hitherto, but the types of crops grown included paddy, maize and horticultural crops, fetched which higher prices. For example, the price of 100kg of maize and rice was TAS 60 000 and 70 000 respectively. Furthermore, availability of irrigation infrastructure in the lowland areas enabled farmers to cultivate throughout the year contrary to other villages in the highland areas, which depended on rain-fed agriculture. Thorlakson (2011) argued that location had a significant impact on farm productivity and household wealth.

Moreover, exposure, infrastructure, resource management regime, disease and pest (such as nematode and mites) were among the factors mentioned to reduce local communities' resilience to climate variability (Vincent, 2007; Eriksen *et al.,* 2008). This is exemplified by poor road network and market, resource depletion, poor access to social needs like clean and safe water and extension services. In addition, farmers in the lowland depended on irrigation water tapped from Pangani River. But a very wet or dry year far beyond the normal conditions, may lead to water intake failure, thus affecting resilience of subsistence farmers in the subsequent year.

5.4 Role of Trees on Farm in Mitigating Carbon Dioxide Emission

Agroforestry, an ecologically and environmentally sustainable land use, offers great promise towards mitigating the rising atmospheric CO_2 levels through C sequestration (Nair, 2011). Tree crops sequester C at a higher rate than those contained only in annual crops or grasslands (Brakas and Aune, 2011). Nair *et al*. (2009); Jose (2009); Singh and Pandey (2011) reported that annual crops are less resilient since they only accumulate carbon through roots and retention of crop residues compared to tree crops that accumulate carbon through, roots, litter and aboveground biomass.

This study revealed a great variation in AF practices, with a higher trees density in woodlots and higher diversity in other categories as discussed earlier. Parklands had an average carbon stock of 5.3 Mg C ha^{-1}, homegardens had an average of 8 Mg C ha^{-1}, and woodlots had 45 Mg C ha^{-1}. The carbon stock reported from this study in woodlots of 45 Mg C ha^{-1} is much higher than that reported by (Kimaro *et al*., 2011); Walsh *et al*., 2008) ; Udawatta and Jose, 2011). But the carbon stock reported in this study were similar to that of tropical agroforestry that ranged from 7.9 to105 Mg C ha^{-1} as reported by (Roshetko *et al*., 2002; Montagnini and Nair, 2004; Verchot *et al*., 2007 and Yadava, 2010).

The variation in Carbon estimate reported above is explained by the higher density and diversity of trees species. Other studies revealed that C storage in plant biomass is only feasible in perennial AFs with a mixture of fast-growing and slow-growing species, sprouting tree species and multipurpose trees, since the woody component represents an important part of the total biomass (Albrecht and Kandji, 2003; Nair *et al*., 2009; Kumar, 2011). Thus, intensifying coppicing and multipurpose trees in AFs whereas carbon sequestration does not end at the wood harvest is necessary since will augment forest integrity. The sprouting and fast growing of *Eucalyptus* woodlots were reported to be more efficient than even native forests in term of carbon sequestration by offsetting carbon that is lost from harvesting of trees (Moges, 2010).

Carbon stocks reported in this study were slightly lower than that of tropical homegarden practiced in Kerala adjacent Buffer zone of Lore Lindu National Park in Central Sulaweshi, Indonesia and Cocoa based AF practiced in Ogbese Forest reserve Ekiti State, Nigeria that ranged from 16 to 96.01 Mg C ha^{-1} as reported by

(Kumar, 2011; Wardah *et al*., 2011; Oke and Olatiilu, 2011) respectively. This study and several other literatures exemplify the contributions of farm size, management, socio-economic needs, species diversity, age of trees, local climate and tree stocking/ spacing for carbon variability among AFs (Barnett and Adger, 2007; Kumar, 2011). However, carbon variation reported earlier can be attributed to relatively age variation of the trees, higher level of disturbance (pruning and damage), intensive management practices and small land size that forced homegarden not only having higher density of wood perennials but also accumulation of other plant crops per unit area (Yadava, 2010; Kumar, 2011; Oke and Olatiilu, 2011).

The aforementioned studies indicated that tree based systems are important sources of carbon sinks which are targeted by REDD+ (Angelsen *et al*., 2012), even if variations of carbon stock in AFs as described above depended upon several factors (Albrecht and Kandji, 2003; Nair, 2008; Brakas and Aune, 2011; Nair, 2011; Singh and Pandey, 2011). For example trees species abundance and diversity in this study varied from the highlands to the lowlands. *Mangifera indica*, *Cordia africana* and *Grevellia robusta* were dominant in medium altitude, while in the highlands *Eucalyptus saligna* ranked the top; others were *Coffea arabica*, *Grevellia robusta*, *Cordia africana* and *Persea americana*. In the Lowlands (semi-arid) *Faidherbia albida* ranked higher, others were *Salvadora persica*, *Azadirachta indica* , *Tamarindus indica* and *Kigelia africana.* Multipurpose tree species such as Mango (*Mangifera indica*), Avocado (*Persea americana*), Jackfruits (*Artocarpus heterophyllus*), *Faidherbia albida* and *Albizia species* were all top ranked C-stores.

Similarly, higher carbon accumulation rate from agroforestry with high diversity facilitated a better nutrient use and therefore increased C sequestration compared with non-agroforest systems (Nair *et al*., 2009; Howlett *et al*., 2011; Singh and Pandey, 2011).

Similarly, as result of replanting trees to AFs through time, C that is lost from senescing trees will be offset by C sequestered by individuals tree that are planted in anticipation of the older trees` senescing. In this regards AFs seem attractive since there is no complete removal of biomass from the agroforestry systems, signifying the permanence of these systems compared to plantation forest (e.g. Sileshi *et al*., 2007 and Kumar, 2011).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study described the potential of agroforestry in increasing resilience of subsistence farmers. Agroforestry systems reflected diversity in terms of the multiple benefits from trees, crops and livestock integrated in agriculture systems. Agroforestry products seemed to improve resilience of smallholder farmers against climate change, particularly by improving farm production (food, fodder, timber, fuel wood, and manure), ecosystem services (soil improvement, climate amelioration, wind break, erosion control, and disease and pest control) and household income. Using linear regression model, irrigation practices in AFs were statistically significant enhancing farmer`s resilience to climate variability due to increased income as a result of the diversity of products distributed throughout the year.

This study has shown that AFs have great potential to mitigate CO_2 emissions with high significant variation compared with tree-less agricultural systems, and therefore their implementation should be considered as a climate-smart land use option in Mwanga District Tanzania.

The study has also shown that the factors that constrained resilience of AFs included diversity crop and tree species in place, knowledge, local climate, management in place, disturbance or damage, land use conflict and household income.

5.2 Recommendations

Based on the above findings, a number of recommendations to enhance household resilience to climate change and variability in Mwanga District have been made. These are presented below and are of two categories: management and further research.

5.2.1 Recommendations for scaling up AF and management improvement

(i) The most urgent intervention for scaling up AF is to institute effective extension services, training and outreach programms in order to enhance farmer`s agroforestry practices with primacy to multifunctional values of AF such as using extracts from garlic and *Leucaena leucocephala* in controlling mites and nematodes and manure , soil improvement respectively

(ii) Maintenance of traditional agroforestry systems and strategic creation of new systems such as beekeeping and aquaculture in rice farms should be in place;

(iii) New cash crops like passion fruits, sunflower, cardamom and sweet melon that are useful in improving household income should be improved;

(iv) Measure should immediately be put in place in order to improve the existing irrigation systems so as to reduce water loss by evaporation as well as increasing area under production;

(v) Markets and value added innovation for non-timber products such as Mango (*Mangifera indica*), Avocado (*Persea americana*), Jackfruits (*Artocarpus heterophyllus*), *Syzigium species*, honey, candle and soap from *Salvadora persica* should be improved.

5.2.2 Recommendation for future studies

The findings of this study are only a small fraction of the total knowledge needed to address the impacts of climate change and variability. Further investigation must therefore be vigorously pursued. Below are recommended areas for further research.

(i) This study has indicated the existence of trade-offs like shifting cultivation (slash and burn), overgrazing, land and water use conflicts. Further research is recommended to understand and address competing claims that reduce adaptive capacity of farmers or systems.

(ii) This study has also indicated a potential of using sheep dung to control nematodes that attack banana. A scientific study is recommended to prove its effectiveness and efficiency in controlling nematodes.

(iii) The results of this study suggest that research priorities should consider extending agroforestry species that match farmer preferences and include those options that have direct potential for increasing farmers' resilience to climate change.

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APPENDICES

Appendix 1: Household Questionnaires for agroforestry practitioners

Name of the household head/ respondent..

Date of the interview.......................................Questionnaire No...........................

Village:

.....................................Ward............................Division:...............................

Households characterization

1. Sex Male...................... 2 .Female ....( )

2. Age.......................................Years

3. Years of residence in the

Villages........................Occupation...................................

4. Marital Status:- 1. Single 2. Widowed. 3. Married 4. Separated 5. Divorced

5. Education:- 1. No formal education 2. Secondary education;

3. Adult education 4. Post secondary education; 5. Primary education.

6. Total number of household member:...........................Dependant.......................

7. What are the economic activities of a household? (1) Agriculture

(2) Agroforestry (3) Casual employment (4) permanent employment

8. Land parcel, size and mode of acquisition

Number of plot	Size (ha/M^2)	Uses	Mode of acquisition

Key: (1) Purchased (2) given by government (3) inherited (4) Cleared (5) lent

9. Do you cultivate more than one crop Yes/No? If yes mention the crops............

10. Do you apply any fertilizer on you plot cultivated Yes/No? If yes name it.......

11. If you’re not using mineral fertilizer give the reason................. ....

12. What is the main source of labour for your farm activities?

(1) Family members (2) Hired labour (3) Both 1&2 (4) Others specify.........

13. Which AF technology do you practices among these?

(1) Woodlot (2) homegarden (3) mixed intercropping (4) Other (specify)....

14. Which type of tree species do you own, uses and their ranking?

Rank	Tree species (name)	Quantity	Uses
1			
2			

15. Where did you get seedlings? (1) Given free (2) raise (3) buy (4) others (specify)

16 Mention the crops that you intercrop .1............2..............e.t.c and Why............?

17. For the past 10 years have experience any prolonged drought? Yes/ No..........

18. Does prolonged drought affected crop yield or livestock in your area

Yes/No......

19. If, Yes mention (a) crops which is most affected 1....... ....2..................

(b) Tree species which is most affected 1............2.............

(c) Livestock which is most affected 1..............2............

20. If, No mention (a) crops which are drought resistance 1..............2...........3..........

(b)Tree which are drought resistance 1.........2...........3............

(c) Livestock which are drought resistance 1.............2............

21. Mention four benefits obtained from your AF farm (s) 1.........2.......3..........4........

22. Mention four major challenges or problem you experiencing in managing AF?

1............................2...................................3............................4.......................

23. Mention four coping strategy in each of the above challenges? 1 ....

2...3..................................4..............................

24. Do you think these coping strategies are sustainable? If No, Explain.....................

25. Do extension officer visit you? (1) Yes (2) No

26. If yes, whom one (s) (1) crops officer (2) forester (3) livestock officer (4) Other..

27. If not where do you get extension services? (1) Friends (2) Tv/radio (3) others.....

28. Have you received any short course or seminar? If yes........ Mention it.................

29. Is there any changes in tree species /crops variety for the past 10 year Yes/No ?

(a) If yes what are those plant species and crops intercropped previously ... .

(b) What are the New crops.................and

30. What are the reasons for adopting new crops/ tree/ livestock.................................

31. Do you normally need wood based material daily? Yes/No ....

32. If Yes, where do you acquire the daily wood (a) Buy (b) agroforestry ()

33. For the past 10 years is there any change in AF products demand Yes/No?

34. If Yes which AF product is more demanded.........................uses.................

35. What are the causes of increased AF product consumption?.............................

36. Is your AF satisfies wood and non wood demand to the households? Yes/No

(a) If, No where do you obtain to satisfy household need?...........................

(b) If yes, what are they and its uses......................

Type of AF products	Local name	Uses

37. Is there any set aside land for grazing, wood, building material? Yes /No?

38. If, No where do you obtain the above services...

39. How many types of tree have been retained/ planted in your farm?

S/ N.	Tree local name	Number of trees	Retained	Planted	Uses
1					
2					

40. Mention strategies for up scaling AF?..................... ....

SECTION C: ECONOMIC SECURITY (household assets and income streams)

41. What household income generated from AF products?

Products	Annual production (Kg)	Sold (Tshs)	Amount consumed Kg)	Amount stored (Kg)
Cash crops				
Tree product				
Jack fruits				
Mango fruits				
horticultural				
Spice				
Banana				
Maize				
Others; specify				

42. Where do you sell your products (1) Villages (2) Town (3) others (specify);......

43. Which among these is hindering the market of AF?

(1) Poor road (2) information (3) poor processing technology ( )

44. Do the level of production from AF and income satisfy most of your household`s basic needs? (1) Yes (2) No ( )

45. If, No mention 4 suggestion that can be done to improve level of production........

Appendix 2: Household Questionnaire for Non Agroforestry Practitioners

Name of the household head/ respondent..

Date of the interview.......................................Questionnaire No..........................

Village: ....Ward............................Division:..............................

Households characterization

1. Sex Male...................... 2 .Female ....( )

2. Age.....................................Years

3. Years of residence in the

Villages.......................Occupation...................................

4. Marital Status:- 1. Single 2. Widowed. 3. Married 4. Separated 5. Divorced

5. Education:- 1. No formal education 2. Secondary education;

3. Adult education 4. Post secondary education; 5. Primary education.

6. Total number of household member:...........................Dependant.......................

7. What are the economic activities of a household? (1) Agriculture

(2) Agroforestry (3) Casual employment (4) permanent employment

8. Land parcel, size and mode of acquisition

Number of plot	Size (ha/M^2)	Uses	Mode of acquisition

Key: (1) Purchased (2) given by government (3) inherited (4) Cleared (5) lent

9. Do you cultivate more than one crop Yes/No? If yes mention the crops............

10. Do you apply any fertilizer on you plot cultivated Yes/No? If yes name it.......

11. If you’re not using mineral fertilizer give the reason................. ....

12. What is the main source of labour for your farm activities?

(1) Family members (2) Hired labour (3) Both 1&2 (4) Others specify.........

13 What are the major crops do you grow, rank according to their importance

Rank	Type of crop	production bag/year	Amount consumed bag	Amount sold bag/Tsh	Amount stored
1					
2					

14. Where do you sell your product (1) Village (2) in town (3) others (specify)..........

15. Do the production and income satisfy your household`s basic need? Yes/No

16. If No what are the reasons and your suggestion for improvement (mention).........

17. Do you keep livestock Yes/No

18. If yes, how many and what are benefits?

19. Where do you obtain livestock fodder?.......................................

20. Is there any problem facing farm management and livestock practice? YES/NO

21. If yes, mention your coping strategy?

22. What is your future planning concerning your involvement in AFS?.....................

Thank you

Appendix 3: Checklist for Key informants and leaders

Dear Leaders/ extension officers/ Key Informants e.t.c.,(.....................................)

Therefore, your `are kindly requested to respond trustfully to the following questions.

I thank you in advance.

1. What is the current trend of adoption in AF practices in the District?..................

2. Which tree species is more preferred by farmer and its uses...............................

3. Where do farmers get planting materials?..

4. What are the existing organization (s) supporting AF in the district?.............

5. What do they do to support communities?

6. Are there challenges hinder sustainability of AF? If yes which ones,

7. Is there any changes in AF practices over past 10 years? If Yes Why?...............

8. Where do communities obtain wood fuel? _

9. What is the household expenditure on wood fuel per month? _

10. Is there any changes in the uses or demand of wood fuel ? if so rank...........

11. Is there changes in crops in the past 10 years or more? YES/NO?_

12. If yes what are new crops practised and adopted by the household?...................

13. How the changes in crops did affected households income? _

14. Is there been changes in cash crops in the past 10 years or more YES/NO? _

15. If yes name the cash crops? _

16. Did the changes in cash crops affected AF practices? _

17. Is there changes in markets for crops in the past 10 years or more YES/NO? _

18. If yes which crops or product fetch higher price?

19. Mention the coping strategy for communities against drought or stress?

Thank you

Appendix 4: Ecological / Inventory Data form

Date..Recorder...

Village................................Ward....................Division.....................District................

Plot No......................Eastings..................Northings..................Vegetation type........

Trees inventory form

Code/tree No.	Local name	Scientific Name	DBH (cm)	Age (Year)	Above Biomass	Below ground	Uses
1.							
2.							
3.							
4							
5							
6							
7							
8							
9							
10							
11							