CLIMATE SMART AGRICULTURAL PRACTISES AND FOOD SECURITY: A CASE OF MBEYA AND SONGWE REGIONS IN TANZANIA

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EXTENDED ABSTRACT

Although Climate Smart Agriculture Practises (CSA-practises) have been promoted and implemented in the Tanzania, but usage of CSA-practises is still low while their impact on food security is not well documented, especially when used in combinations. This study examined the usage of different CSA-practises and their impact on food security among farming households in Mbeya and Songwe Regions in Tanzania with specific objectives to; a) assess the usage and intensity of using multiple CSA-Practises by farming households b) assess the determinants of using combinations of CSA-Practises by farming households c) evaluate the impact of using combination of crop rotation, residue retention and intercropping on food security d) evaluate the impact of using combination of organic manure, irrigation and drought tolerant maize seeds on food security and e) evaluate the impact of climate-smart irrigation practise on food security.

Multistage sampling technique was employed in sampling 1443 farming households. A household survey was conducted whereby the primary data were collected using a structured questionnaire. The Household Dietary Diversity Score per Adult Equivalent Unit (HDDS/AEU) and Food Variety Score per Adult Equivalent Unit (FVS/AEU) were used as indicators to measure household food security.

To assess the usage of the multiple CSA-practises a multivariate probit model was used while the ordered probit model was used to examine the intensity of using CSA-practises. A multinomial probit model was employed to estimate the factors influencing the use of combinations of CSA-practises (i.e. crop-rotation, crop residue retention and intercropping).

To examine the impact of using a combination of CSA-practises (crop rotation, residue retention and intercropping), a multinomial endogenous switching regression model was employed. Furthermore, the study employed a multinomial endogenous treatment effect regression model to evaluated the impact of using organic manure, drought-tolerant maize seeds. and irrigation on food security. Furthermore, endogenous switching regression model was employed to evaluate the impact of using climate smart irrigation on food security. The evaluation methods used in this study are appropriate in the analysis of the control for both observed and unobserved heterogeneity. Other evaluation approaches such as propensity score matching and inversely probability-weighted regression (IPWR) can only control observed heterogeneity which leads to unbiased estimates.

The results from multivariate probit (objective one) showed that the use of CSA-practises was positively influenced by gender of the head of the household, farm size, education of the head of household, location, size of the household, occupation, and farmer organizations membership. Moreover, it was found that the use of drought-tolerant maize seeds and crop rotation was positively associated while the use of a residue-retention and crop-rotation in combination, the use of organic manure and crop-rotation, combination of intercropping and residue-retention and the use of intercropping and organic manure were significantly and positively associated at significant level 1 %. This implies that farming households consider these combinations as complements.

The study examined the determinants of farm households' decision to use combinations CSA-practises (objective two) and found that production diversification, gender and livestock ownership were positively and significantly influence the usage of combinations of residue-retention and intercropping. In addition, education level and gender of the head of the household were positively and significantly affect in the usage of combination of crop rotation, crop residue and intercropping This comprehensive study is significant for finer understanding of the synergistic effect of interrelated CSA-practises.

The result for objective three found that usage of CSA-practises depends on either it is used in isolation or in combinations, and the usage of these CSA-practises significantly increase food variety score per adult equivalent unit when used either singly or jointly. Furthermore, the use of intercropping in isolation show the highest food variety scores per adult equivalent unit among all the possible combinations of CSA-practises. Moreover, the use of crop rotation in isolation also showed a high pay off after intercropping followed by a joint combination of crop rotation and residue retention. Thus, the usage of a combination of crop rotation, intercropping and crop residue retention was found to be the best food security portfolio.

Results from objective four found that the characteristics of the household, plot characteristics and institutional characteristics (e.g access to extension services) influences the usage of a different combination of CSA-practises. The study also found that the highest payoff of food security could be achieved when CSA-practises are used in combination than in isolation. The combination of drought-tolerant maize seeds and irrigation gave higher payoff than the combination of all three CSA-practises.

Finally, the findings from objective five showed that radio ownership, education of the household head, farm experience, production diversity and livestock ownership were the determinants of using irrigation in the study area. The average treatment effect of the treated

(ATT) and the average treatment effect of untreated (ATU) were positive and highly significant for irrigators and non-irrigators. That is, the use of irrigation as a CSA-practise has improved food security of the farming households.

It is recommended that, inorder in order to enhance the usage of CSA-practise, policy makers and local government authorities should target equipping extension workers and other agricultural practitionners with adequate items of infrastructure that enable their easy movement to the farmers. In addition, more more extension agents should be trained and deployed in the country to reduce the workload of the limited number of extension officers available inoder to improve agricultural productivity and food security

The study calls for policy makers on policies and plans that promote CSA-practises as a combination, including other interrelated practises which upscaling CSA-practises usage. Furthermore, there is a need to promote the usage of CSA-practise in isolation or in combination. In addition, the study suggests that based on the practises considered in this study, usage of a combination of various practises results in better food security compared to the usage of these practises individually. This suggests that agricultural practitioners should promote combinations of CSA-practises to improve food security in the farming households.

It is recommended that policymakers should consider rehabilitating the existing irrigation schemes while constructing new irrigation schemes to widen the impacts of irrigation to household food security. However, despite the positive impact of irrigation, it is recommended that other irrigation practises such as drip irrigation, sprinkler irrigation should be used in the areas where construction of small-scale irrigation is not possible.

DECLARATION

I, Abiud January Bongole, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work, done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

Abiud January Bongole **Date**
(PhD Candidate)

The above declaration is confirmed.

Professor Kenneth M.K Bengesi (PhD) **Date**
(Supervisor)

Professor Joseph Hella (PhD) **Date**
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DEDICATION

I dedicate this work to my mother, Julitha Bongole, who invested her time and other resources to enable me pursue my education. To my wife, Elizabeth Sway Bongole and our children: Julitha, Dementria, Joshua, Jeremiah, and Melkizedeck for their love and tireless support.

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ABBREVIATIONS AND ACRONYMS

ADP-Mbozi	Action for Development Programs – Mbozi
AGRA	African Green Revolution Alliance
AMCOS	Agricultural Marketing Cooperative Societies
ASDP	Agricultural Sector Development Program
ASDS	Agriculture Sector Development Strategy
ATT	Average Treatment Effect on the treated
ATU	Average Treatment Effects on the Untreated
CARMATEC	Centre for Agricultural Meachanization and Rural Technology
CIMMYT	Centro Internacional de Mejoramiento de maiz y Trigo
CSA	Climate Smart Agriculture
DTMS	Drought Tolerant Maize Seeds
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization
FIML	Full Information Maximum Likelihood
FVS	Food Variety Score
HDDS	Household Dietary Diversity Score
IPCC	International Panel for Climate Change
LR	Likelihood Ration
MESR	Multinomial Endogenous Switching Regression
MNL	Multinomial Logit
MVP	Multivariate Probit
NSGRP	National Strategy for Growth and Reduction of Poverty
ODK	Open data Kit
OLS	Ordinary Least Square

PCA	Principle Component Analysis
PDI	Poor Dietary Diversity
PhD	Doctor of Philosophy
PSM	Propensity Score Matching
SAGCOT	Southern Agricultural Growth Corridor
SNV	Stichting Nederlandse Vrijwilligers
SUA	Sokoine University of Agriculture
TARI	Tanzania Agriculture Research Institutes
TCSAA	Tanzania Climate-Smart Agriculture Alliance
TFNC	Tanzania Food and Nutrition Centre
TLU	Tropical Livestock Unit
UNFCCC	United Nations Framework Convention on Climate Change
URT	United Republic of Tanzania
VIF	Variance Inflation Factor
WFP	World Food Organization

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Climate change is a threat to food security systems and one of the biggest challenges particularly in the agricultural dependent countries (FAO, 2019; FAO, 2017). Agriculture sector should increase productivity in order to improve food security under the challenge of climate change and rapid population growth by 2050 (Harvey *et al.,* 2018). This is vital as statistics show that in 2018 still, 821 million people in the world were food insecure chronically, an increase up from 815 million in 2017 (FAO, 2018). Although, still a reduction from about 900 million in 2000 (FAO, 2015).

In Africa, about 181 million people were food insecure in 2010 while in 2017 the number of food insecure people increased to about 236 million (FAO, 2018). Food insecurity and climate change in African countries have affected poor farming households which are struggling to eradicate hunger and addressing challenges which hinder both supply and demand for food (Ochieng, 2018).

According to McGuire (2015) 95% of the farming households in Africa are facing challenges of unreliable rainfall, poor soil fertility and the impact of climate change and variability which affect agricultural productivity, hence household food insecurity. The Food and Agriculture Organization FAO (2010a) defines food security as a ‘‘situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life’’

Agriculture contribute about 65.5% of employment; provides livelihood to more than 70% of population, 29% of GDP; 30% of exports and 65% of inputs to the industrial sector (URT 2016). However, the situation of food security in Tanzania is mixed, which reflect the effect of climate change across agro-ecological zones and other causes like soil infertility, drought and low usage of agricultural practises (Maliondo *et al.*, 2012; Müller *et al.*, 2011).

Climate change and variability is already affecting food security (i.e. food availability, accessibility, utilization and price stability) in the country. For example, according IPCC (2014) the average annual temperature increased by 1.0^{0}C while the annual rainfall decreased by 2.8 mm per month per decade since the early 1960s. It is also projected that the annual mean temperatures are expected to rise by 2.2 ^{0}C by 2100 (IPCC, 2014).

In the Southern Highlands of Mbeya and Songwe Regions, there is evidence of increasing of annual mean temperature by 0.27 ^{0}C /decade since the 1960s and declining rainfall, frequent droughts and significant increases in spatial and temporal variability of rainfall (Craparo *et al.,* 2015; Mbululo and Nyihirani, 2012). Change in temperature and extreme weather event are expected to increase the challenge of pest and disease, land degradation; as a result, declining and uneven yield trends with significant effects on household food security (Nyasimi *et al.,* 2017). Therefore, it is important for the country to have strategies which increase agriculture productivity and income, climate change adaptation and reduction of greenhouse gases emission in order to boost household food security (Zeleke and Aberra, 2014).

Majority of farming households in Mbeya and Songwe Regions and Tanzania at large are agriculture dependent for their livelihood despite the production constraints triggered by the climate change. The ability to cope with the climate change impacts depends mostly on the household's adaptive capacity to climate change. Various approaches have been suggested for reducing the impacts of climate change in agriculture sector (Maliondo *et al.*, 2012). Inorder to to maintain livelihood of the farming households though agriculture production climate-smart agriculture (CSA) have appeared to be very promising approach that can incorporate the benefits of a sustainable increase in agricultural productivity, the adaptation and building of resilient agricultural and food security systems, as well as the reduction of greenhouse gas (GHG) emissions from agricultural activities (FAO, 2010a).

Therefore, CSA is the appropriate approach to reduce the climate change impact (Asfaw *et al.*, 2016; Campbell *et al.*, 2014). CSA concept was originally put forth by FAO in 2010 after the Hague conference on Agriculture, Food Security and Climate Change in 2009 (FAO, 2010b). The main objective of CSA is to reset agriculture in the perspective of a changing climate, to assure a 'triple win', consequently, adaptation, mitigation and development (FAO, 2010a). CSA has therefore been defined as an approach that increases agricultural productivity and incomes; improves adaptation to climate change, reducing or removing Greenhouse Gases hence enhancing the achievement of national food security (FAO, 2014).

Climate change and variability is already affecting or expected to affect food security in Tanzania. Currently, Tanzania highlights four major adaptation investments such as agricultural research, extension, expansion of irrigation, and road infrastructure development to nurture a growing and resilient agriculture sector in a changing climate (URT, 2017).

Tanzania has various policies and framework to transformation of Tanzania’s agriculture under the error of climate change These include; the Tanzania Development Vision 2025, the National Strategy for Growth and Reduction of Poverty I and II (NSGRP I & II), the Agriculture Sector Development Strategy (ASDS), Agricultural Sector Development Program I and II (ASDP) and the recent Tanzania's green revolution initiative known as Kilimo Kwanza (URT, 2016).

In Tanzania, CSA-practises are important practises in addressing the impact of climate change (URT, 2016). The government of Tanzania and other local and international organizations, such as African Green Revolution Alliances (AGRA), Centre for Agriculture Mechanization and Rural Technology (CARMATEC), Tanzania Agriculture Research Institutes (ARI), ADP-Mbozi are promoting and implementing various of CSA-practises projects in order to reduce the impacts of climate change (URT, 2017; AGRA, 2016).

The practises include: training and promotion of the use of drought tolerant seed, use of organic manure, use of intercropping, use of irrigation, use of crop rotation, use crop residue and use of crop diversification (Mkonda and He, 2017). Finally, a Tanzania Climate-Smart Agriculture Alliance (TCSAA) was established to organise CSA-initiatives within the framework of the National CSA Programme (URT, 2017).

CSA-practises can address the impact of climate change in agriculture through sequestering soil carbon, improving soil fertility, and enhancing crop yields and incomes (Lee, 2005; Woodfine, 2009; Branca *et al.*, 2011; Manda, *et al.*, 2015; Teklewold, *et al.*, 2013). Teklewold *et al.*, (2013) indicated that usage of drought tolerant seeds is likely to be an important strategy in adaptation to future climate change, especially when it is combined with crop rotation. Combination of crop rotation and intercropping have been proved to deliver many ecosystem services, including soil carbon sequestration, nitrogen fixation and breaking the life cycle of pests, improving weed suppression (Di Falco *et al.,* 2010; Jhamtani, 2011; Tilman *et al.,* 2002; Woodfine, 2009) while increasing crop yield. Teklewold *et al.,* (2013) further reports that combination of crop rotation and intercropping can also reduce the use of chemical fertilizers and pesticides and hence contributes to mitigation of climate change. Therefore, this study aimed to investigate the determinants of using CSA-practises in isolation or in combination and its impact on household food security in Mbeya and Songwe regions in Tanzania.

1.2 Problem Statement

Farming households in Tanzania are important to reduce food insecurity and bring sustainable development (AGRA 2016). However, agricultural production in these countries has been affected by climate change, climate variability and market constraints (Gebremariam *et al.*, 2016). In Tanzania, climate change threatens agricultural productivity and farming household welfare resulting in food insecurity (Craparo *et al.*, 2015).

Despite inspiring economic growth and the living standard improvements for the past twenty years, food insecurity remains a major economic and social problem in Tanzania. In 2020 the country ranked 89 out of 107 countries on the Global Hunger Index (GHI, 2020). In the Southern Highlands ofTanzania (Mbeya and Songwe Regions) about 44.7% of children below five years were stunted which is relatively high compared to the South West Highlands 43.1%, Ruvuma region 44.4 %, Geita Region 40.5% and at national level 34.4% (TFNC, 2017).

Therefore, appropriate approach should be considered to improve agriculture productivity and food security while reducing the negative impacts of climate change (Tessema, 2016). Several empirical studies have revealed that the negative impacts of climate change can be handled through the usage of proper agricultural practices (Kassie *et al.,* 2014; Ngoma, *et al.,* 2015). CSA has been considered as an appropriate approach to improve food security in the under the climate change era (FAO, 2010a). The approach is vital as it has triple benefits of improving agriculture productivity and income, improve climate change adaptation and educe or remove the greenhouse hence food security improvement (FAO, 2010b).

Despite the CSA-practises benefits and the efforts made by the government and non-governmental organizations to promote usage of CSA-practises to farming households, but still there is no enough evidence on determinants of using CSA-practises and their usage impact on food security (Tenge *et al*., 2004; Maliondo *et al*., 2012).

Nevertheless, several studies have analysed the relationship between usage of agricultural practises and overall welfare among the farming households in Tanzania (i.e. Chegere and Stage, 2020; Lovo and Veronesi, 2019; Kim *et al.,* 2019; Ayenew *et al.*, 2017; Tasciotti and Wagner, 2015). However, the most of these studies concentrated on the usage and impact of single practises and cannot control for the observed and unobserved heterogeneities which lead to the bias estimate.

Therefore, studies that have analysed the determinants of using combination of CSA-practises and its impact on household food security are still scarce in the literature. This study assessed the usage and intensity of using CSA-practises, determinants of using combination of CSA-practises and evaluate the subsequent impact of using them on household food security in Mbeya and Songwe Regions in Tanzania.

1.3 Research Justification

The main contribution in this study is in the following ways. It articulates the synergetic effects rising from the combination of CSA-practises in helping to achieve households' food security. Furthermore, the study investigated whether usage of CSA-practises in combination or in isolation will improve food security. The knowledge is appropriate to the on-going debate on whether farming households should use CSA-practises in piecemeal or in the combination to improve household food security.

In addition, this study encompasses the empirical and methodological approach in the literature by implementing both parametric and non-parametric approaches to evaluate the impact of CSA-practises on food security while controlling the observed and unobserved heterogeneity. The study relevant for designing extension policy by recognising CSA-practises combinations with the highest payoff.

1.4 Objectives

1.4.1 Overall objective

The overall objective of this study was to contribute in improving the livelihood of farm households through evaluation of the impact of usage of climate smart agricultural practises on food security among farm households in Mbeya and Songwe regions.

1.4.2 Specific objectives

The specific objectives of the study were to:

i) assess the usage and intensity of using multiple CSA-Practises by farming households in the study area

ii) assess the determinants of using combination of climate-smart agriculture practises by farming households in the study area

iii) evaluate the impact of using combination of crop rotation, residue retention and intercropping on food security in the study area

iv) evaluate the impact of using combination of organic manure, irrigation and drought tolerant maize seeds on food security in the study area

v) evaluate the impact of climate-smart irrigation practise on food security in the study area

1.5 Research Hypotheses

This study is directed by the following four hypotheses

i) There is no complementarity or substitutability on multiple use of climate smart agriculture practises.

ii) Farming household will choose a combination of crop rotation, residue retention and intercropping that maximizes utility subject to production constraints.

iii) Farming household will choose a combination of organic manure, drought-tolerant maize seeds and irrigation that maximizes utility subject to production constraints.

iv) Farming household will use irrigation as a climate smart agriculture practise if the benefit of using it is higher than of not using.

1.6 Conceptual Framework

Climate change is a major problem in developing countries as it affects agricultural productivity and food security (FAO, 2019). The impact of climate change could be reduced if the majority of farming households use CSA-practises as established by FAO in 2010. Farming households used CSA-practises with a goal of increasing productivity, improving climate change adaptation capacity and reducing or removing greenhouse gases (Lipper *et al.*, 2014). Combination of these goals can improve agricultural productivity, hence food security (FAO, 2013).

In this study, the agricultural practises which fit into the CSA framework as recommended by FAO were identified. Farming households surveyed were asked to mention agricultural practises they applied in their plots in the previous season preceding the survey. In this study, the factors which influenced the multiple CSA-practises, the intensity of using multiple CSA-practises, the determinants of using combination of CSA-practises and the impact of using CSA-practises on household food security were conceptualized. That is to say, farming households use various CSA-practises, such as crop rotation, residue retention, intercropping, organic manure, drought-tolerant maize seeds and irrigation to improve crop productivity and ultimately improve household food security.

The usage of CSA-practises can be influenced by household characteristics, plot/farm characteristics, geographical locations, institutional characteristics and resource endowments

(Abegunde *et al.,* 2020; Aryal *et al.,* 2018; Akrofi *et al.,* 2019). These factors can affect the level of usage or usage intensity. Figure 1-1 summarizes how this study conceptualizes CSA-practises usage among farming households and the usage impact on food security.

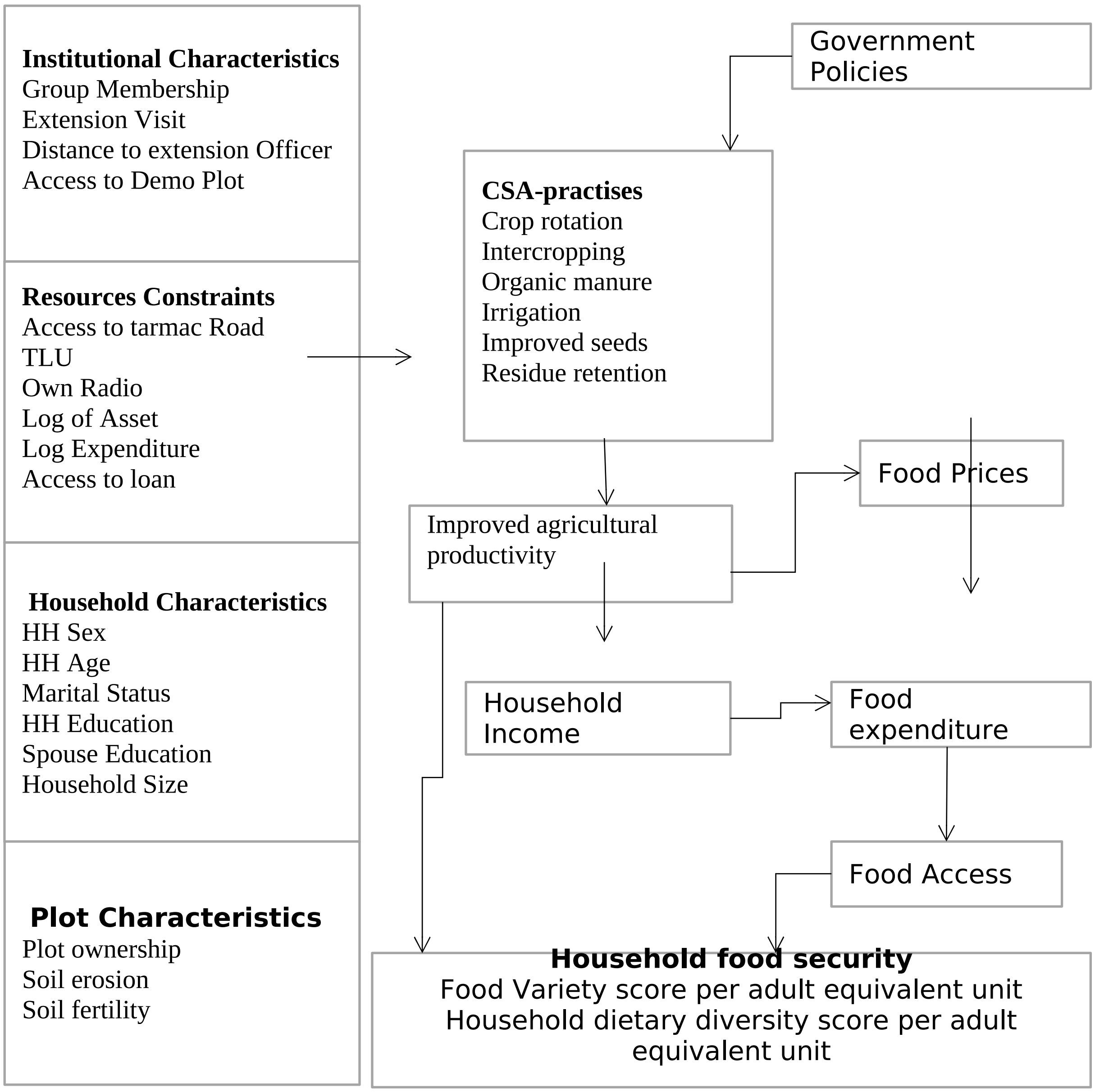

Figure 1. 1 **Conceptual Framework**

Usage of CSA-practises is hypothesized to affect household food security. It is assumed that the usage of CSA-practises can naturally increase food crop yield (maize, soya beans, common beans and paddy). An increased food crop yield is vital in the generation of household income as a result of selling the surplus food crops. The increased income means less household food insecurity as it helps farming households to buy other foods which are not produced by the household. This may improve the food security status of household members. The consumption of maize, soya beans, common beans and paddy as a result of increased yields also ensures food security.

However, there is a possibility of endogeneity in household' decisions on the use CSA-practises. These decisions are likely to be affected by observed and unobservable characteristics that may be correlated with the outcome variables (household dietary diversity score per adult equivalent Unit (HDDS/AEU) and food variety score per adult equivalent unit (FVS/AEU) (Kassie *et al.*, 2014).

To separate the impact of usage and to effectively analyse the factors affecting the usage of CSA-practises, a joint framework model such as multinomial endogenous switching regression, multinomial endogenous treatment effects and endogenous switching regression models were employed. The advantage of using these approaches is that they evaluating both an individual practise and combination of practises while capturing the interactions between uses of alternative practises (Wu and Babcock, 1998; Mansur *et al.*, 2008).

1.7 Theoretical Framework

The agricultural household model was used in this study to analyse its objectives as it allows one to understand the welfare of the poor. The assumption of this model is that farming households have an objective function to maximize utility subject to production constraints (i.e. drought, floods, pests and diseases and other climate change effects). The focus of agricultural household models is on the number of assumptions about the workings of the wider economy within which farming household's production takes place. However, not all assumptions are shared in these models but they use the same theoretical methods to explain the behaviour of the farming households. The agricultural household models include the profit maximization model, utility maximising model and risk-averse model.

1.7.1 Profit-maximising model

The profit maximising model was developed by Schultz (1964) and he hypothesised that in developing countries farming households are efficient but poor. Schultz argues that in developing countries, the low productivity of the factors of production is caused by the low-income levels and not because of allocation inefficiencies. This implies that the farming households can use CSA-practices individually or in combination to maximize the profit (i.e. increased productivity and income, improving climate change adaptation capacity, reducing/removing greenhouse gases and improving food security).

The policy implication is that agricultural experts such as agricultural extension officers or farm advisers could not assist farming households to allocate resources in order to increase productivity of the factors of production but they should educate the farming households on the production factors which lead to increase productivity. In case of this study farming households in the study area different organization such as district councils, SNV-Tanzania, Tanzania Agriculture Research Institutes (TARI) promotes and encourage farming households to use the CSA-practises (crop rotation, intercropping, irrigation, organic manure, irrigation, drought tolerant maize seeds and crop residue retention) to improve food security of the household through increased productivity and income, improved climate change adaptation and reducing greenhouse gases. However, the profit maximising model has been criticised to be silent on the aspect of consumption in the farming households' decision processes.

Ray (2006) developed an aspiration window which formed a cognitive world and may be multidimensional. Ray argued that the farming household can aspire better living standard and other aspirations such as good health, recognition, education etc. In addition these aspirations can complement each other, or they can substitute each other.

In this study, farming households can be aspired to use CSA-practises to improve agriculture productivity, improve adaptation to climate change or mitigate greenhouse gases. However, the use of CSA-practises can be complementing one another or some can substitute the other. According to Millar (2006) criticised that poor farming households in developing countries do not make decisions based on their best interest in the end. Therefore, these criticisms show a contradicting point at which poor farming households are rational towards benefits of outcome or other aspirations. Currently the neoclassical agricultural household models such as utility maximising model have become popular as have incorporated the production and consumption goals of the poor farming households.

1.7.2 The utility-maximising model

The utility maximization approach considers the production and consumption decisions as interdependent. The utility-maximising model was developed from the Chayanov's work in 1920s where he doubts the profit-maximising model (Millar, 1970). Chayanov argued that the farms of poor farming households are operated by the family and the labour allocation by family members is positively related to the ratio of consumers.

The difference on economic achievements among farming households are connected with the size of the household and the composition. These reveal an inconsistent approach to the hypothesis that poor farming households manage their farms to maximize benefits (food security). Becker (1965) modelled the farming household decision and allocation household resource by considering household as a producer and consumer unit.

The farming household consume the goods produced by the household or goods purchased in the market (i.e goods which are not produced by the household) and leisure to maximize their utility subject to the budget constraints (Taylor and Adelman, 2003). This means farming households the excess food produced for consumption is sold in the market while the shortage of the food produced by the household can be purchased from the market in order to diversify the food consumed hence improve household food security (Taylor and Adelman, 2003). Similarly, excess labour is likely to be sold, while shortage of labour forces household to buy leading to labour balance

However, the production and consumption are considered independent under the assumption that the markets are prefect; prices are exogenous and good are tradable. Therefore, in this situation, family labor allocation is linked to market-determined wage as time to work and leisure are independent (De Janvry and Sadoulet, 1996). Therefore, the model is said to be non-separable when production decisions for the case of this study the decision to use CSA-practises either in isolation or in combination are determined by the characteristics of the consumer (plot characteristics, household characteristics, institutional characteristics, etc.) as a result of presence of market imperfections (De Janvry and Sadoulet, 1996). The utility maximizing model been applied in various contexts. These applications include, examining the determinants of agriculture practices/technologies and the impact of using them on household welfare.

Based on this study in the situation of imperfect labour market and food insecurity due to climate change, farming households should be compensated to adjust labour allocation through investment on CSA-practises which improve productivity and food security and commodity consumption. Then the allocation of labour and food consumption decisions is connected through the endogenous price which fulfils the equilibrium of supply and demand equilibrium.

As other farming household elsewhere, farming households in Tanzania, particularly from Mbeya and Songwe Regions are food producers and consumers. That means, they are involved in the decision making of food production and consumption. However, these households are facing production constraints, such as missing input and credit markets, a high level of unemployment and high transaction costs.

Farming households in the study area used the food produced for their own consumption and supply in significant proportional of the factor input. Therefore, assuming the production and consumption decision as independent is completely wrong. Furthermore, farming households in the rural areas are gifted assets such as physical capital, financial, natural, social and human capital which are used to build their livelihoods. The farming households maximises utility by efficient use of these assets. However, the decision to use these assets to improve agricultural productivity is affected by climate change, climate variability, and market consraints (Gebremariam *et al.*, 2018; Maliondo *et al.*, 2012).

Based on this theory the introduction of CSA-practises such as residue retention, intercropping, drought-tolerant seeds, irrigation, organic manure and crop rotation could affect the farming households' expectation to increase productivity, increasing adaptation to climate change and mitigating greenhouse gases, hence household food security (FAO, 2010). These, in turn, could motivate farming households to invest in different CSA-practises to improve household food security (Asfaw *et al*., 2012).

However, the theory failed to explain the effect of risk and uncertainty in agricultural production decision making. Taylor and Adelman (2003) argued that farming households are not risk-neutral; and if it is assumed to be so, the objective function and constraints can be over-simplified. This gap can be filled by the risk-averse model explained below.

1.7.3 Risk-averse model

The farming households exposed to risks and uncertainties which affect their agricultural production because uncertainty and risk play a major role in production decisions. For example, Shemsanga *et al.* (2010) found that agriculture risk such as weather, pest, diseases many farmers affect production decision as the lead to lower yield and quality of food. Kangalawe *et al.* (2011) found that among the farming household used coping strategies such as drought-tolerant maize seeds, crop diversification irrigation among others to combat the production risks and uncertainties. Shemsanga *et al.* (2016) shows that poor farming households find difficult to handle the impacts climate change using improved technologies and decide to rely on their indigenous skills.

Based on the context of risk, the expected utility was explained by von Neumann and Morgenstern (1986) after the initial work of principle for decision-making theory by Bernoulli (1738). The early description of expected theory to agriculture can refer to the work of Dillon (1971). The study provides recognition of the personal nature of decision making in terms of belief and preferences, and that could represent the best possible to risky choice in agriculture. Newbery and Stiglitz (1981) contribute on commodity price stabilization issues, and explore the problems of risk in agriculture.

In general, there are two approaches to capture the basic ideas of these works. First, the expected utility model allows household to make choices on the given preferences of outcomes and beliefs on possibility of occurrence. Second, the households are risk-averse, meaning that they prefer low risky choice than the high risky alternatives. Farming households in the study area use drought tolerant maize seed, crop diversity and irrigation to minimise risks in agricultural production. There the study used the combination of agricultural household models to analyse the objective of the study. Therefore, the three farm household approaches explained above are the appropriate for the analysis of this study.

1.8 General Description of Research Methodology and Data

1.8.1 Study area

The study was conducted in two regions and four districts. That is, in Mbeya and Mbarali districts in Mbeya Region and Mbozi and Momba districts in Songwe Region in Tanzania.

These regions the breadbasket area of Tanzania where different types of crops are cultivated such as maize, beans, soya beans and paddy rice. Selection of the study area was based on the cultivation of staple food crops such as paddy, maize, common beans and soya beans. In addition, food and nutritional security vulnerability was another selection criterion, because 37.7 % of children below five years are stunted (TFNC, 2014). The study area is also considered as appropriate for this study because farmers primarily rely on food crop production for their livelihoods. Furthermore, mixed agronomic practises were also the main driver for selection of the study area.

1.8.2 Sampling and data collection

The study used cross-sectional data collected from a farm household survey in the Southern Highlands of Mbeya and Songwe in Tanzania. The survey was conducted between September–December 2017 by the Sokoine University of Agriculture in partnership with the Integrated Project to Improve Agricultural Productivity and Food Security in the Bread Basket area of Southern Highlands of Tanzania. The sample covered 1443 farm households where multistage sampling was used to select farmer organizations (FOs) from each district, and households from each FO.

First, based on their food production potential crops (maize, paddy, common beans, and soya beans), whereby four districts were selected purposively from two regions of the Southern Highlands of Tanzania (Mbeya and Songwe Regions). Second, 51 wards were randomly selected out of 92 wards. Third, FOs in each ward were identified then farming households from the selected FOs were sampled using a proportionate random sampling to get a total of 1443 households. The male and female structured questionnaires were used to collect data where open data kit was used. Different information were collected such as household demographics, socioeconomic characteristics, CSA-practises used, crop production and marketing, input use, food consumption, and other farm- and farmer-specific characteristics.

1.8.3 Sample size calculation

The minimum required sample size is 1549 households. The number is determined by the approach based on the precision rate and confidence level (Habib *et al.*, 2014). The estimation formula for the sample size is;

$n = ¿¿$

Where $P$the prevalence of food security, E is the margin error (Precision). Generally, E is 10 percent of P and $Z_{\frac{\alpha}{2}}$ is normal deviate for two-tailed alternative hypothesis at a level of significance of 5 percent; ($Z_{\frac{\alpha}{2}}$*is 1.96*). D is the design effect reflects the sampling design used in the survey type of study. Previous literature gives the estimate P prevalence of household dietary diversity as 21.6 percent in the population surveyed, and assuming 95% confidence interval or 5% level of significance and 10% margin of error, the sample size can be calculated as follow as;

$n = ¿¿$

Total sample sizes of 1557 households were then selected for the survey. However, some households (114) were dropped during data cleaning prior to analysis as they did not have sufficient data thereby, reducing the sample to 1443 households.

1.9 The and Limitation of the Study

This study was conducted in the Southern Highlands of Mbeya and Songwe regions in Tanzania, targeting farm households which cultivate food crops (maize, beans soya beans and paddy). The study collected different information based on the previous production season. Further, household characteristics, farm/plot characteristics, resources endowment, institutional characteristics factors were required to establish how they influence usage of CSA-practises and its impact on household food security. However, the study was limited to the analysis of the household level and did not consider the seasonal variation on food production.

1.10 The Organization of the Study

This document is structured as follows; The paper titled "Usage and Intensity of using Multiple CSA-practises in the Southern Highlands of Tanzania" was presented in Chapter Two while in Chapter Three present a paper titled "Combination of Climate Smart Agriculture Practises: An Analysis of Farm Households' Decisions in the Southern Highlands of Tanzania". Chapter Four present a paper titled the "Impact of the Combination of Climate Smart Agriculture Practises on Food Security: A Counterfactual Analysis from Mbeya and Songwe Regions in Tanzania" Chapter Five presents a paper on "Combining Climate Smart Agriculture Practises Pays off: Evidence on Food Security from Southern Highland Zone of Tanzania". In Chapter Six present the paper titled "Understanding the Impact of Climate Smart Irrigation on Household Food Security: A Counterfactual Analysis of Southern Highland Zone of Tanzania" In Chapter Seven; the synthesis of the study was presented.

Reference

Abegunde, V. O., Sibanda, M., & Obi, A. (2020). Determinants of the Adoption of Climate-Smart Agricultural Practises by Small-Scale Farming Households in King Cetshwayo District Municipality, South Africa. *Sustainability*, *12*(1), 195.

African Green Revolution Alliance (AGRA) (2016). Tanzania Annual Report. Available from https://agra.org/2016AnnualReport/. Accessed (11/07/2018)

Agrawala, S., Moehner, A., Hemp, A., van Aalst, M., Hitz, S., Smith, J., Meena, H., Mwakifwamba, S.M., Hyera, T., Mwaipopo, O.U., (2003). Development and climate change in Tanzania: focus on Mount Kilimanjaro. OECD Report, Paris, France. 72 pp.

Akrofi, N. A., Sarpong, D. B., Somuah, H. A. S., & Osei-Owusu, Y. (2019). Paying for privately installed irrigation services in Northern Ghana: The case of the smallholder Bhungroo Irrigation Technology. *Agricultural water management*, *216*, 284-293.

Aryal, J. P., Jat, M. L., Sapkota, T. B., Khatri-Chhetri, A., Kassie, M., & Maharjan, S. (2018). Adoption of multiple climate-smart agricultural practises in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies and Management*. 10 (3), 407-427.

Asfaw, S., McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., (2016). What determines farmers' adaptive capacity? Empirical evidence from Malawi. Food Secur. Sci. Sociol. Econ. Food. Prod. Acce. Food. 8 (2).

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food policy*, *37*(3), 283-295.

Becker, G. S. (1965). A Theory of the Allocation of Time. *The economic journal, 75*(299), 493-517.

Beyene, A. D., Mekonnen, A., Kassie, M., Di Falco, S., & Bezabih, M. (2017). Determinants of Usage and Impacts of Sustainable Land Management and Climate-Smart Agricultural Practises (SLM-CSA): Panel Data Evidence from the Ethiopian Highlands. *Environment for Development Discussion Paper Series*, (17-10).

Campbell, B.M., Philip Thornton, P., Zougmore, R., van Asten, P., Lipper, L., (2014). Sustainable Intensification: what is its role in climate smart agriculture? Curre. Opin. Environ. Sust. 8, 39 - 43.

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

De Janvry, A., & Sadoulet, E. (1996). *Household modeling for the design of poverty alleviation strategies* (No. 1557-2016-132652), University of California.

Dillon, J. L. (1971). An expository review of bernoullian decision theory in agriculture: Is utility futility? *Review of marketing and agricultural economics*, *39*(430-2016-31041), 3-80.

FAO (2010a). Climate-Smart Agriculture Sourcebook. Food and Agriculture Organization of the United Nations. Rome. Available from http://www.fao.org (Accessed 13/10/2017).

FAO (2014) FAO success stories on climate-smart agriculture. Food and Agriculture Organization of the United Nations. Available from: http://www.fao.org/3/a-i3817e.pdf (Accessed 11/11/2017).

FAO), (2018). The state of food insecurity in the world. Food and Agricultural Organisation of the United Nations, Rome. Available from http://www.fao.org (Accessed 14/2/2019).

FAO, (2010b). The State of Food Insecurity in the World: Addressing food insecurity in protracted crises. Food and Agriculture Organization of the United Nations (FAO) and World Food Programme (WFP). Available from http://www.fao.org (Accessed 13/10/2017).

FAO, (2015). The state of food insecurity in the world. Food and Agricultural Organisation of the United Nations, Rome. Available from http://www.fao.org (Accessed 14/1/2018).

FAO, (2017). The state of food insecurity in the world. Food and Agricultural Organisation of the United Nations, Rome. Available from http://www.fao.org (Accessed 10/2/2018).

FAO, (2019). The state of food insecurity in the world. Food and Agricultural Organisation of the United Nations, Rome. Available from http://www.fao.org (Accessed 29/5/2019).

Gebremariam, G., & Wünscher, T. (2016). Combining sustainable agricultural practises pays off: evidence on welfare effects from Northern Ghana (No. 310-2016-5382)

Available at: https://ideas.repec.org/p/ags/aaae16/246452.html. (Accessed 23 May 2019)

Global Hunger Index, (2020). Available at; https://www.globalhungerindex.org/ranking.html (Accessed 23April 2021)

Habib, S., Aslam, S., Hussain, A., Yasmeen, S., & Ibrahim, M. (2014). The impact of organizational culture on job satisfaction, employees' commitment, and turnover intention. *Advances in Economics and Business*, *2*(6), 215-222.

Harvey, C. A., Saborio-Rodríguez, M., Martinez-Rodríguez, M. R., Viguera, B., Chain-Guadarrama, A., Vignola, R., & Alpizar, F. (2018). Climate change impacts and adaptation among smallholder farmers in Central America. *Agriculture & Food Security*, *7*(1), 1-20.

IPCC. Climate Change (2014): Impacts, adaptation, and vulnerability, part B regional aspects, Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, New York; 2014.

Kangalawe, R., Mwakalila, S., & Masolwa, P. (2011). Climate change impacts, local knowledge and coping strategies in the great Ruaha river catchment area, Tanzania.

Kassie, M., Jaleta, M., & Mattei, A. (2014). Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach. *Food Security*, *6*(2), 217-230.

Lipper, L.; Thornton, P.; Campbell, B.M.; Baedeker, T.; Braimoh, A.; Bwalya, M.; Caron, P.; Cattaneo, A.; Garrity, D.; Henry, K. (2014). Climate-smart agriculture for food security. Nat. Clim. Chang. 4, 1068–1072.

Maliondo, S. M. S., Mpeta, E. J., & Olson, J. (2012). Climate change and food security in Tanzania: an analysis of current knowledge and research gaps and recommendations for a research agenda. *Ohio State University and Sokoine University of Agriculture: Columbus, OH, USA*.

Mansur, E.T., Mendelsohn, R., Morrison, W., 2008. Climate change adaptation: a study of fuel choice and consumption in the US energy sector. *Journal of Environmental Economics and Management 55*, 175–193.

Mbululo, Y., & Nyihirani, F. (2012). Climate characteristics over southern highlands Tanzania. *Atmospheric and Climate Sciences*. 2, 454-463

McGuire, S. (2015). FAO, IFAD, and WFP. The state of food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress. Rome: Available at; https://academic.oup.com/advances/article/6/5/623/4558110 Accessed 25 April 2020)

Michler, J. D., Tjernström, E., Verkaart, S., & Mausch, K. (2019). Money matters: The role of yields and profits in agricultural technology adoption. *American Journal of Agricultural Economics*, *101*(3), 710-731.

Mignouna, D. B., Manyong, V. M., Rusike, J., Mutabazi, K. D. S., & Senkondo, E. M. (2011). Determinants of adopting imazapyr-resistant maize technologies and its impact on household income in Western Kenya. *AgBioForum*, 14(3): 158-163.

Millar, J. R. (1970). A reformulation of AV Chayanov's theory of the peasant economy. *Economic Development and Cultural Change*, *18*(2), 219-229.

Mkonda, M. Y., & He, X. Conservation agriculture in Tanzania. *Sustainable agriculture reviews*. (pp. 309-324). Switzerland. Springer International Publishing.

Müller, C., Cramer, W., Hare, W.L., and Lotze-Campen, H. (2011). "Climate Change Risks for African Agriculture." Proceedings of the National Academy of Sciences of the United States of America (PNAS) 11: 4313–4315.

Ngoma, H., Mason, N. M., & Sitko, N. J. (2015). Does minimum tillage with planting basins or ripping raise maize yields? Meso-panel data evidence from Zambia. *Agriculture, Ecosystems & Environment*, *212*, 21-29.

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., & Mungai, C. (2017). Adoption and dissemination pathways for climate-smart agriculture technologies and practises for climate-resilient livelihoods in Lushoto, Northeast Tanzania. *Climate*, *5*(3), 63.

Ochieng, J., Afari-Sefa, V., Karanja, D., Kessy, R., Rajendran, S., & Samali, S. (2018). How promoting consumption of traditional African vegetables affects household nutrition security in Tanzania. *Renewable Agriculture and Food Systems*, *33*(2), 105-115.

Schultz, T. W. (1964). *Transforming traditional agriculture* Yale University press. *New Haven*, 212.

Shemsanga, C., Omabia, A.N. and Gu, Y. 2010. The cost of climate change in Tanzania: impacts and adaptations. Journal of American Science. 6 (3), 182- 196.

Tanzania Food and Nutrition Center, TFNC. (2017). Tanzania National Nutrition Survey.

Taylor, J. and Adelman, I. (2003). "Agricultural household models: Genesis, evolution, and extensions." *Review of Economics of the Household* 1(1-2): 33–58.

Taylor, J. E., & Adelman, I. (2003). Agricultural household models: genesis, evolution, and extensions. *Review of Economics of the Household*, *1*(1), 33-58.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics*, *93*, 85-93.

Tenge, A. J., De Graaff, J., & Hella, J. P. (2004). Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands, Tanzania. *Land Degradation & Development*, *15*(2), 99-114.

Tessema, Y. M., Asafu-Adjaye, J., Kassie, M., & Mallawaarachchi, T. (2016). Do neighbours matter in technology adoption? The case of conservation tillage in northwest Ethiopia. African Journal of Agricultural and Resource Economics, 11(311-2016-5659), 211-225.

United Republic of Tanzania (2017). A*nnual agriculture sample survey*. Government of printer, Dodoma, Tanzania. 88pp

United Republic of Tanzania, (2016). Agricultural Sector Development Programme Phase Two (ASDP II). Ministry of Agriculture, Food Security and Cooperatives. Dar es Salaam.

United Republic of Tanzania, (URT). (2017). A*nnual agriculture sample survey*. Government of printer, Dodoma, Tanzania. 88pp

Von Neumann, J. (1986). John von Neumann on technological prospects and global limits. *Population and Development Review*, *12*(1), 117-126.

Wu, J., & Babcock, B. A. (1998). The choice of tillage, rotation, and soil testing practises: Economic and environmental implications. *American Journal of Agricultural Economics*, *80*(3), 494-511.

Zeleke, M. T., and Aberra, Y. (2014). Determinants of the adoption of land management strategies against climate change in Northwest Ethiopia. Ethiopian Renaissance Journal of Social Sciences and the Humanities, 1, 93-118. Kassie, M., Marenya, P., Tessema, Y., Jaleta, M., Zeng, D.

CHAPTER TWO

USAGE AND INTENSITY OF USING MULTIPLE CSA-PRACTISES IN THE SOUTHERN HIGHLANDS OF TANZANIA.

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Abstract

Climate change is the main global problem which affects agricultural development and household food security. Climate-smart agriculture (CSA) is one of the approaches developed by FAO to address the impact of climate change through increasing agriculture productivity, improve adaptation to climate change and mitigate greenhouse gases emission. However, the CSA-practises usage by farmers is still low in the developing countries, Tanzania inclusive. To understand the challenges in the use of CSA-practises, an analysis which combines multivariate and ordered probit models were employed to analyse the decisions to use and the intensity to use the six CSA-practises (i.e. drought-tolerant maize seed, crop rotation, organic manure, intercropping, irrigation and residue retention) frequently practised in the study area. The study sampled 1443 farming households from two regions (Mbeya and Songwe) in the Southern Highlands of Tanzania. Results show that farming households are using CSA-practises as complements. The results are important in designing combinations of CSA-practises. The study also found that gender of the head of the household, geographical location, and plot ownership are important determinants of the use of the type and number of CSA-practises. It is recommended that agriculture experts should carefully design combinations of CSA-practises for the aim of increasing agricultural productivity, resilience to climate change, mitigation of greenhouse gases and improvement of food security.

Keywords: Climate Smart Agriculture Practises, Multivariate Probit Model, Ordered Probit Model

2.1 Introduction

Climate change is the main global problems which affect agriculture development (IFAD, 2011). In agricultural production climate change is important in determining the type of crop to be grown by the farming households as it directly or indirectly affects production and food supply (Tambo and Abdoulaye, 2012). Climate change lead to the accumulation of greenhouse gases caused by human socio-economic activities such as; agricultural production, deforestation and bush burning. Farming households in Sub Saharan African (SSA) countries solely depend on agriculture as a means of their livelihood (Azumah *et al.*, 2020). However, the farming system in these countries largely depends on rainfal, thus creating it extremely susceptible to climate change, which results into negative impacts on agricultural productivity, income and food supply (FAO, 2014). For example, Nwaobiala and Nottidge (2013) predicted that climate changes might affect crop production in SSA by 10 – 20 % by 2050 or even up to 50%.

Tanzania is not exceptional from other SSA countries in the effect of climate change. This is due to the fact that the temperature in Tanzania is expected to increase by 2˚C to 4˚C by 2100, and more warming during the dry season and in the interior regions of the country is expected (Hulme *et al*., 2001; Tumbo *et al.*, 2010). The country is also experiencing frequent floods and drought while in some areas it is highly affected by unreliable rainfall which results into low yield and food insecurity problems (Maliondo *et al.*, 2012). According to Rowhani *et al.* (2011), production of maize, rice and sorghum is expeted to decrease by 13, 7.6, and 8.8 % respectively by 2050 as a result of climate change.

However, several agricultural approaches have been used in the developing countries to improve agriculture productivity in this era of climate change (Abegunde *et al.*, 2020). Climate-smart agriculture (CSA) proposed by Food and Agriculture Organization (FAO) as one of the promising approach in improving agriculture productivity and income, increase climate change adaptation and mitigate greenhouse gases (Lipper *et al.*, 2014; FAO, 2010). Various CSA-practises have been identified by FAO among them are residue retention, irrigation practises, reduced tillage, organic manure, intercropping, and organic fertilizers, use of cover crop, etc. (Muzangwa *et al.*,2017). These practises when used in isolation or in combination can deliver either two or three of the three CSA benefits (FAO, 2010).

Several researches (e.g see, Kimaro *et al.*, 2019; Kurgat *et al.*, 2020; Kurgat *et al*., 2020; Aryal *et al.*, 2018; Akrofi-Atiotianti *et al.*, 2020) examined the usage of CSA-practises by farming households. Generally, these studies found that, household characteristics, plot characteristics, institutional characteristics and some resource constraints were significant determinants of using CSA-practises in Tanzania and elsewhere. However, the majority of these studies have analysed single practise without considering that CSA incorporates a set of practises and farming households can use them in combination (Vera and Justin, 2017).

In addition, little is known about the multiple uses of CSA-practises in Tanzania, particularly in Mbeya and Songwe regions. According to Teklewold *et al.* (2013), the usage of CSA practises in combination could build a sustainable agricultural system which is resilient to climate change and other factors which are constraint to agricultural production. The CSA-practises considered in this study includes crop rotation, intercropping, irrigation, organic manure, drought tolerant maize seeds and residue retention. To understand the challenges in the use of CSA-practises, an analysis which combines multivariate and ordered probit models were employed to analyse the decisions to use and the intensity to use the multiple CSA-practises

The study seeks to add to the limited literature on determinants of usage of CSA-practises where household characteristics, plot characteristic, institutional characteristics and resource constraints were considered. The specific objective of the study was to examine the usage and the intensity of using multiple CSA-practises in the Southern Highlands of Tanzania.

This study relied on four contributions: first, the study used a comprehensive household level survey recently conducted on food crops (maize, paddy, beans and soya beans) farming systems in Mbeya and Songwe regions; second, the study employed methods which consider the interdependence between CSA-practises and joint analysis of the usage decision. A number of CSA-practises were considered, such as crop rotation, irrigation, drought-tolerant maize seeds, residue retention, intercropping and organic manure.

Understanding the interrelationship between set of CSA-practises is crucial for the on-going debate on whether farm household should use CSA-practises in isolation or in package. This will assist policy-makers and agricultural extension agents to put strategies that promote CSA-practises to farmers. Third, the study concentrated on the importance of household characteristics, plot characteristics and institutional characteristics, to determine the probability and the intensity of usage of CSA-practises. Fourth, this study extends the concentration from the probability of usage decision to the extent of usage as measured by the number of CSA-practises used.

The following section presents the analytical and conceptual framework. Section 2.2 presents the analytical and conceptual framework. Section 2.3 presents the methodology of the study and section 2.4 present results and discusions. Section 2.5 presented the conclusion and policy implications.

2.2 Analytical and Conceptual Framework

In examining factors which influence the usage of CSA-practises usually the probit and logit models are used in many studies. The probit or logit model as univariate models they use single equation for each practise. However, the weaknesses of these models is that they do not consider the interdependence when multiple practises are used (Teklewold *et al*., 2013; Muriithi *et al.,* 2018; Mwungu *et al.,* 2018) and are not able to account for the fact that farming household are more willing to use more than one practise based on their experiences and benefits obtained from each practise.

Using the probit and logit model cannot tell if the farming household tend to use practises as a complements or as a substitute. These weeknesses can be accounted by the use of the multivariate probit model (MVP) as it can account for the simultaneous usage of multiple CSA-practises and consider the correlation among the disturbance terms that may arise from the relationship between the practises.

2.2.1 A Multivariate Probit Model (MVP)

Farming households can use a combination of CSA-practises to tackle the negative impacts of climate change and other production constraints (Kassie *et al.,* 2013). However, some CSA-practises are not mutual exclusive, in such a way that the use of one CSA-practise can affect the use of the other. Therefore, the interdependent and simultaneous decisions to use can omit the important economic information if the univariate modelling is used for analysis (Kassie *et al.,* 2013). Therefore, to consider possible complementarities and substitutability between the CSA-practises used, a MVP can be an appropriate model (Greene, 2003).

However, the univariate modes are not adequate to account for the complementarities between practises. For example, many farmers who use irrigation may also use drought-tolerant maize seeds; nevertheless, unless the researchers analyse this effect, they will not be able to understand the factors that enhance the use of drought-tolerant maize seeds by the farming households.

Theoretically, a CSA-practise is likely to be used by the farming households if the utility of using the practise is higher than the practise which is not used. Let assume a i^{th} farming household ($i=1,2,....,N$) decide to use the j^{th} CSA-practises (where $j$represents the usage of crop rotation (C_r), irrigation (I_r), intercropping (I_{cr}), organic manure (O_m), residue retentionR_r and drought resistant maize seeds (D_s). Let U_0 and U_1 represent the benefits from using conventional agricultural practises and CSA-practises, respectively.

A farming household can decide to use the j^{th}CSA-practises if the net benefit $\left(y_{ij}^{¿}\right)$is higher $B_{ij}^{¿}=U_j^{¿}-U_0>0$. Therefore, the net benefit is a latent variable $\left(y_{ij}^{¿}\right)$, which is determined by the observed farming household characteristics, plot characteristics, institutional characteristics and resource constraints (X_i) and the error term (ε_i) as shown below:

$$y_{ij}^{¿}=X_i^{'}\beta_j+\varepsilon_i \qquad j=¿)\text{..} \quad (1)$$

The unobserved characteristics in equation 1 can be transformed into observed binary outcome for each CSA-practise used by farming household as shown in equation 2.

$$y_{ij} = \begin{cases} 1 \, if \, B_{ij}^{¿} > 0 \\ 0 \, otherwise \end{cases} \quad j = (C_r, I_r, I_{cr}, O_m, R_r, D_s) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

In a MVP model, with the prospect of using multiple CSA-practises, the error terms jointly follow a multivariate normal distribution with zero conditional mean and variance normalised to unity, i.e. $\mu_{C_r}, \mu_{I_r}, \mu_{I_{cr}}, \mu_{O_m}, \mu_{R_r}, , \mu_{D_s} \rightarrow^{MVN} (0, \Omega)$ and the covariance matrix (X) is given by:

$$\Omega = \begin{bmatrix} 1 & \rho_{C_r I_r} & \rho_{C_r I_{cr}} & \rho_{C_r O_m} & \rho_{C_r R_r} & \rho_{C_r D_s} \\ \rho_{I_r C_r} & 1 & \rho_{I_r I_{cr}} & \rho_{I_r O_m} & \rho_{I_r R_r} & \rho_{C_r D_s} \\ \rho_{I_{cr} C_r} & \rho_{I_{cr} I_r} & 1 & \rho_{I_{cr} O_m} & \rho_{I_{cr} R_r} & \rho_{I_{cr} D_s} \\ \rho_{O_m C_r} & \rho_{O_m I_r} & \rho_{O_m I_{cr}} & 1 & \rho_{O_m R_r} & \rho_{O_m D_s} \\ \rho_{R_r C_r} & \rho_{R_r I_r} & \rho_{R_r I_{cr}} & \rho_{R_r O_m} & 1 & \rho_{R_r D_s} \\ \rho_{D_s C_r} & \rho_{D_s I_r} & \rho_{D_{sr} I_{cr}} & \rho_{D_s O_m} & \rho_{D_s R_r} & 1 \end{bmatrix} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3)$$

The off diagonal elements in the covariance matrix represent the unobserved correlation between the stochastic components of the different types of CSA-practises. This assumption means that equation (2) gives a MVP model that jointly represents decisions to use a particular CSA-practise. The specification with non-zero off-diagonal elements allows for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the usage of alternative CSA-practises.

2.2.2 An Ordered Probit Model

The MVP model is concerned with the probability of using CSA-practises but it does not explain the difference between farming households which use one CSA-practise and those who use multiple CSA-practises. It is difficult to define the demarcation between users and non-users in determining the factors which affect the intensity of CSA-practises usage

(Wollni *et al.*, 2010). The majority of farm households surveyed in this study were not using the whole package but they used combinations of these practises in their farms. Therefore, it is not easy to quantify the intensity of usage of the package of CSA-practises. The study followed the D'Souza *et al.*, (1993) and Wollni *et al.*, (2010), the study applied the number of CSA-practises used as dependent variable to overcome this problem.

The study treated the information of the number of CSA-practises used as a count variable. According to Wollni *et al.*, (2010) the poisson regression model is normally used to analyse count data which assume that, all events have the equal chance of occurrence. Though, in the application, the chance of using the first CSA-practise could be different from the chance of using a second practise, given that in the latter case the farming household has already gained some experience and already exposed to information about that CSA-practise.

As the numbers of CSA-practises used were considered as ordinal variable, hence ordered probit model was employed in the estimations. Different latent variables were involved in the model for the frequency function of CSA-practises $(T^{¿})$. As mentioned earlier, the i^{th} farm household $(i=1,\ldots.,N)$ decides to use a certain number of CSA-practises based on the maximization of an underlying utility function:

$$T_i^{¿}=X_i^{'}\alpha+\varepsilon_i \quad \ldots\ldots (4)$$

X_i represents vector of household characteristics, plot/farm characteristics, institutional characteristics and resource constraints; α stands for a vector of parameters to be estimated; and ε_i is unobserved characteristics. Farming household can decide to use an additional CSA-practise if the utility of using it is higher than the utility of not using it. According to McKelvey and Zavoina, (1975) when the level of utility of individual farming household $T_i^{¿}$ is unobserved, then the observed level of CSA-practises T_i is assumed to be related to the latent variable $T_i^{¿}$ in the following way:

$T_i = j$ if and only if $\mu_j \leq T_j^{¿} < \mu_{j+1}$ for $j = 0, \ldots.., J$

J is the number of CSA-practises used; μ_{j+1} present the threshold levels that are estimated. This equation states that if the number of CSA-practises T_i is between μ_0 and μ_{j+1} , the response to the question on the number of CSA-practises used is equal to j $(T_i = j ¿$. The parameters α and μ are estimated using a maximum likelihood.

2.2.3 Conceptual Framework

In this study the agricultural practises that have been identified to fit into the CSA framework as CSA-practises among farming households in the study areas were used for conceptualization. Farming households were asked to list the practises they used in their farms in the previous season. Then the agricultural practises which fit into the CSA profile based on FAO recommendation and the literature were identified for the study. The study follows Aryal *et al*. (2018) and Teklewold *et al*. (2020), to examine the level of using by the number of CSA-practises used by the farming households surveyed.

The usage of agricultural practises by farming households is not spontaneous, but there are important players involved in the farming system. The farming household characteristics such as age, gender, marital status, etc., plot characteristic, institutional characteristics and resource constraints are considered as factors which influence the usage of CSA-practises. These factors influence usage, but they also influence the level of usage intensity. Figure 2.1 summarizes how this study conceptualizes the usage of CSA-practises and the level of usage intensity among farming households.

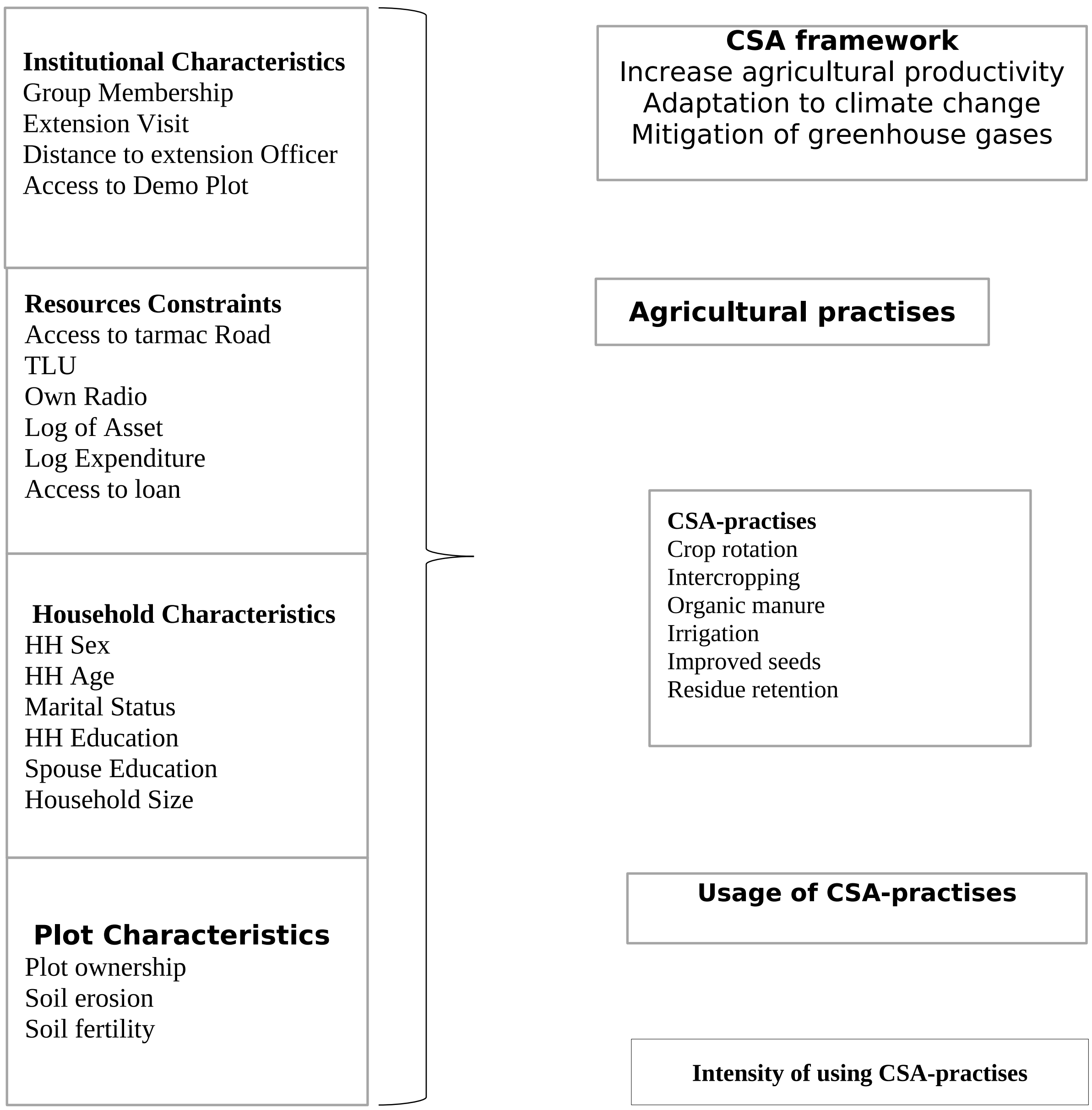

Figure 2. 1 Conceptual Framework

2.3 Methodology

2.3.1 Study area

The study was conducted in Mbeya and Mbarali districts in Mbeya Region and Mbozi and Momba districts in Songwe Region in Tanzania. These regions are in the Southern Highlands Zone, which is the breadbasket area of Tanzania where a various food crops are cultivated including maize, beans, soya beans and paddy rice. The study selected two regions and four districts because they are the main producers of food crops such as maize, paddy rice, beans and soya beans zone in Tanzania.

In addition, food and nutritional security vulnerability was another selection criterion because 37.7% of children below five years are stunted (TFNC, 2014). The study area also was regarded best for this study since farmers from these regions/districts primarily rely on food crop production for their livelihoods. The difference in geographical location is another reason for selection of these study areas, as it would enable to generalize the results. Furthermore, mixed agronomic practises are also the main driver for selection of this study area.

2.3.2 Sampling and data collection

The study used cross-sectional data collected from a farm household survey in the Southern Highlands of Mbeya and Songwe in Tanzania. The survey was conducted between September–December 2017 by the Sokoine University of Agriculture in partnership with the Integrated Project to Improve Agricultural Productivity and Food Security in the Bread Basket area of Southern Highlands of Tanzania. The sample covered 1443 farm households where multistage sampling was used to select farmer organizations (FOs) from each district, and households from each FO.

First, based on their food production potential crops (maize, paddy, common beans, and soya beans), whereby four districts were selected purposively from two regions of the Southern Highlands of Tanzania (Mbeya and Songwe Regions). Second, 51 wards were randomly selected out of 92 wards. Third, FOs in each ward were identified then farming households from the selected FOs were sampled using a proportionate random sampling to get a total of 1443 households. The male and female structured questionnaires were used to collect data where open data kit was used. Different information were collected such as household demographics, socioeconomic characteristics, CSA-practises used, crop production and marketing, input use, food consumption, and other farm- and farmer-specific characteristics.

2.3.3 Description of dependent variables

In the structured questionnaires the farming households surveyed listed the agricultural practises they used for their farms. Then, the agricultural practises which fit into the CSA profile based on FAO recommendations were identified for the study while considering their potential to deliver triple win objectives (Bolinder *et al.,* 2020; Teklewold *et al.,* 2019; Teixeira *et al.,* 2018; Arslan, 2013; Masuka *et al.,* 2017). The CSA-practises most used by the farming households were crop rotation, intercropping, irrigation, organic manure, residue retention and drought-tolerant maize seeds. These practises are described in Appendix 2.1.

2.3.4 Independent variables and hypotheses

The exogenous variables used in this study are based on theoretical frameworks and past climate studies (Teklewold *et al.*, 2019; Bolinder *et al.*, 2020; Oumer and Burton, 2018). The information on household characteristics, plot characteristics, institutional characteristics and resource constraints for farming households visited were collected and used for the model specification. Table 2.1 present the descriptions and measure of the exogenous variables used.

Table 2. 1: Definition and summary statistics of variables in the analysis

Variables	Description	Mean
Practises used (n = 1443)		
Crop rotation	% of households that have used the crop rotation	66.67
Irrigation	% of households that have used the irrigation	23.28
Drought tolerant maize seeds	% of households that have used the DTMS	60.64
Residue retention	% of households that have used the residue retention	46.5
Organic Manure	% of households that have used the organic manure	36.94
Intercropping	% of households that have used the intercropping	33.96
The Household Characteristics		
Gender of the household head	% of male household head	84.89
Age of the household head	Age of the head of the household in years	50.3985
Marital status	% of married household head	0.8205
Education of the household head	Years of education of the household head	6.1455
Education of the spouse	Years of education of the spouse	2.8974
Household size	Number of household members	5.3818
Age of the spouse	Age of the spouse	39.4338
Farming experience	Years of farm experience	22.0624
Number of occupations	Number of occupations of household head	2.2176
Geographical location		
Region	1= Songwe Region	0.4934
Mbozi District	1 = Mbozi District	
Mbarali District	1= Mbarali District	
Farm Characteristics		
Farm size	Farm size in acre	7.962
Soil fertility	1 = good soil fertility	47.5
Production diversity	Number of crops cultivated	2.8039

Soil erosion	1 = No soil erosion	0.3115
Farm distance	Farm distance from home, minutes	18.0589
Institutional Characteristics		
Number of group membership	1= More than one group membership	27.51
Extension services	1= Access to extension services	16.42
Distance to the extension offices	Extension office distance from home in minutes	23.6377
Distance to the local market	Market distance from home in minutes	62.2633
Household wealth		
Livestock ownership (TLU)	Livestock herd size (tropical livestock units; TLU)	1.7242
Logarithm of Asset	Logarithm of Asset index	13.1498
Farm ownership	1 = own a farm	0.8579
Average number of plots cultivated	Number of plots	2.9381

2.3.5 Concerns in estimations of the econometric models

There are different factors which determine the decision of farm households to use agriculture practises. Therefore, it is important to control them in estimating the MVP model (Kassie *et al.*, 2013). However, there is a possibility of multicollinearity[1] problem when independent variables are added in the model.

Therefore, the study used the inflation factor to test for the multicollinearity for the continuous variables included in the model. The results showed that the variance inflation factor (VIF) values were less than 10 indicating that there was no serious relationship between the explanatory variables included in the model. Furthermore, the contingent coefficients were used to test multicollinearity for the categorical variables used in the model. Again, the results showed the contingent coefficients between the categorical variables as the contingent coefficient was less than 0.75 for all cases.

[1] According to Wooldridge, (2010) multicollinearity exists whenever two or more of the predictors in a regression model are moderately or highly correlated.

2.4 Results and Discussion

2.4.1 Descriptive statistics

The study found the average farm size was 7.9 Acre while the distance from the homestead to the farm was found to be 18.06 minutes. The distance from homestead to nearest market was found to be 62.26 working minutes. The average age of head of the household was found to be 53 years while the farming experience was found to be 22.06 years. This implies that farming households in the study area are in the productive age with high experience in food crop production. Kassie (2013) holds that household heads at the productive age and high farming experiences can influence the usage of agricultural technologies positively.

The study found that the farming household visited in the study area are male dominated as evidenced by 84.89 % share of male household heads with an average of 2.2 occupations and spent an average of 6.14 years schooling. The household size was found to be 5.38 members while the local market been 62.26 walking minutes away. The average tropical livestock unit (TLU) was found to be 1.72 with an average of 3 plots cultivated in the previous season.

2.4.2 The rate of using CSA-practises

Table 2.2 show the specific rate of using various CSA-practises. The results show that usage rates ranged from 33.96% (intercropping) to 66.67% (crop rotation). The rates of using other practises are 60.64% for drought-tolerant maize seeds, 46.5% for residue retention. The usage rate of organic manure, intercropping and irrigation were found to be 36.94, 33.96 and 23.28 % respectively. The intensity of using these practises ranged between zero to six practises, which means that some farming households used up to six practises while other households did not use any other practise.

The findings are the same as the study by Kpadonou *et al.* (2017), which found that the use of CSA-practises varies across socio-economic settings of the households and the types of practises. The findings disclose that there is a need for the government and other agricultural practitioners to promote the usage of CSA-practised in order to improve household income and food security. As such, understanding the major drivers and constraints to usage and intensity of using CSA-practises is crucial to provide evidence-based policy making for agricultural development in SSA.

2.4.3 Complementarity and trade-off among CSA-practises

The simultaneous usage of CSA-practises shows a likelihood of correlation (interdependence) among the CSA-practise. The study used the pair-wise correlation across the MVP residuals and Table 2.3 shows the estimates. The result the likelihood ratio test (Chi^2 (15) = 63.9175; Prob > chi^2 = 0.000) rejects the null hypothesis of zero covariance of the error terms across the equations. Table 2.2 shows the use of combinations of drought-tolerant maize seeds and crop rotation is positive and significant at 10%.

Combinations of residue retention and crop rotation, organic manure and crop rotation, intercropping and residue retention, intercropping and organic manure are significantly and positively associated at significant level 1%. In addition, the use of combinations of organic manure and drought-tolerant maize seeds is also positive and significant at 5%. This indicates that that farming households consider these CSA-practises as complements (i.e. farming households apply these technologies simultaneously). The complementary between CSA-practises were similar to the finding of Kanyenji *et al.* (2020) who found organic manure and intercropping complement each other in farming system in western Kenya.

Table 2. 2: Complementarities and substitutability of CSA-practises: Correlation coefficient of the error term matrix

	Crop rotation	irrigation	DTMS	Residue retention	Organic Manure	Intercropping
Crop rotation	1					
irrigation	-0.159**	1				
	(0.0697)					
DTMS	0.0915*	-0.0588	1			
	(0.0541)	(0.057)				
Residue retention	0.231***	-0.076	0.045	1		
	(0.0539)	(0.0541)	(0.0422)			
Organic Manure	0.192***	-0.068	0.107**	0.0666	1	
	(0.0549)	(0.0587)	(0.0463)	(0.0435)		
Intercropping	0.0597	-0.0125	-0.0153	0.128***	0.130***	1
	(0.0549)	(0.057)	(0.0442)	(0.0426)	(0.0458)	

The Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0: chi^2 (15) = 63.9175 Prob > chi2 =0.0000 Standard errors in parentheses

2.4.4 Determinants of using CSA-practises

Results of the MVP model estimated using the maximum likelihood method at household level are shown in Table 2.3. Result shows that the model fits the data since the Wald test shows, Wald $\chi^2(125)=1052.48$; Prob > $\chi^2=0.0000$ of the null hypothesis, that all regression coefficients in each equation are jointly equal to zero are rejected. This shows the relevance of the model to account for the unobserved correlations across decisions to use combination of CSA-technologies.

Additionally, the use of MVP was confirmed as the appropriate model in this study as the significance of the LR tests [Chi-Square$(\chi^2 = 63.9175, \rho = 0.000)$. Therefore, we reject the hypothesis that the CSA-technologies considered in this study (irrigation, organic manure, intercropping, crop rotation, drought tolerant maize seeds and residue retention) are independent.

Table 2. 3:Estimates of the MVP model

Variables	Crop rotation		Irrigation		DTMS		Residue retention		Organic manure		Intercropping	
	Coef.	**Std Err.**	**Coef.**	**Std Err.**	**Coef.**	**Std Err.**	**Coef.**	**Std Err.**	**Coef.**	**Std Err**	**Coef.**	**Std Err.**
Household Characteristics												
Gender of the household head	0.781***	0.2400	-0.267	0.2490	-0.109	0.1760	0.284*	0.1680	0.327*	0.1850	-0.0271	0.1780
Age of the household head	-0.00455	0.0063	0.0253***	0.0068	0.000140	0.0046	-0.000918	0.0044	0.00209	0.0049	0.00125	0.0047
Marital status	-0.238	0.2380	0.0705	0.2520	0.252	0.1660	-0.153	0.1570	-0.118	0.1730	-0.116	0.1700
Education of the household head	0.0120	0.0209	0.0827***	0.0224	-0.0114	0.0150	0.00155	0.0142	0.0107	0.0156	0.0193	0.0151
Education of the spouse	0.0299	0.0468	-0.00622	0.0511	0.0504	0.0324	-0.0268	0.0306	-0.0169	0.0337	0.0376	0.0318
Household size	-0.0365	0.0253	-0.0369	0.0273	0.0298*	0.0177	0.0138	0.0167	0.0154	0.0179	0.0302*	0.0177
Age of the spouse	0.000360	0.0055	0.00216	0.0059	-0.00566	0.0040	-0.00562	0.0039	-0.00145	0.0043	-0.000284	0.0040
Farming experience	0.00406	0.0051	-0.0147***	0.0054	-0.00461	0.0038	-0.00381	0.0037	0.00582	0.0040	0.00313	0.0038
Number of occupation	0.518***	0.0861	0.104	0.0876	-0.0401	0.0588	0.156***	0.0560	0.205***	0.0618	0.126**	0.0586
Farm Characteristics												
Farm size	-0.000574	0.0069	0.00505	0.0088	0.0112**	0.0048	-0.000465	0.0040	0.00223	0.0043	-0.00685	0.0049
Moderate soil fertility	0.00520	0.1050	-0.160	0.1110	0.0295	0.0726	0.0984	0.0690	-0.171**	0.0748	-0.00339	0.0725
Moderate soil erosion	-0.304***	0.1170	-0.404***	0.1340	0.0506	0.0801	-0.0489	0.0762	0.0893	0.0814	0.110	0.0794
Farm distance	0.00221	0.0036	-0.00846**	0.0035	-0.00452**	0.0021	0.00198	0.0020	-0.00664***	0.0023	-0.000484	0.0022
Production diversity	0.225***	0.0766	-0.00698	0.0707	0.0610	0.0505	-0.0675	0.0458	0.157***	0.0496	0.489***	0.0511
Geographical location												
Region	1.387***	0.1540	-7.830	142.2000	0.324***	0.0801	0.230***	0.0768	0.379***	0.0809	-0.0400	0.0808
Institutional Characteristics												
Number of group membership	0.175	0.1330	0.333**	0.1330	-0.136*	0.0823	0.398***	0.0779	0.0816	0.0821	0.0146	0.0814
Access to extension services	-0.119	0.1580	-0.374**	0.1850	0.148	0.1020	-0.275***	0.0952	0.145	0.0998	-0.0224	0.0996
Distance to the extension office	-0.00360**	0.0017	0.0196***	0.0021	-0.0109***	0.0013	0.00384***	0.0012	-0.00936***	0.0015	0.00100	0.0013
Distance to the market	-0.000524	0.0008	-0.00326***	0.0009	0.000178	0.0004	-0.000252	0.0005	-3.14e-05	0.0002	0.000232	0.0003
Household wealth												
Asset ownership	0.00837	0.0458	0.243***	0.0483	0.0794**	0.0317	0.0468	0.0298	0.124***	0.0330	-0.0179	0.0319
Farm ownership	0.223*	0.1280	-0.327**	0.1430	-0.00257	0.1050	0.0983	0.1000	0.275**	0.1170	0.0397	0.1070
Livestock ownership (TLU)	0.00489	0.0160	-0.00808	0.0164	0.00289	0.0121	0.00171	0.0116	0.0438***	0.0120	-0.0195	0.0144
Number of plots owed	0.119*	0.0703	-0.0588	0.0634	0.172***	0.0459	0.0201	0.0409	0.135***	0.0440	-0.111**	0.0444
Constant	-1.656**	0.6780	-4.259***	0.7240	-1.289***	0.4720	-1.087**	0.4530	-3.943***	0.5110	-1.926***	0.4830

*** p<0.01, ** p<0.05, * p<0.1

The results show that the gender of the head of the household positively and significantly influenced the usage of crop rotation, residue retention and organic manure. This indicates that male household heads were more likely to use these practises compared to their counterpart female household head. The results are consistent with the study by Ngoma *et al.* (2015) and Mwangi and Kariuki (2015), who found that the gender influenced positively the use of conservation agriculture practises.

Farm size found to influence positively the usage of drought-tolerant maize seeds at a significant level of 5%. Farmers in rural Tanzania consider having large farm as a sign of wealth. So, farmers with large farm can afford to buy agricultural inputs, including drought-tolerant maize seeds.

The age of the head of the household had a significant and positive effect on the use of irrigation at a significant level of 1%. This implies that aged people were more participated in irrigation farming than youths in the study area. The low level of participation of youths in irrigation farming could be because they are not members of farmer organizations such as Agricultural Marketing Cooperative Societies (AMCOS) in which the majority of irrigation schemes are owned by these AMCOS. However, participation of aged people in irrigation farming could be an advantage in terms of social capital as the majority are members of the AMCOS.

Farming households with more occupations have revealed to have a positive link with the use of crop rotation, residue retention, organic manure and intercropping. The positive effects of occupations on these practises suggest that farm households with many occupations are likely to intensify their spending to procure organic manure, hiring farm and other farm implements, as their financial barriers may be overcome by their engagement different sources of income. The result is also similar to that of Diiro (2013) who found number of occupations have a positive association with the usage of pesticides. The study by Danso-Abbeam *et al.,* (2019) also found a positive effect of different sources of household income on the use of agro-chemicals. However, Kanyenji *et al.* (2020) found that farming households whose farming is the main occupation, had an increased probability of using organic manure since its application is labour intensive, and thus full-time farmers had more time on their disposal to transport and apply the manure on their plots.

The study found that agricultural extension services had a negative and significant effect on the use of irrigation practise. This implies that whether farming households have received extension services or not, they might not use a certain practise. Therefore, just having contact with an extension agent for extension services was not important. The important thing is the decision to use an irrigation practise. The study did not meet the a priori expectation since agricultural extension is meant to influence practise uptake by farming households and promote cross learning and experience sharing among farming households. Similarly, a study by Teklewold *et al*. (2017) finds that access to extension services have a negative and significant effect of using chemical fertilizers and improved seeds.

Furthermore, the study found a negative and significant association on access to agricultural extension services and residue retention. This might be caused by the opportunity cost of using the crop residue such as maize or paddy residues for mulching or for feeding animals. This was supported by Tey *et al*. (2014) who argued that for farming households which keep livestock, there is a possibility of increased requirement of animal feed demand; as a result, leads to increased utilization of crop residue as livestock feed instead of using them for mulching

The study moreover found that the farm size has positive association with the usage of drought-tolerant maize seeds. This means that, farming households with large farm size aimed to maximize profit and risk averse; therefore, they are likely to use drought-tolerant seed to avoid risks related with climate change. In addition, farming households with large farms use their land to apply agricultural practises compared to those with smaller farms. The finding is consistent with the findings of Danso-Abbeam and Baiyegunh (2017) who found a positive association between that farm size and the usage of pesticides and chemical fertilizers. Bezu *et al.* (2014) also found a positive relationship between farm size and the usage of improved maize variety.

The study found that the education level of head of the household was found to have positive and significant effect with the probability of using irrigation practise at 1% level of significance. Household heads with higher education can use irrigation technologies as they might be more innovative and they have ability to assess usage risks compared to their counterparts. Similar results were found by Ntshangase *et al.* (2018), who found the education level of the head of the household to be significantly and positively correlated with the use of zero tillage as a CSA-practise at 1 % significant level.

According to Kassie *et al.* (2013), the distance from home to the nearest market can be considered as a proxy to the market information. The study found a negative association on the use of irrigation. This suggests that access to input and output market is imperative in enabling usage, through assisting input and output transport, reducing the cost of the household’s time and enabling more timely market information. Farming households which have access to market were more likely to use irrigation because farming households in the study area that have access to markets were selling more of their crops that use irrigation, especially paddy in Mbarali district.

Asset ownership was found positive and significant associated with the use of irrigation, drought-tolerant seeds and residue retention. This is perhaps because better-off farming households may have the capacity to purchase drought tolerant maize seed and other costs associated with the usage of irrigation. This finding is in agreement with that of Beyene *et al.*, (2017) who found asset ownership to be correlated with the decision to use the number of CSA-practises such as tree planting and intercropping.

The location variable (region) was found to be positive with significant connected with the farming household’s decision to use crop rotation, drought-tolerant maize seeds, residue retention and organic manure. This means that farming households in Songwe region use these practises more than their counterparts in the Mbeya Region. This might be because Songwe Region receives more interventions on various CSA-technologies provided by non-governmental organizations such as AGRA, ADP- Mbozi, One-Acre fund which are more based in Songwe Region than in Mbeya Region. Similarly, the study by Donkoh *et al.* (2019) found the Brong-Ahafo region variable to positive and significantly connected with the usage of pesticides but negatively and significantly connected with the use of chemical fertilizers.

Land ownership showed a positive impact on the usage of crop rotation and organic manure. This suggests that farming households are likely to use these practises on their owned plots. In this regard, it implies that rent in a farm or a plot is associated with poor agricultural practises (Gray and Kevane, 2001).

2.4.5 Factors explaining the intensity of CSA-practises usage

Farming households in the study area have used multiple CSA-practises but the usage intensity differs. The study employed an ordered probit model to explain determinants of CSA-practises' usage intensity. Farming household can use a certain CSA-practise base on their needs. For example, farming households which live in drought areas like Mbarali district can opt to use irrigation than areas with high rainfall, like Mbozi and Mbeya rural. Likewise, farming households which kept different types of livestock might use farm yard manure compared to their counterparts.

Therefore, Appendex 2-1 presents the marginal effects of the outcome variables where farming households which did not use any practise were given the value of 0 then the value of 1, 2, 3, 4, 5 and 6 were given for the households used one, two, three, four, five and six CSA-practises respectively. The chi^2 statistics for the ordered probit model is statistically highly significant (LR chi^2 (34) = 1519.24; Prob > chi^2 = 0.000) and rejects the null hypothesis (all slope coefficients equal to zero).

The results from Appendix 2-2 show that the independent variables vary over the different intensity levels. It shows that farming households with higher production diversity has the probability of using at least three four, five or six CSA-practises at the percentages higher by 3.25, 7.35, 3.19 and 0.31 points respectively. Farming households can diversify their production by employing different CSA-practises which are compatible with temperature or rainfall variability to take advantage of beneficial climate conditions. This result is similar to the study by Teklewold *et al.* (2019), which found that farming household diversifies their production system to reduce the risks of climate change and diversity in Ethiopia.

The study found the probability of using three, four, five and six practises is higher by 1.59, 3.57, 1.55 and 0.15 %age points respectively in household with many occupations compared to those with few occupations. This implies that household heads with many occupations used more CSA-practises because they were not facing financial constraints which could hinder them to invest on multiple CSA-practises. However, this finding is conflicting to that of Oumer and Burton (2018) who showed that number of occupations significantly decreased the intensity of using more than two practises by 14%. The coefficient for gender of the household's head was significantly positive. Farming households headed by men have the probability of using five and six by 1.76 and 0.16 % higher than farming households headed by female.

Membership to more than one farmer organisations also has link with the intensity to the usage of CSA-practises. The study found that the probability of using two, three, four, five and six practises is higher by 3.51, 1.54, 4.19, 1.93 and 0.2% age points respectively for the household head joined in more than one farmer organisations compared to the faming household head joined only in one farmer organisation.

This is due to the fact that, being a member of many organisations can help members to get different knowledge about the effect of climate change and variability which lead them to use multiple CSA-practises to reduce the increasing risks, and reduce the consequences of climate change and variability. The study is the same as the study by Teklewold *et al.* (2019), which found that membership of farmer organisation increased the intensity of CSA-practises used by the farming households in of Ethiopia.

The number of the cultivated plots by the farming households in the previous season preceding the survey shows a positive relationship on the number of CSA-practises used. Some variables such as the distance from to the agricultural extension office and local market distance from home have shown a negative effect on the number of the practises used. Geographical location also has association with the number of CSA practises used.

Farming households in Songwe region have the probability of using three, four, five and six by 1.16, 2.64, 1.15 and 0.11 % higher than farming households in Mbeya region. The findings of this study support other literatures which conclude that farming household in developing countries; Tanzania being inclusive are normally adapted to climate risks by using multiple adaptation practises (Shiferaw *et al.*, 2009). Farms/plots' ownership influences the intensity of CSA-practises, where the probability of using three, four, four and five practises is higher by 1.59, 3.57, 2.84 and 1.23 %age points respectively compared to farming households which rented-in farms/plots for agricultural production. The result is related to the work of Teklewold *et al.* (2019) on their study of usage CSA-in the Nile Basin of Ethiopia.

The study found the education of the spouse, tropical livestock unit, plot size, household size, soil erosion, access to market, soil fertility and access to extension services and age, marital status, education of the household head were insignificantly related to the intensity of usage of CSA-practises in our study area. This is consistent with some studies such as Oladimeji *et al.* (2020) which found the household size to be insignificant on usage of conservation practises. The finding is different with the findings of Aryal *et al.* (2018) who found the age of head of the household, credit, and famer organization membership were significantly influenced the intensity of usage of soil conservation practises.

2.5 Conclusion and Policy Implications

A cross-sectional study data was obtained from 1443 farming households in the southern highlands of Tanzania where the factors that determine the usage and intensity of using of CSA-practises were examined. The multivariate logit model (MVP) was employed to examine the usage of multiple CSA-practises while the ordered probit (OP) was employed to examine the factors influencing the intensity to use different CSA-practises. Understanding constraints and supporting factors for the use of CSA-practises helps in designing and formulating extension messages and agricultural policies that can accelerate the dissemination of CSA-practises.

The study found that the intensity of using these CSA-practises considered in this study is also very low. More than 70 % of the farming households use only one to three practises, indicating that an important potential still exists to improve the specific usage rates as well as the intensity of using CSA-practises. Policymakers must target practises with lower usage rates and provide farming households with further incentives towards the intensification of their use.

The study found that the farm households are using CSA-practises as complements; therefore, government and non-governmental organisations dealing with agriculture development have to consider complementarities among these CSA-practises and promote them to farming households. In addition, the complementarities among the CSA-practises can have vital policy implications. For example, a policy amendment that impacts one practise can have an impat on the use of other practises. Therefore, these complementarities can be used to define appropriate combination of CSA-practises used in specific areas.

The findings confirmed that wealthier farming households, particularly those with access to household assets and plot/farm ownership are more likely to use these practises. Policies that enable farming households to secure their own land for cultivation as a motivation of using multiple CSA-practises should be considered. Furthermore, the study highlighted the contribution of gender of the household head on the use of CSA-practises. This calls for the policymakers to target female-headed households who showed lower incentives in intensifying the use of CSA-practises, possibly because of their limited control over labour and land assets.

Promotion of CSA-practise, primarily organic manure, is essential to reduce the need of synthetic fertilizers. Therefore, any practices such as organic manure that increase N use efficiency can substantially reduce emissions from agriculture. The results from our analysis show that gender of the household head, livestock ownership, asset ownership, production diversity, occupation are positively associated with the decision to use organic manure. As suggested by Sapkota *et al.* (2019), the policymakers need to set up alternative pathways for agricultural development so that it can achieve high-yield, low-emission targets in agricultural production. Setting up such an alternative pathway needs to consider several factors, which include not only the type of agricultural technology/practices but also the socio-economic and human behavioral dimensions.

Access to markets and extension services and other information sources are found to play a crucial role in increasing CSA usage intensity to use. Therefore, it is important to focus on policies and plans that improve market access and the quality of extension services. Dissemination of CSA knowledge and its role in climate risk mitigation is critical to promote it. More CSA training for farmers, government extension staff working at the local level, and use of communication tools to share and promote knowledge on CSA use to combat the global challenge of climate change are essential. Understanding barriers and enabling conditions to CSA usage helps in designing and formulating extension messages and agricultural policies that can accelerate CSA dissemination and help safeguard agricultural production and food security in Tanzania.

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References

Abegunde, V. O., Sibanda, M., & Obi, A. (2020). Determinants of the Adoption of Climate-Smart Agricultural Practises by Small-Scale Farming Households in King Cetshwayo District Municipality, South Africa. *Sustainability*, *12* (1), 195.

Arslan, H. (2013). Application of multivariate statistical techniques in the assessment of groundwater quality in seawater intrusion area in Bafra Plain, Turkey. *Environmental monitoring and assessment*, *185*(3), 2439-2452.

Aryal, J. P., Jat, M. L., Sapkota, T. B., Khatri-Chhetri, A., Kassie, M., & Maharjan, S. (2018). Adoption of multiple climate-smart agricultural practises in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies and Management*. 10 (3), 407-427.

Azumah, S. B., Adzawla, W., Donkoh, S. A., & Anani, P. Y. (2020). Effects of climate adaptation on households' livelihood vulnerability in South Tongu and Zabzugu districts of Ghana. *Climate and Development*, 1-12

Bellon, M. R., & Taylor, J. E. (1993). " Folk" soil taxonomy and the partial adoption of new seed varieties. *Economic Development and Cultural Change*, *41*(4), 763-786.

Bolinder, M. A., Crotty, F., Elsen, A., Frac, M., Kismányoky, T., Lipiec, J., & Kätterer, T. (2020). The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: a synthesis of reviews. *Mitigation and Adaptation Strategies for Global Change*, *25*(6), 929-952.

Chalise, K. S., Singh, S., Wegner, B. R., Kumar, S., Pérez-Gutiérrez, J. D., Osborne, S. L., & Rohila, J. S. (2019). Cover crops and returning residue impact on soil organic carbon, bulk density, penetration resistance, water retention, infiltration, and soybean yield. *Agronomy Journal*, *111*(1), 99-108.

Danso-Abbeam, G., Dagunga, G., & Ehiakpor, D. S. (2019). Adoption of Zai technology for soil fertility management: evidence from Upper East region, Ghana. *Journal of Economic Structures*, *8*(1), 1-14.

Diiro, G. M. (2013). Impact of off-farm income on agricultural technology adoption intensity and productivity. Working paper (11) International *Food Policy Reasearch Institute*.

Donkoh, S. A., Azumah, S. B., & Awuni, J. A. (2019). Adoption of improved agricultural technologies among rice farmers in Ghana: A multivariate probit approach. *Ghana Journal of Development Studies*, *16*(1), 46-67.

FAO (2010) Climate-smart agriculture sourcebook. Food and Agriculture Organization of the United Nations. Available from: http://www.fao.org/docrep/018/i3325e/i3325e.pdf (Accessed 11/10/2017).

FAO (2014) FAO success stories on climate-smart agriculture. Food and Agriculture Organization of the United Nations. Available from: http://www.fao.org/3/a-i3817e.pdf (Accessed 11/11/2017).

Hassen, A., Talore, D. G., Tesfamariam, E. H., Friend, M. A., & Mpanza, T. D. E. (2017). Potential use of forage-legume intercropping technologies to adapt to climate-change impacts on mixed crop-livestock systems in Africa: a review. *Regional Environmental Change*, *17*(6), 1713-1724.

Hossain, M.S., Hossain, A., Sarkar, M.A.R., Jahiruddin, M., Teixeira da Silva, I.A., Hossain, M.I., (2016). Productivity and soil fertility of the rice-wheat system in the High Ganges River Floodplain of Bangladesh is influenced by the inclusion of legumes and manure. Agriculture, Ecosystems and Environment, 218: 40-52.

Hulme, M., Doherty, R., Ngara, T., New, M., and Lister, D. (2001). "African Climate Change: 1900–2100." *Climate Research* 17: 145–168.

IFAD. Rural Poverty Report 2011. International Fund for Agricultural Development (Rome, Italy: IFAD, 2011).

Jagadish, S.V.K., Septiningsih, E.M., Kohli, A., Thomson, M.J., Ye, C., Redofia, E., Kumar, A., Gregorio, G.B., Wassmann, R., Ismail, A.M., Singh, R.K., (2012). Genetic advances in adapting rice to a rapidly changing climate. Journal of Agronomy and Crop Science, 198(5): 360-373.

Kanyenji, G. M., Oluoch-Kosura, W., Onyango, C. M., & Karanja Ng'ang'a, S. (2020). Prospects and constraints in smallholder farmers' adoption of multiple soil carbon enhancing practises in Western Kenya. *Heliyon*, *6*(3).

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practises in smallholder systems: Evidence from rural Tanzania. *Technological forecasting and social change*, *80* (3), 525-540.

Khaitov, B., Yun, H. J., Lee, Y., Ruziev, F., Le, T. H., Umurzokov, M., ... & Park, K. W. (2019). Impact of Organic Manure on Growth, Nutrient Content and Yield of Chilli Pepper under Various Temperature Environments. *International journal of environmental research and public health*, *16*(17), 3031.

Khaitov, B., Yun, H. J., Lee, Y., Ruziev, F., Le, T. H., Umurzokov, M., and Park, K. W. (2019). Impact of Organic Manure on Growth, Nutrient Content and Yield of Chilli Pepper under Various Temperature Environments. *International journal of environmental research and public health*, *16*(17), 3031.

Kimaro, F. D., Jumanne, S., Sindato, E. M., Kayange, N., & Chami, N. (2019). Prevalence and factors associated with renal dysfunction among children with sickle cell disease attending the sickle cell disease clinic at a tertiary hospital in Northwestern Tanzania. *PloS one*, *14*(6).

Kpadonou, R. A. B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., & Kiema, A. (2017). Advancing climate-smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. *Land Use Policy*, *61*, 196-207.

Kurgat, B. K., Lamanna, C., Kimaro, A. A., Namoi, N., Manda, L., & Rosenstock, T. S. (2020). Adoption of Climate-Smart Agriculture Technologies in Tanzania. *Frontiers in Sustainable Food Systems*, *4*, 55.

Lipper, L.; Thornton, P.; Campbell, B.M.; Baedeker, T.; Braimoh, A.; Bwalya, M.; Caron, P.; Cattaneo, A.; Garrity, D.; Henry, K.; (2014). Climate-smart agriculture for food security. Nat. Clim. Chang., 4, 1068–1072.

Lötjönen, S., & Ollikainen, M. (2017). Does crop rotation with legumes provide an efficient means to reduce nutrient loads and GHG emissions? *Review of agricultural, food and environmental studies*, *98* (4), 283-312.

Magorokosho, C., Vivek, B.& MacRobert, J. (2009). *Characterization of maize germplasm in Eastern and Southern Africa: Results of the 2008 regional trials coordinated by CIMMYT*. CIMMYT: Harare.

Maliondo, S. M. S., Mpeta, E. J., & Olson, J. (2012). Climate change and food security in Tanzania: an analysis of current knowledge and research gaps and recommendations for a research agenda. *Ohio State University and Sokoine University of Agriculture: Columbus, OH, USA*.

Masuka, B., Atlin, G. N., Olsen, M., Magorokosho, C., Labuschagne, M., Crossa, J., and Macrobert, J. (2017). Gains in maize genetic improvement in Eastern and Southern Africa: I. CIMMYT hybrid breeding pipeline. *Crop Science, 57*(1), 168-179.

Muriithi, B. W., Menale, K., Diiro, G., & Muricho, G. (2018). Does gender matter in the adoption of push-pull pest management and other sustainable agricultural practises? Evidence from Western Kenya. *Food security*, *10*(2), 253-272.

Mwangi, M., & Kariuki, S. (2015). Factors determining usage of new agricultural practise by smallholder farmers in developing countries. *Journal of Economics and sustainable development*, *6*(5), 208 -216

Ngema, P.; Sibanda, M.; Musemwa, L. (2018). Household Food Security Status and Its Determinants in Maphumulo Local Municipality, South Africa.Sustainability, 10, 3307.

Ngoma, H., Mason, N. M., & Sitko, N. J. (2015). Does minimum tillage with planting basins or ripping raise maize yields? Meso-panel data evidence from Zambia. *Agriculture, Ecosystems & Environment*, *212*, 21-29.

Nwaobiala, C. U., & Nottidge, D. O. (2013). Effect of climatic variables on cassava farmers' production in Abia State, Nigeria. *Nigerian Journal of Agriculture, Food and Environment*, *9*(4), 57-62.

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., & Mungai, C. (2017). Adoption and dissemination pathways for climate-smart agriculture technologies and practises for climate-resilient livelihoods in Lushoto, Northeast Tanzania. *Climate*, *5*(3), 63.

Oladimeji, T. E., Oyinbo, O., Hassan, A. A., & Yusuf, O. (2020). Understanding the Interdependence and Temporal Dynamics of Smallholders' Adoption of Soil Conservation Practises: Evidence from Nigeria. *Sustainability*, *12*(7), 2736.

Onyeneke, R. U., Igberi, C. O., Uwadoka, C. O., & Aligbe, J. O. (2018). Status of climate-smart agriculture in southeast Nigeria. *GeoJournal*, *83*(2), 333-346.

Oumer, A.M.; Burton, M. (2018). Drivers and synergies in the adoption of sustainable agricultural intensification practises: A dynamic perspective. In Proceedings of the 2018 Agricultural and Applied Economics Association Annual Meeting, Washington, DC, USA.

Page, K. L., Dang, Y. P., Dalal, R. C., Reeves, S., Thomas, G., Wang, W., & Thompson, J. P. (2019). Changes in soil water storage with no-tillage and crop residue retention on a Vertisol: Impact on productivity and profitability over a 50-year period. *Soil and Tillage Research*, *194*, 104319.

Ricord, M. (2018). *Evaluating intercropping systems as a sustainable agroecosystem alternative to reduce greenhouse gas emissions* (Master's thesis, Master of Environmental Studies in Environment and Resource Studies, University of Waterloo), (pp 151)

Rowhani, P., Lobell, D. B., Linderman, M., & Ramankutty, N. (2011). Climate variability and crop production in Tanzania. *Agricultural and forest meteorology*, *151*(4), 449-46.

Sapkota, T. B., Vetter, S. H., Jat, M. L., Sirohi, S., Shirsath, P. B., Singh, R., & Stirling, C. M. (2019). Cost-effective opportunities for climate change mitigation in Indian agriculture. *Science of the Total Environment*, *655*, 1342-1354.

Shiferaw, B. A., Okello, J., & Reddy, R. V. (2009). Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment, development and sustainability*, *11*(3), 601-619.

Smith, V.H., McBride, R.C., Shurin, J.B., Bever, J.D., Crews, T.E., Tilman, G.D., (2015). Crop diversification can contribute to disease risk control in sustainable biofuels production. Frontiers in Ecology and the Environment, 13(10): 561-567.

Tambo, J. A., & Abdoulaye, T. (2012). Climate change and agricultural technology adoption: the case of drought tolerant maize in rural Nigeria. *Mitigation and Adaptation Strategies for Global Change*, *17*(3), 277-292.

Tanzania Food and Nutrition Centre (2014). Tanzania National Nutrition Survey 2014. Dar es Salaam, Tanzania. Available at https://www.unicef.org/esaro/Tanzania_National_Nutrition_Survey_2014_Final_Report_18012015.pdf. (Accessed January 2017)

Teixeira, E. I., de Ruiter, J., Ausseil, A. G., Daigneault, A., Johnstone, P., Holmes, A., ... & Ewert, F. (2018). Adapting crop rotations to climate change in regional impact modelling assessments. *Science of the Total Environment*, *616*, 785-795.

Teklewold, H., & Mekonnen, A. (2020). Weather at Different Growth Stages, Multiple Practices and Risk Exposures: Panel Data Evidence from Ethiopia. *Climate Change Economics*, *11*(02),

Teklewold, H., Gebrehiwot, T., & Bezabih, M. (2019). Climate smart agricultural practices and gender differentiated nutrition outcome: An empirical evidence from Ethiopia. *World Development*, *122*, 38-53.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor. *Ecological Economics*, *93*, 85-93.

Teklewold, H., Mekonnen, A., Kohlin, G., & Di Falco, S. (2017). Does Adoption of Multiple Climate Smart Practises Improve Farmers" Climate Resilience? Evidence from the Nile Basin of Ethiopia. *Climate Change Economics*, *8*(01).

Tesfaye, K., Kruseman, G., Cairns, J. E., Zaman-Allah, M., Wegary, D., Zaidi, P. H., & Erenstein, O. (2018). Potential benefits of drought and heat tolerance for adapting maize to climate change in tropical environments. *Climate risk management*, *19*, 106-119.

Tumbo, S.D., Mpeta, E., Tadross, M., Kahimba, F.C., Mbillinyi, B.P., and Mahoo, H.F. (2010). "Application of Self-Organizing Maps Technique in Downscaling Gcms Climate Change Projections for Same, Tanzania." J. Physics and Chemistry of the Earth 35: 608–617.

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). Effect of climate-smart agricultural practises on household food security in smallholder production systems: micro-level evidence from Kenya. *Agriculture & Food Security*, *7*(1), 80.

Wollni, M., Lee, D. R., & Thies, J. E. (2010). Conservation agriculture, organic marketing, and collective action in the Honduran hillsides. *Agricultural economics*, *41*(3:4), 373-384.

Appendixes

Appendix 2. 1: Selection of CSA-practises and their Contribution to Triple Win Objectives

CSA-practises	**Definition and justification for inclusion**	
Crop rotation	Definition	A practise in which growing more than one crop are grown across time (Teklewold *et al.,* 2019).
	Adaptation	Helps in improving soil health, decreasing the occurrence of pests and diseases, improves crop diversification and prevents soils erosion (Teixeira *et al.*,

		2018).
	Mitigation	According to Teklewold *et al.* (2019) crop rotation decreases the application of nitrogenous fertilizers when leguminous crops are introduced. It also maintains and/or improves soil carbon stocks.
	Productivity	Improvements in farm productivity of pasture, feed and food crops (Teixeira *et al.*, 2018).
	Household welfare	Improved income and food security due to improved agricultural productivity (Teklewold *et al.*, (2019).
Intercropping	Definition	The act of growing two or more crops per unit of land area simultaneously.
	Adaptation	It controls weeds, improves water holding capacity, it contributes to reduce crop failure risk increases food availability and dietary diversity (Teklewold *et al.*, 2019).
	Mitigation	Maintains or improves soil carbon stock or organic matter content, reduces the need for chemical fertilizer (Hassen *et al.*, 2017).
	Productivity	According to Teklewold *et al.* (2019) intercropping improves productivity, hence promoting sustainable utilization of resources such as land and water; diversifies income sources.
	Household welfare	Enhanced income and food security due to enhanced productivity (Hassen *et al.*, 2017).
Irrigation (Irrigation canal lining)	Definition	Irrigation is defined as the process of applying a controlled amount of water to the plant at the recommended intervals.
	Adaptation	Improves infiltration and retention by the soil, reduces water loss due to runoff and evaporation, and improves the quality and availability of ground and surface water (Arslan, 2013).
	Mitigation	Efficiency use of irrigation water reduce GHG emission
	Productivity	According to Arslan (2013) the use of irrigation Increases water availability in the soil hence is enabling the agricultural production.
	Household welfare	Enhanced income and food security due to enhanced productivity.

Continue…

CSA-practises	Definition and justification for inclusion	
Organic manure	Definition	It is the application of animal wastes in the farm (Teklewold *et al.*, 2019).
	Adaptation	Improves soil structure and its water holding capacity with minimum leaching (Khaitov *et al.*, 2019).
	Mitigation	Increases carbon storage in soils, reduces

		the need of synthetic fertilizers and related GHG emissions (Khaitov *et al.*, 2019).
	Productivity	Increases crop yields and income.
	Household welfare	Improved household income and food security as a result of improved productivity.
Drought tolerant maize seeds	Definition	Are seeds which can produce at least 1–3 tons/ha after suffering water stress for nearly six weeks (Magorokosho *et al.*, 2009).
	Adaptation	The seeds have the ability to withstand an abiotic stress (Masuka *et al.*, 2017).
	Mitigation	Leads to reduction in emissions due to the lowering the usage of fuel for irrigation.
	Productivity	Contributes to reductions in production costs, enable production and yield stability even in the scarcity of water for irrigation (Masuka *et al.*, 2017).
	Household welfare	Addressing food security and income (Bellon and Taylor, 1993).
Residue retention	Definition	Is considered to be crop remains which are left in the field after harvest (Bolinder *et al.*, 2020).
	Adaptation	Enhances soil moisture, fertility and reduces soil erosion (Chalise *et al.*, 2019).
	Mitigation	Increases carbon storage in soils, reduces use of synthetic fertilizers and related GHG emissions. (Bolinder *et al.*, 2020).
	Productivity	Increases crop yields and income (Bolinder *et al.*, 2020).
	Household welfare	Addressing food security and income (Page *et al.*, 2019).

Appendex 2. 2: Estimates of the ordered probit model and marginal effects of key variable

Variables	Coef.	Std. Err.	Pr (Y = 0|X)	Std. Err.	Pr (Y = 1|X)	Std. Err.	Pr (Y = 2|X)	Std. Err.	Pr (Y = 3|X)	Std. Err.
Gender of head of the household	0.2250	0.1367	-0.012	0.00843	-0.04334	0.0278	-0.0340*	0.01848	0.0252	0.0183
Age of the household head	0.0046	0.0036	0.000	0.00016	-0.00084	0.0007	-0.0008	0.0006	0.0004	0.0003
Marital status	-0.0271	0.1289	0.001	0.00566	0.004915	0.0234	0.0045	0.02146	-0.0024	0.0116
Farm experience	-0.0013	0.0030	0.000	0.00013	0.000231	0.0005	0.0002	0.00049	-0.0001	0.0003
Production diversity	0.3590**	0.0382	-0.0156***	0.00272	-0.0652***	0.0077	-0.0598***	0.0075	0.0323***	0.0051
Occupation	0.1742	0.0454	-0.0076***	0.00225	-0.0316***	0.0084	-0.0290***	0.0078	0.0157***	0.0045
Level of education of the head of the household	0.0144	0.0116	-0.001	0.00051	-0.00262	0.0021	-0.0024	0.00193	0.0013	0.0011
Level of education of the spouse	0.0129	0.0249	-0.001	0.0011	-0.00234	0.0045	-0.0021	0.00414	0.0012	0.0023
Household size	0.0208	0.0136	-0.001	0.00061	-0.00378	0.0025	-0.0035	0.00227	0.0019	0.0013
Age of the spouse	-0.0056*	0.0031	0.000	0.00014	0.0010*	0.0006	0.0009*	0.00052	-0.0005*	0.0003
Tropical Livestock Unit	0.0055	0.0094	0.000	0.00041	-0.001	0.0017	-0.0009	0.00156	0.0005	0.0009
Total plot size	0.0000	0.0032	0.000	0.00014	2.74E-06	0.0006	0.0000	0.00054	0.0000	0.0003
Geographical location	-0.1293**	0.0622	0.0056**	0.00282	-0.0234*	0.0114	-0.0215*	0.01042	0.0116**	0.0057
Soil fertility	-0.0088	0.0560	0.000	0.00246	0.001595	0.0102	0.0015	0.00932	-0.0008	0.0051
Soil erosion	-0.0225	0.0617	0.001	0.00276	0.004101	0.0113	0.0037	0.01018	-0.0021	0.0057
More membership	0.2029***	0.0632	-0.0081***	0.00259	-0.0354***	0.0107	0.0351***	0.01147	0.0154***	0.0044
Average farm distance	-0.0028*	0.0017	0.000	0.00008	0.000511	0.0003	0.001	0.00028	-0.0003	0.0002
Extension services	-0.0412	0.0769	0.002	0.00359	0.007573	0.0143	0.007	0.01245	-0.0039	0.0076
Distance to the extension office	-0.0028***	0.0010	0.000	0.00005	0.0005***	0.0002	0.0004***	0.00017	-0.0001***	0.0001
Access to market	-0.0001	0.0001	0.000	0	1.41E-05	0.0000	0.001	0.00002	0.0000	0.0000
Log of asset	0.1152***	0.0243	0.0051***	0.00127	-0.0209***	0.0046	-0.0192***	0.0042	0.0103***	0.0025
Plot ownership	0.1389*	0.0815	-0.0061*	0.00367	-0.02525	0.0149	0.0231*	0.01366	0.0125*	0.0075
Number of plot cultivated	0.0574*	0.0336	-0.0025*	0.00152	-0.01042	0.0061	-0.0096*	0.00564	0.0223	0.0052

Continue...

Variables	Pr (Y = 4|X)	Std. Err.	Pr (Y = 5|X)	Std. Err.	Pr (Y = 6|X)	Std. Err.
Gender of head of the household	0.0446	0.026	0.0176*	0.0095	0.0016*	0.0009
Age of the household head	0.0009	0.001	0.0004	0.0003	0.0001	0.0000
Marital status of the household head	-0.0055	0.026	-0.0024	0.0114	-0.0002	0.0011
Farm experience	-0.0003	0.001	-0.0001	0.0003	0.0000	0.0000
Production diversity	0.0735***	0.009	0.0319***	0.0043	0.0031***	0.0011
Occupation	0.0357***	0.009	0.0155***	0.0042	0.0015**	0.0006
Level of education of the head of the household	0.0030	0.002	0.0013	0.0010	0.0001	0.0001
Education of the spouse	0.0026	0.005	0.0011	0.0022	0.0001	0.0002
Household size	0.0043	0.003	0.0018	0.0012	0.0002	0.0001
Age of the spouse	-0.0011*	0.001	-0.0005*	0.0003	0.0000	0.0000
Tropical Livestock Unit	0.0011	0.002	0.0005	0.0008	0.0000	0.0001
Total plot size	0.0000	0.001	-0.0001	0.0003	0.0000	0.0000
Geographical location	0.0264**	0.013	0.0115**	0.0056	0.0011*	0.0007
Soil fertility	-0.0018	0.011	-0.0008	0.0050	-0.0001	0.0005
Soil erosion	-0.0046	0.013	-0.0020	0.0054	-0.0002	0.0005
More membership	0.0419***	0.013	0.0193***	0.0067	0.0020**	0.0010
Average farm distance	-0.0006*	0.000	-0.0002*	0.0002	0.0000	0.0000
Extension services	-0.0084	0.016	-0.0036	0.0065	-0.0003	0.0006
Distance to the extension office	-0.0006***	0.000	0.0002***	0.0001	-0.0001**	0.0011
Access to market	0.0001	0.002	0.0011	0.0001	0.0021	0.0023
Asset ownership	0.0236***	0.005	0.0102***	0.0023	0.0010**	0.0004
Plot ownership	0.0284*	0.017	0.0123*	0.0073	0.0012	0.0008
Number of plot cultivated	0.0117*	0.007	0.0051*	0.0030	0.0005	0.0003
/cut1	1.477797	0.369582				
/cut2	2.510713	0.370806				
/cut3	3.391741	0.373057				
/cut4	4.325163	0.376861				
/cut5	5.258687	0.381774				
/cut6	6.351345	0.401489				

CHAPTER THREE

COMBINATION OF CLIMATE SMART AGRICULTURE PRACTISES: AN ANALYSIS OF FARM HOUSEHOLDS' DECISIONS IN SOUTHERN HIGHLANDS OF TANZANIA

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Abstract

Developing countries are facing challenges in agriculture development due to change in market conditions, food demand and climate. The effect of climate change causes a major threat to agricultural production and food security in Tanzania, and Climate-smart Agriculture (CSA) is crucial in addressing the potential impacts. A cross-sectional study was conduct to collect information from 1443 farm households in the Southern Highlands of Tanzania to analyse factors that determine probability of using multiple combinations of Climate-smart Agriculture practices (CSA-practises) (i.e., crop rotation, crop residue retention and intercropping). The study applied a multinomial logit model was applied to examine the determinants of using

multiple combinations of CSA-practises. The analysis of factors that influence farm households' decision to use CSA-practises revealed that production diversification, gender and livestock ownership were found to be positive and significantly effect on the usage of combination of crop residue retention and intercropping ($C_0R_1I_1$). In addition, education level and gender of the head of the household had positive and significant in the usage of combination of crop rotation, crop residue retention and intercropping ($C_1R_1I_1$). This comprehensive study is significant for a finer understanding of the synergistic effect of interrelated CSA-practises. The study calls for policy makers to enact policies and plans that promote CSA-practises as a combination, including other interrelated practises to upscale CSA-practises usage while harnessing the synergies between them.

Keywords: CSA-practises; usage; crop rotation; crop residue retention; intercropping.

3.1 Introduction

Climate change is the biggest challenge to food security systems in the 21st Century. The global population have to reduce the impact of climate change as it is known that the capacity to control the pace of climate change by reducing the effect of temperature change with the limit of 2°C for long run is now difficult (IPCC 2014). The major consequences of climate change include the unreliable precipitation, floods, drought, storms and landslides which lead to harm of the life of human being, decline of crop and livestock yield, soil erosion, etc., and hence negatively affect household food security (Goglio *et al.*, 2018; Byishimo, 2017).

Developing countries are facing challenges in agriculture development due to change in market conditions, food demand and climate. It is predicted that the annual mean temperature of the extensive area in the middle of the 21st Century will be 2 °C higher than during the late 20th Century with an increase of drought incidence and unpredictable precipitation (IPCC, 2014). The impacts of these changes are expected to increase pests and diseases for crops and livestock, affect water supplies, adversely affect biodiversity, hence food insecurity (Grossi, *et al.,* 2018). Consequently, climate change and agriculture appear to be interconnected in such a way that climate change has positive or negative impacts on agriculture through temperature and rainfall changes. However, agriculture also affects climate through emissions of greenhouse gases (Grossi, *et al.,* 2018). It is estimated that agriculture through use of fossil fuels cultivation of organic soils and poor management of inorganic fertilizer contributes up to 30 % of the total global greenhouse gas emitted (Garnett 2012).

Tanzania is one of the vulnerable countries to climate change threats. Studies by Mkonda and He, (2017) and Mashingo, (2010) shows that, since 1960 there is an increase of 10 °C annual temperature and decrease of rainfall by 2.8 mm per month. An increase of drought, floods and storms with a negative impact on food crop production and a serious impact on food security especially in the rural farming households are also predicted (Mbilinyi, *et al.,* 2013). In addition, the negative effects of climate change increase socio-economic impact on people especially in poor farming households (Mbilinyi, *et al.,* 2013). Rural Tanzanian's smallholder farmers, who are already bearing the brunt of climate vagaries, are the most exposed to the risks associated to climate change (Mashingo, 2010).

Given the negative impacts of climate change, farmers in Tanzania especially in Southern Highlands are trying to make changes to their agricultural practises (Mkonda and He, 2017). These changes aimed to transform both crop and livestock production though usage of improved seed varieties, crop rotation, animal breeds, soil and land management practises, water conservation practises, and improved fodder production among others (Capone *et al.*, 2014). These practises referred to as climate-smart agriculture (CSA-practises) which are likely to enhance adaptive capacity, improve food security, and reduce/remove greenhouse gases in resource-poor smallholder farming systems (Capone *et al.*, 2014).

As defined by the FAO (2010), CSA refers to agriculture practises/technologies that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievement of national food security and development goals. Thus, CSA is not a new agricultural system, but is a new approach which guides the needed changes of agricultural systems, given the necessity to jointly address food security and climate change (Long *et al.*, 2016).

Farm households in Southern Highlands of Tanzania (Mbeya and Songwe Regions) have used CSA-practises on their farms voluntarily (Mkonda and He, 2017; Banjarnahor *et al.* 2014; Shetto *et al.* 2007). This study considered three CSA-practises which are crop rotation, intercropping and residue retention. Several studies have shown that crop rotation has the advantage of breaking pest’s life cycle, deliver soil carbon sequestration, improve soil fertility through nitrogen fixation and suspend weeds hence increase crop productivity (Di Falco *et al.*, 2010). Usage of crop residue is another important aspect of CSA-practise as it can assist to improve soil moisture and decrease soil erosion while intercropping is potential in enhancing utilization of plant growth resources such as growing space, water, nutrients and light (Bybee-Finley and Ryan, 2018).

Previous researches mostly focus on the usage of single practise considered as a single unit. However, farmers typically use multiple practises to deal with their overlapping production constraints caused by climate change such as unreliable rainfall, rise in temperature, increased pest and diseases, soil erosion and low soil fertility (Mashingo, 2010). In addition, practise usage decisions are path dependent: the choice of practise used most recently by farmers is partly dependent on their earlier practise choices (i.e., Aurangozeb 2019; Kaweesa *et al.*, 2018: Thuo *et al.,* 2017; Nyasimi *et al.*, 2017; Ghimire *et al.*, 2015).

Interestingly, usage of multiple combinations of CSA-practises on households in Africa and Tanzania in particular has currently received consideration but empirical evidence is still inadequate particularly in Tanzania (Beyene *et al.*, 2017; Di Faclo *et al.*, 2013). This is to say, if the inter-relatedness of various CSA-practises are not considered, the effects of exogenous decision on usage of CSA-practices made by farming households which might underestimated or overestimated. Therefore, there is inadequate evidence on how the usage of multiple CSA-practises by farming households in Tanzania responds to climate change. Then, to fill this knowledge gap it is vital to examine the factors which motivate farming households to use different combinations of CSA-practises where a multinomial logit model was applied to jointly examine farming households’ usage decisions.

This study adds to the literature on the economics of climate change in the following ways. First, it contributes to the narrow literature on usage of multiple combination of CSA- practises in the aspect of changing climate to understand the synergistic effect of inter-related CSA-practises. Second, the study investigates for the first time, to our knowledge that treating farmers' usage choices in combination of practises is important in order to better understand the synergistic effect of interrelated CSA-practises. These are important contributions to assist governments and agricultural extension practitioners to design effective agricultural extension policies related farmers' usage of CSA-practises.

3.2 Overview of Literature

3.2.1 The concept of Climate-Smart Agriculture

The concept of CSA-practise marked to guide agriculture management in the climate change era (Anderson *et al.*, 2017). The aim of CSA is to support efforts at local and global level through using agricultural systems for sustainable achievement of food security for all people at all times, through integrating necessary adaptation and capturing potential mitigation (Lipper *et al.*, 2014).

There are number of objectives used to achieve this aim which include improving agricultural productivity to support reasonable rises in incomes, improving food security and development, building resilience to climate change and to reduce greenhouse gases emission from agriculture (FAO, 2010). Interventions ranging from climate information services to field management have potential to achieve these goals (Nyasimi *et al*., 2017).

3.2.2 Conceptual framework and econometric specification

According to Beyene *et al.* (2017) famers can either use agricultural practises in isolation or in a combination Teklewold *et al.* (2017) argued that farmers are faced with choices and trade-off when they use or decide to use new practise or practice. In developing countries farmers differ in terms of their culture, resource endowments and preference hence have different decisions in CSA-practises usage (Loevinsohn *et al.*, 2013).

Therefore, farmers can use a combination of practises to generate income, attain food security and reduce poverty. This indicates that decision to use a certain CSA-practise is essentially multivariate, and the use of univariate modelling would eliminate valuable information about interdependent and simultaneous usage of these practices (Aryal *et al.,* 2018). This is very important because ignoring these interdependencies can result into inconsistent policy recommendations (Beyene *et al.,* 2017).

However, farming households are exposed to some uncertainty of risk and shock events as a result of climate change and other production constraints, therefore effects of these constraints play an important role in the usage of CSA-practises decisions. Therefore, the study applied the theory of the maximization of expected utility to explain the decisions of farming households on usage CSA-practises either in isolation or in combinations/packages.

This theory was devoted by von Neumann and Morgenstern (1986) and has been one of the best decision-making theories. Based on this theory, farming households will use a given CSA-practise in isolation or in combination only if the expected utility obtained from the certain CSA-practise beats that of the business as usual. The utility derived from choice q for farm household $i$equals;

$U_{iq}=\mu_{iq}+\varepsilon_{iq}$.. (1)

Take into consideration that U_{iq} is the utility related with choice q for the farming household$i$, and ε_{iq} is the error term related with that particular choice. Therefore, the probability of choosing option 1 is the probability that the utility from option 1 exceeds the utility from option 2:

$Pr(y_i=1)=Pr\ (U_{i1}>U_{i2})$

¿ $Pr\ (\mu_{i1}+\varepsilon_{i1}>\mu_{i2}+\varepsilon_{i2})$

¿ $Pr\ (\varepsilon_{i1}-\varepsilon_{i2}>\mu_{i2}-\mu_{i1})$ .... (2)

When there are J choices, as in our case, the probability of choice y is

$Pr(y_i=q)=Pr\ (U_q>U_j\ \forall\ j\neq q)$ .... (3)

The form of the discrete choice model is determined under the assumption that distribution of ε and the association of how μ_q , the average utility for choice$q$, to measured variables. To obtain the Multinomial Logit (MNL) model, let the average utility be a linear combination of the attributes of household, plot, and institutional:

$\mu_{iq}=Z_i\vartheta_q$ .... (4)

Z is a $n\,x\,k$ matrix of the independent variables, and ϑ is a $k\,x\,1$ vector of parameters to be estimated. Equation (iv) stand as a basis for the maximum likelihood estimator. Now let $Pr(Y_i=q|Z_i,\vartheta_2,\ldots\ldots\ldots,\vartheta_j)$present the probability of observing $Y_i=q$ given Z_i with parameters

ϑ_2 through ϑ_j. Let p_i be the probability of observing the value of y that was actually observed for the i^{th} observation. Therefore, the likelihood function, if the observations are independent, is:

$$L(\vartheta_2,\ldots\ldots,\vartheta_j|Y,Z)=\prod_{i=1}^{N} p_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Substituting p_i in the above equation yields:

$$(\vartheta_2,\ldots\ldots,\vartheta_j|Y,Z)=\prod_{i=1}^{N}\coprod_{y_{i=q}}\frac{\exp(Z_i\vartheta_q)¿¿}{\sum_{j=1}^{j}\exp ¿¿¿} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

By taking logs, the log likelihood equation could be maximized with numerical methods to estimate the $\vartheta's$. Therefore, resulting into estimates which are consistent, asymptotically normal, and asymptotically efficient (Amemiya, 1981).

3.2.3 Empirical review

Previous studies related to the determinants of usage of CSA-practises have been conducted in Tanzania and elsewhere. For example, using binary a study conducted by Aurangozeb (2019) in Rangpur, India, showed that practises usage of rural women had significant negative correlation with their usage of integrated homestead farming practises. Thuo *et al.* (2017) in his study of the usage of tissue culture practise in Lower Eastern region of Kenya found that, access to the market, gender, education, access to agricultural extension services, access to land subsidy policy, and income level were the important determinants in the usage of tissue culture practise.

Ghimire *et al.* (2015) argued that the factors influencing the likelihood of using improved rice variety in Central Nepal are the yield potential, access to market, proper extension services, the size of the farm, and farmers' education level. Mittal and Mehar (2015) in their study they found that education level of the head of the household, farm size, and age of the head of the household were identified as major factors affecting the usage of modern agricultural information in India.

Manda *et.al.* (2015) found the use of sustainable agriculture practices in Zambia decreased with off-farm income, gender of the head of the household and the distance from home to the local market. The study contradicted with the study by Lavison (2013) who concluded that gender of the head of the household and access to the local market influenced the usage of agricultural practises. Furthermore, Kariyasa and Dewi (2013) found that access to agricultural information level of education of the head of the household, distance to the meeting place, agricultural productivity level and age of the head of the household influenced the usage of integrated crop management practices.

The study by Fisher *et al.* (2015) applied a multinomial logit model to examine the usage of different varieties of maize in eastern and southern Africa. The study found that older heads of the household were more likely to grow local maize and less likely to grow non-drought tolerant maize seeds compare to younger household heads. Again the study found that head of the households with higher level of education were more likely to grow drought tolerant maize seeds and less likely to grow local maize.

Nkonya *et al.* (1997) found that the farming experience of the head of the household was the only factor that significantly influenced usage of improved maize Tanzania. Furthermore, the study found that the number of livestock owned by the household influenced the usage of chemical fertilizers. In addition, the study found the age of the head of the household, gender of the head of the household, education level of the head of the household and household size influenced the usage of chemical fertilizer.

Study by Eleni (2008) showed that head of the household who engaged in non-farm activities were more or less used the soil and water conservation practises as a CSA-practise. Similarly, the findings by Belay *et al*. (2004) indicated that participation in non-farm activities negatively influenced the continued use of soil and water conservation measures. The study by Eleni (2008) also showed that farmers who use chemical fertilizers are more likely to use soil and water conservation practices compare to non-user of chemical fertilizers.

3.3 Study Methodology

3.3.1 Study area

The study was conducted in two regions and four districts. That is, in Mbeya and Mbarali districts in Mbeya Region and Mbozi and Momba districts in Songwe Region in Tanzania. These regions the breadbasket area of Tanzania where different types of crops are cultivated such as maize, beans, soya beans and paddy rice.

Selection of the study area was based on the cultivation of staple food crops such as paddy, maize, common beans and soya beans. In addition, food and nutritional security vulnerability was another selection criterion, because 37.7 % of children below five years are stunted (TFNC, 2014). The study area is also considered as appropriate for this study because farmers primarily rely on food crop production for their livelihoods. Furthermore, mixed agronomic practises were also the main driver for selection of the study area.

3.3.2 Sampling and data collection

A cross-sectional study was conducted to collect information from the household through structured interviews under the project titled ‘‘Integrated Project to Increase Agriculture Productivity in the Bread Basket Area of Southern Highlands of Tanzania”. The project aimed to stimulate agricultural development by increasing the productivity of selected commodities such as maize, rice, soya beans and common beans.

This was achieved through a value chain development approach, integrating various areas of intervention, such as development of farmer organizations, improved access to inputs through agro-dealer networks, extension, establishment of CSA-practises demonstration plots and access to output markets through contracting with processors. Data were collected from four districts (Mbarali, Mbozi, Momba and Mbeya) in Mbeya and Songwe regions.

The study population included the farming households cultivating paddy, maize, common beans and soya beans where the selected respondents for the survey were households. The study involved a multistage sampling where in the first step random sampling technique was used to select farmer organisations from lists obtained from the district agriculture irrigation and cooperative offices from the respective districts. Within selected farmers' organisations, households were randomly selected from group membership lists provided by the group leaders using simple random sampling techniques.

Total sample sizes of 1557 households were then selected for the survey. However, about 114 households were dropped during data cleaning prior to analysis as they did not have sufficient data thereby, reducing the sample to 1443 households. Data collection for this study was done in February 2017 through face-to-face administration of questionnaires. We used tablets for data collection under the android application called Open Data Kit (ODK) in which the questionnaire was in both Swahili and English versions.

3.3.3 Empirical model

The CSA-practises considered in this study include crop rotation, crop residue and intercropping, providing eight mutually exclusive combinations of practises (2^3). A MNL model was used to estimate the probability of CSA-practises usage conditional on a vector of explanatory variables. Household characteristics are classified among eight combinations of CSA-practises based on the usage status as shown in Table 3-1.

Table 3. 1: Combination of usage of crop rotation, crop residue and intercropping

SN	CSA combinations	Description
1	$C_0R_0I_0$	$C_0R_0I_0$ = 1 if a farmer is a non-user
2	$C_1R_0I_0$	$C_1R_0I_0$ = 1 if a farmer only uses crop rotation; 0 other wise
3	$C_0R_1I_0$	$C_0R_1I_0$ = 1 If a farmer uses crop residue; 0 other wise
4	$C_0R_0I_1$	$C_0R_0I_1$ = 1 If a farmer uses intercropping; 0 other wise

5	$C_1R_1I_0$	$C_1R_1I_0$ = 1 If a farmer uses crop rotation and crop residue; 0 other wise
6	$C_1R_0I_1$	$C_1R_0I_1$= 1 If a farmer uses crop rotation and intercropping; 0 other wise
7	$C_0R_1I_1$	$C_0R_1I_1$= 1 If a farmer uses crop residue and intercropping; 0 other wise
8	$C_1R_1I_1$	$F_1P_1I_1$= 1 If a farmer uses crop rotation crop residue and intercropping; 0 other wise

Let Y_j takes the value 1 if the j^{th} household chooses the q^{th} combination of CSA-practise; 0 otherwise. The relative odds (P) of the used CSA-practises are expressed using the following MNL model:

$$\log \frac{P_{jq}}{P_{jM}} = Z'_j \vartheta_q + \varepsilon_{j,} j = (1, \ldots\ldots, n), q = \text{¿})$$ …………………. (7)

The log is the natural logarithm, Z represents the exogenous explanatory vector and ϑ is a vector of parameters to be estimated, and ε is a random disturbance term. q stands for the conditional probability for the choice which is derived as follows [for more detail, see Greene (2003)]:

$$P_{jq} = Prob(Y_{jq} = 1) = \exp \text{¿¿}$$ ………………… (8)

Which, alternatively, can be written as:

$$P_{jq} = \frac{\exp(Z'_j \vartheta_q)}{1 + \sum_{k=1}^{M-1} \exp \text{¿¿¿}}$$ ……………..……………………… (9)

$$P_{jq} = \frac{1}{1 + \sum_{k=1}^{M-1} \exp \text{¿¿¿}}$$ ……………………………………………………………… (10

3.4 Variables used in the Empirical Analysis

3.4.1 Dependent variables

The study considered the dependent variables (CSA-practises) as a combination of crop rotation, crop residue retention and intercropping as shown in Table 3-1. According to Teklewold *et al.* (2019) crop rotation practise is defined as the art of growing more than one crop across time. As a CSA-practice crop rotation play a potential role for adaptation to climate change as it helps in improving soil fertility, decreasing the incidence pests and diseases, and reduce of soils erosion (Teixeira *et al.*, 2018; Ma *et al.*, 2018).

Crop rotation also is important as helps to mitigation to greenhouse gases as it reduces the need for nitrogenous fertilizers application when leguminous crops are introduced and maintain and or improves soil carbon stock (Teklewold *et al.*, (2019). The practise is important in the Improvements in farm productivity of pasture, feed and food crops (Teixeira *et al.*, 2018).

Intercropping is defined as the art of growing two or more crops simultaneously in a unit of land (Dyer *et al.*, 2012). The practise is considered climate smart as it controls weeds, improve water holding capacity, it improves physical, chemical and biological characteristics of the soil (Bybee-Finley and Ryan, 2018). Above all it intercropping decrease the rate of crop failure hence improves food security (Teklewold *et al.*, 2019). In mitigation of greenhouse gases intercropping maintain soil carbon stock or organic matter content and reduces the need for chemical fertilizer (Hassen *et al.*, 2017). According to Teklewold *et al.* (2019) the practise improves productivity therefore is important in promoting sustainable utilization of land, water and other scarce resources.

Crop residue retention is considered to be crop remains which are left in the field after harvest (Bolinder *et al.,* 2020). Crop residue retention enhances soil moisture, fertility and reduces soil erosion (Chalise *et al.*, 2019: Ma *et al.*, 2018) In addition, the practise improves carbon storage, decreases use of chemical fertilizers (Bolinder *et al.*, 2020).

3.4.2 Explanatory variables

The explanatory variables included in the analysis are based on the empirical literature (Beyene *et al.,* 2017; Teklewold, *et al.* 2017; Manda *et al.,* 2015; Kassie et *al.,* 2014; Kassie et *al.,* 2013). Level of education of the head of the household measured by the years of schooling was expected to be positively and significantly associated with the usage of CSA-practises either in isolation or in combination. According to Khonje *et al.* (2015) educated farm household head is expected to use CSA-practises individually or in combination than households with less or no education. it is also expected that the education level of spouse of the head of the household may positively affect usage of the practices either in isolation or in combination (Manda *et al.,* 2015). The definition of variables in the analysis are shown in Table 3-2.

Age of the head of the household measured in years, was expected to affect positively or negatively the possibility of using CSA-practises. This implies that as a household head become aged there is a possibility of becoming more risk averse regarding using CSA-practises (Kaliba *et al.*, 2000). The gender of the head of the household (dummy variable) was expected to influence farming households to use different combinations of CSA-practices. A study by Doss and Morris (2001) found that the households headed by female are less likely to use agricultural practises because of poor access to productive assets such as land acquisition. It is, therefore, hypothesised that male headed households are expected use of CSA-practises either in combination or in isolation compare to the household headed by female.

Household size measured in number was considered as a proxy for available household labour. Large households are expected to use CSA-practises than smaller households. This is due to the fact that the usage of CSA practises requires additional labour. Farming household' decision to use a CSA-practise will be dependent on the labour force available. Plot characteristics like plot size, land ownership, soil fertility, and distance from home to the farm can influence the usage of CSA-practises either in isolation or in combination (Beyene *et al.*, 2017).

Access to extension services, farmer organization memberships and access to demonstration plots were included in the model as institutional characteristics. The extension service was measured as a dummy variable and was considered as an imperative source of information to farmers (Manda *et al.*, 2015). It is, therefore, hypothesised that extension services will increase usage of CSA-practises either in isolation or in combination. Agricultural extension services typically play a critical role in improving usage and innovation (Chowdhury *et al.*, 2014).

Table 3. 2: Definition of variables in the analysis

Variable	**Type of variable**	**Description of the variables**
Household size	Discrete	Household members living together under the same roof and eating from the same pot
Education of the head of the household	Discrete	Years spent in schooling

Gender of the household head	Dummy	1 if the head is male, 0 otherwise
Age of the household head	Continuous	Age of household head (in years)
Marital status of the household head	Dummy	1 if the head is male, 0 otherwise
Farming experience of the household head	Continuous	Household head’s farm experience in years
Livestock ownership (TLU)	Continuous	Livestock holding in Tropical Livestock Units
Mobile phone ownership	Dummy	1 if the head is male, 0 otherwise
Radio ownership	Dummy	1 if the head is male, 0 otherwise
Television ownership	Dummy	1 if the head is male, 0 otherwise
Ownership of productive assets	Discrete	Productive assets owned
Income diversification	Continuous	Number of different income sources
Land ownership	Dummy	1 if the head is male, 0 otherwise
Access to demonstration plots	Dummy	1 if the head is male, 0 otherwise
Extension services	Dummy	1 if the head is male, 0 otherwise
Distance to the extension office	Continuous	Distance from from home to the extension office in minute
Access to tarmac road	Continuous	Distance from home to the tarmac road in minute
Membership of multiple organizations	Dummy	1 if the head is a member of more than one organization male, 0 otherwise
Access to loan	Dummy	1 if the household head is male, 0 otherwise
Average plot distance	Continuous	Distance from home to the plot in minute
Plots cultivated	Discrete	Number of plots cultivated
Soil fertility	Dummy	1 if the land is fertile, 0 otherwise
Soil erosion	Dummy	1 if the land is eroded, 0 otherwise
Production Diversity	Discrete	Number of crops cultivated in acre
Total Plot Size	Discrete	Total plot size owne in Acre
Mbozi District	Dummy	1 if the district is Mbozi, 0 otherwise
Momba District	Dummy	1 if the district is Momba, 0 otherwise
Mbarali District	Dummy	1 if the district is Mbarali, 0 otherwise

Farmer organization membership measured by dummy variable (membership in more than one farmer organization =1 or otherwise) may increase access to information on CSA- practises hence increase the probability of using CSA-practices (Mathenge *et al.,* 2012). Access to agricultural demonstration plots measured by dummy variable increased knowledge about the CSA-practises. Farming households with knowledge about the CSA-practises are more likely to have higher usage than those which do not know about the practises (Chowdhury *et al.,* 2014).

According Kassie *et al.* (2013) plot size measured in acre can influence the usage of agricultural practises. For example, farming households with larger plots can decide to allocate more land to practices such as the combined CSA-practises. This means that farming households with larger farm would be more inclined to the usage CSA-practises compared with those with less land. However, farming households with larger plots might use less intensive methods than those with small plots (Kassie *et al.*, 2013). Therefore, this study hypothesises that farming households with larger plots will be more likely to use the CSA-practises either in isolation or in combination compared to farming households with smaller plots.

3.4.3 Multinomial logit regression model

The Multinomial logit model was employed to determine the factors that influence farming households to choose a combination/package of CSA-practises in the study area. Different tests which are essential for running the multinomial logit model were taken. The first test was Hausman test which test the validity of the independence of the irrelevant alternatives (IIA) assumptions. It is suggested that the multinomial logit model is an appropriate to model the usage of CSA-practise as the Hausman test failed to reject the null hypothesis of the independence of the usage of CSA-practises. Other important tests before running the mode were the test for heteroskedasticity and multicollinearity.

A white test was used to detect for the problem of heteroskedasticity for the hypothesised independent variables. The white test was preferred over the Breusch-Pagan test because of its capacity to incorporate the magnitude and the direction of the change for non-linear forms of heteroskedasticity (Wooldridge, 2010). The results showed that the chi^2 of 118 was insignificant which implies the absence of the heteroskedasticity problem. Thus, the application of the MNL model was found to be appropriate and the model has been used by other researchers like Deressa *et al.* (2008) to estimate the decision for the usage of climate change adaptation technologies by farmers in Ethiopia.

3.5 Results

3.5.1 Preliminary diagnostics of the variables to be used in the econometric analysis

Tests for statistical problems like multicollinearity and heteroskedasticity were conducted for all variable used in the model. According to Wooldridge, (2010) define multicollinearity as the existence of two or more predictor variables in the regression model which are correlated. The Variance Inflation Factor (VIF) was applied in this study to test for the multicollinearity problem. The VIF results found that there was no linear relationship among the explanatory continuous variables as VIF values were less than 10. Same results for the categorical variables used in the model were found no serious linear relationship because contingent coefficients were less than 0.75 in all cases. Therefore, the study confirmed that, there was no strong association among all hypothesized explanatory variables. Therefore, all of the proposed potential explanatory variables were used in regression analysis.

3.5.2 Determinants of using combination of CSA-practises

The study applied a multinomial logit (MNL) regression model to identify drivers for farmers' usage of multiple combinations of CSA-practises. In this study, an unordered multinomial logit model is useful because it can take care of categorical dependent variables (such as nominal categories of dependent variables having multiple choices). The model estimates the effect of the individual variables on the probability of choosing a type of multiple combination CSA-practises.

The principle component analysis (PCA) was applied to identify the most common CSA-practises used in the study area. The PCA was used to group these practises whereby related practises were grouped into the cluster (components) based on use. The PCA is btter than the conventional grouping method which make it difficult to conclude about a group in cases where few practises could represent the entire group. The components were rotated using the varimax method in such a way that a smaller number of highly correlated CSA-practises would be put under each component for easy interpretation and generalization about a group (Chatterjee *et al.,* 2015). These practises comprised of the decision categories for the multinomial logit model having combinations as shown in Table 3-3.

The explanatory variables were entered into Multinomial logit model (MNL) to examine the effect using CSA-practises either in isolation or in a combination. The MNL results show the probability of chi-square where likelihood ratio statistics are highly significant at $p < 0.0000$, indicating that the model has a strong explanatory power.

Table 3. 3: Marginal effects from the multinomial logit for the choice of CSA-practises

Variables	$C_1R_0I_0$	$C_0R_1I_0$	$C_0R_0I_1$	$C_1R_1I_0$	$C_1R_0I_1$	$C_0R_1I_1$	$C_1R_1I_1$
	dy/dx	dy/dx	dy/dx	dy/dx	dy/dx	dy/dx	dy/dx
Household Characteristics							
Household size	-0.0003	-0.00683	0.0034	0.0003	0.0034	0.0006	-0.0030
	0.803	0.0210**	0.1310	0.8910	0.1030	0.8980	0.6040
Education of the household head	0.0004	-0.00006	-0.0019	-0.0048	-0.0002	0.0016	0.0088
	0.554	0.9750	0.3210	0.0380**	0.9140	0.6650	0.0650*
Gender of the household head	0.0041	-0.00938	-0.0545	0.0073	-0.0372	-0.0035	0.1297
	0.69	0.7210	0.0040***	0.7980	0.0580*	0.9360	0.0360**
Age of the household head	0.0001	-0.00014	-0.0008	0.0003	-0.0007	0.0003	0.0000
	0.651	0.7890	0.0770*	0.4880	0.1130	0.7930	0.9890
Marital status of the household head	-0.0128	0.01386	0.0152	0.0049	0.0345	0.0141	-0.0923
	0.133	0.5830	0.3090	0.8250	0.0690*	0.7190	0.1030
Farming experience of the household head	-0.0002	-0.00011	0.0002	-0.0010	0.0006	0.0027	-0.0009
	0.19	0.8330	0.5580	0.0610*	0.1700	0.0050***	0.4800
Households resource endowment							
Livestock ownership (TLU)	0.0005	-0.00071	-0.0057	-0.0002	0.0012	0.0002	0.0041
	0.337	0.7190	0.0960*	0.9070	0.2910	0.9430	0.3860
Mobile phone ownership	0.0018	-0.00648	-0.0137	0.0324	-0.0051	-0.0067	-0.0194
	0.752	0.6480	0.2910	0.1220	0.7140	0.8180	0.6320
Radio ownership	0.0081	-0.00270	-0.0004	0.0030	0.0068	0.0094	-0.0140
	0.155	0.8110	0.9650	0.7970	0.5350	0.6410	0.5940
Television ownership	-0.0120	-0.00009	-0.0184	0.0042	-0.0009	0.0119	-0.0237
	0.16	0.9960	0.1950	0.7630	0.9390	0.6680	0.4980
Ownership of productive assets	-0.0004	-0.00042	0.0067	-0.0046	-0.0080	0.0050	0.0127
	0.895	0.9450	0.2090	0.4260	0.1600	0.6230	0.3510
Income diversification	-0.0078	-0.02949	-0.0302	-0.0112	-0.0100	-0.0218	0.1476
	0.045**	0.0010***	0.0000***	0.1850	0.0990*	0.1810	0.0000***
Land ownership	0.0036	0.00475	-0.0035	-0.0139	-0.0150	-0.0064	0.0281
	0.456	0.7640	0.7270	0.3860	0.1420	0.8080	0.4030

Continue….

Variables	$C_1R_0I_0$ dy/dx	$C_0R_1I_0$ dy/dx	$C_0R_0I_1$ dy/dx	$C_1R_1I_0$ dy/dx	$C_1R_0I_1$ dy/dx	$C_0R_1I_1$ dy/dx	$C_1R_1I_1$ dy/dx
Institutional services							
Access to demonstration plots	-0.0052	-0.0045	0.0075	-0.0062	-0.0169	-0.0206	0.0601
	0.286	0.6970	0.4390	0.5500	0.0730*	0.278	0.0150**
Access to extension services	-0.0014	0.01345	0.0176	0.0154	0.0256	0.0344	-0.0546
	0.865	0.2970	0.2300	0.1640	0.0300**	0.1710	0.1070
Distance to the extension office	-0.0002	-0.00019	0.0000	0.0001	0.0002	-0.0007	0.0006
	0.064*	0.4240	0.9450	0.4450	0.0860*	0.1060	0.1890
Access to tarmac road	0.0000	-0.00004	0.0000	0.0000	0.0001	-0.0001	-0.0002
	0.09*	0.6290	0.9140	0.4550	0.0550*	0.7740	0.4460
Membership of multiple organizations	-0.0007	-0.02651	-0.0413	-0.0131	-0.0065	-0.0622	0.1384
	0.897	0.0710*	0.0190**	0.2790	0.5880	0.0080***	0.0000***
Access to loan	0.0061	-0.00504	-0.0088	-0.0007	-0.0089	-0.0033	0.0437
	0.235	0.7520	0.4360	0.9580	0.4190	0.8940	0.1680
Plot Characteristics							
Average plot distance	0.0002	-0.00006	-0.0001	0.0000	-0.0002	0.0007	-0.0009
	0.039**	0.8160	0.8060	0.9990	0.4720	0.1970	0.2040
Number of plots cultivated	-0.0009	-0.00021	-0.0042	-0.0002	-0.0019	-0.0202	0.0516
	0.638	0.9570	0.4790	0.9700	0.6870	0.0380**	0.0000***
Soil fertility	0.0056	-0.00335	-0.0039	-0.0023	-0.0109	0.0148	-0.0219
	0.169	0.7410	0.6830	0.8310	0.2530	0.4260	0.3620
Soil erosion	0.0105	-0.00975	-0.0033	0.0063	0.0311	0.0315	-0.0500
	0.051*	0.4100	0.7770	0.5800	0.0010***	0.1010	0.0640*
Production Diversity	-0.0306	-0.02439	0.0226	0.0125	0.0313	0.0787	0.0018
	0.26	0.3670	0.3500	0.6160	0.2320	0.0940*	0.9770
Total Plot Size	0.0003	-0.00013	-0.0015	0.0010	0.0007	-0.0008	0.0003
	0.182	0.8190	0.1860	0.0030**	0.4260	0.6200	0.8790
Geographical Location							
Mbozi District	-0.0875	0.02047	-0.0212	0.0391	-0.0424	0.0584	0.0809
	0.001***	0.1210	0.2000	0.0270**	0.1700	0.0220**	0.0450**
Momba District	-0.0806	0.00072	-0.0562	0.0695	0.0135	-0.1347	0.2496
	0.001	0.9700	0.1040	0.0000***	0.4820	0.0010***	0.0000***
Mbarali District	0.0145**	-0.00653	0.0147	-0.0200	0.0638	-0.0262	-0.0790

*** p<0.01, ** p<0.05, * p<0.1 significance level

The parameters of the MNL model provide the direction of the effect of the independent variables on the response variable but they do not present the magnitude of change. Therefore, the marginal effects which is measured the expected change in probability of a specific choice of CSA-practises with respect to a unit change in an independent variable, are indicated and discussed. The marginal effect results in Table 3-3 were considered for interpretation.

The size of the household size showed a significant and negative influence on the usage of crop residue only ($C_0R_1I_0$). This indicates that a marginal increase in household size would lead to decrease in the probability of using crop residue as a CSA-practise by 0.683%. This finding is contrary to Lugandu (2013) in Karatu and Kongwa districts of Tanzania who found that the household size influenced usage of conservation agriculture with non-user having relatively smaller household size indicating that the source of labour for the smaller household is limited hence impacting on usage of conservation agriculture. This different is caused by the fact that farming households in the study area who own livestock are likely depend on their residues as fodder and are therefore less inclined to retain the residues on the fields.

Gender of the head of the household was found to be significantly and negatively connected with the likelihood of using intercropping ($C_0R_0I_1$) by 0.004 at 1% significant level. The findings show that female headed households were 5.45% associated with the usage of intercropping in isolation compare to male headed households. Result showed a negative association of gender with the likelihood of using combination of crop rotation and intercropping in combination ($C_1R_0I_1$**)** at 0.0580 probability level.

In addition, gender of the household head is significantly and negatively connected with the likelihood of using combination of crop rotation, crop residue and intercropping ($C_1R_1I_1$) by 0.0360 at 5% level of significance. The findings show that female-headed households were 12.97% associated with the usage of combination of crop rotation, crop residue and intercropping as compared to male headed households. These findings concur with the argument that female have more likelihood of using these practises than the male because female are more engaged in agriculture activities than male, regardless they have less control of production resources (Obayelu *et al,* 2014).

As expected, the level of education of the head of the household was significantly and positively connected with the likelihood of using combination of crop rotation, crop residue and intercropping ($C_1R_1I_1$) by 0.0650 at 10% significant level. The findings show that the education level of the household headwas 0.88% associated with the usage of combination of crop rotation, crop residue and intercropping. Contrary to expectation, the education level of of the head of the household decreases the probability of using a combination of crop rotation and crop residue ($C_1R_1I_0$) at 5% significant level ($p < 0.0380$).

This implied that a unit increase in the level of education would result in a 0.48% decrease in the likelihood of using a combination of crop rotation and crop residue. It could be that educated household did not use these combinations of practises because it does not offer risk decrease measures which could protection their investment against risks of climate change. These findings are in similar with the study of Aryal *et al.,* (2018) which found the education level to be significant and negatively correlated with the usage of mixed farming at $p < 0.001$ significan level. Gido *et al.* (2015) argue that more education tends to build the innovativeness and capability to calculate risks by farming households for proper farm adjustments.

The experienced farming household head in farming have an increased likelihood of using a combination of crop residue and intercropping ($C_0R_1I_1$) as CSA-practise. The study found the farming experience of the head of the household to have a positive connection with the usage of a combination of crop residue and intercropping ($C_0R_1I_1$) at 1% significant level ($p < 0.0050$).

Farming households with high experience in farming have more skills in CSA-practises and can spread climate change threat by using CSA-practises complementarities such as practising combination crop residue and intercropping ($C_0R_1I_1$). The findings of this study disclose that as farming households advance in years of farming experience, it increases the usage of combination of crop residual and intercropping by 0.27% as a CSA-practise. Consistent with this study, Ngwira (2014) found that household with high experience in faming activities used conservation agriculture practises than households with less experience.

Crop diversification was found to have a positive and significantly influence on usage of combination of crop residue and intercropping ($C_0R_1I_1$). This implies that farming households with practised crop diversification in their farm are more likely to use a combination of crop residue and intercropping. Therefore, they have to use different combination of CSA-practises for the assurance of higher yield from each crop cultivated.

Access to tarmacked road measured by working distance to the tarmacked roads in minute shown a positive influence on the chance of using a combination of crop rotation and intercropping ($C_1R_0I_1$) at 1% significant level ($p < 0.000$) as CSA-practises. This indicates that a marginal increase in access to tarmacked roads would lead to increase in the probability of using a combination of crop residue and intercropping by 0.01%. It is also positively and significant for the farming households which use crop rotation in isolation ($C_1R_0I_0$). The positive sign implies that farming households with access to tarmacked road invest more on CSA-practises as they have assurance of the access to inputs and output markets.

Extension services has shown a positive and significant association with the chance of using a combination of crop rotation and intercropping ($C_1R_0I_1$) at 1% significant level. This indicates that a one-unit increase in the extension contact is likely to increase the likelihood of farming household using a combination of crop rotation and intercropping as CSA-practises by 2.56%. This implies that farming households with access to extension services are more likely to be informed on CSA-practises.

The finding is similar with a study by Mmbando and Baiyegunhi (2016) who found positive relationship between extension services and usage of drought-tolerant maize seeds in Hai district in Kilimanjaro Tanzania. In addition, the study found that farming households which are away from the office of the extension officer are less likely to use crop rotation in isolation. This is plausible because long distance to the extension office for extension services increases transaction costs. The finding is similar with a study by Aryal *et al.,* (2018) who found that farmers who stay away from the office of the agricultural extension office were less likely to use CSA-practises in the Indo-Gangetic Plains of India.

Livestock ownership measured by Tropical Livestock Unit was found to be negative and significant association with the probability of using intercropping in isolation ($C_0R_0I_1$) at

10% significant level. This indicates that a one-unit increase in the tropical livestock unit is likely to decrease the likelihood of farming household use of intercropping by 0.57%. This implies that there is a decrease in the usage of intercropping as the livestock size increases. This might be because as the livestock increases, farming households have no time to engage on crop production compared to farming households with fewer livestock. On contrary, Tesfaye (2008) reported that the number of livestock owned by the farming household was found to be significant and positive influence on usage of fertilizer in Ethiopia.

The study found that farming households with large plots are more likely to use crop rotation and crop residue retention ($C_1R_1I_0$) in combination. This means that a one-unit increase in the size of the farm is likely to increase the likelihood of using crop rotation and crop residue in combination by 0.10%. Probably, this has been the situation because farming households in the study area follow the legume-cereal cropping system.

3.6 Conclusions

Developing countries face challenges in agriculture development due to change in market conditions, food demand and climate. In these countries climate change causes challenges to agricultural production and food insecurity and climate-smart agriculture is crucial approoach in addressing the potential impacts. CSA-practises can increase crop productivity; income mitigate the greenhouse gases hence improve food security. Whereas, the majority of the previous studies concentrated on the usage of single CSA-practises. However, the usage of combinations of different CSA-practises is currently received attention due to the impact of climate change even though empirical evidence on the usage of these combinations is still scant.

The multinomial logit model results show that usage of CSA-practises either in isolation or in combination is influenced by household, plot and institutional characteristics. Nonetheless, there is need of promoting greater complementarities among CSA-practises. The study found that the major determinants of farming households' decisions to use combination of CSA-practises are the household size, production diversity, farm size, extension services, livestock ownership and occupation. Analysis of determinants of usage revealed that crop diversification, gender and livestock ownership had a positive and significant influence on the usage of combination of crop residue and intercropping ($C_0R_1I_1$). In addition, education level and gender of the household head positively and significantly influenced the usage of combination of crop rotation, crop residue and intercropping ($C_1R_1I_1$).

Based on the above results, it is important to focus on policies and plans that promote each CSA-practise as a combination including other inter-related practises could contribute to upscale CSA-practises usage while harnessing the synergies between them. Dissemination of CSA-practises knowledge and its role in climate risk mitigation is critical to promote it. More CSA training for farmers, government extension staff working at the local level, and use of communication tools to share and promote knowledge on CSA-practises use to combat the global challenge of climate change are essential.

Understanding barriers and enabling conditions to CSA-practises usage helps in designing and formulating extension messages and agricultural policies that can accelerate CSA-practises dissemination and help safeguard agricultural production and food security in Tanzania. In addition, agricultural policy makers should focus at enhancing smallholder farmers' household characteristics by reviewing farmer extension so as to come up with a package that is tailored to the perceived actual needs of farming households and designing farm management usage programmes based on the farmer's household characteristics, such as education, gender, livestock ownership and membership to social groups.

However, it is important to notice that even though the study estimated the determinant of multiple combination of CSA-practise but the study did not consider the implication for the usage to household welfare. Therefore, other research should go further to investigate whether the usage of combination of CSA-practises has higher and positive welfare and productivity effects in the face of climate change.

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References

Amemiya, T. (1981). Qualitative response models: A survey. *Journal of economic literature*, *19*(4), 1483-1536.

Anderson, E. P., Marengo, J., Villalba, R., Halloy, S., Young, B., Cordero, D., ... & Ruiz, D. (2011). Consequences of climate change for ecosystems and ecosystem services in the tropical Andes. *Climate change and biodiversity in the tropical Andes*, *1*, 1-18.

Aryal, J. P., Jat, M. L., Sapkota, T. B., Khatri-Chhetri, A., Kassie, M., Rahut, D. B., & Maharjan, S. (2018). Usage of multiple climate-smart agricultural practises in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies and Management*, *10*(3), 407-427.

Aurangozeb, M. K. (2019). Usage of Integrated Homestead Farming Practises by the Rural Women of RDRS. *Asian Journal of Agricultural Extension, Economics & Sociology*, 1-12.

Banjarnahor, D. (2014). Adoption and adaptation of conservation agriculture in Tanzania southern highlands: lessons learned from Mshewe ward Mbeya region. *Master's thesis: Department of Plant Sciences, Wageningen University*. (pp78)

Belay, K., & Manig, W. (2004). Access to rural land in Eastern Ethiopia: Mismatch between policy and reality. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *105*(2), 123-138.

Beyene, A. D., Mekonnen, A., Kassie, M., Di Falco, S., & Bezabih, M. (2017). Determinants of Usage and Impacts of Sustainable Land Management and Climate-Smart Agricultural Practises (SLM-CSA): Panel Data Evidence from the Ethiopian Highlands. *Environment for Development Discussion Paper Series*, (17-10).

Bolinder, M. A., Crotty, F., Elsen, A., Frac, M., Kismányoky, T., Lipiec, J., ... & Kätterer, T. (2020). The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: a synthesis of reviews. *Mitigation and Adaptation Strategies for Global Change*, *25*(6), 929-952.

Bybee-Finley, K., & Ryan, M. (2018). Advancing intercropping research and practises in industrialized agricultural landscapes. *Agriculture*, *8*(6), 80.

Byishimo, P. (2017). *Assessment of Climate Change Impacts on Crop Yields and Farmers'Adaptation Measures: A Case of Rwanda* (No. 634-2017-5825).

Capone, R., Bilali, H. E., Debs, P., Cardone, G., & Driouech, N. (2014). Food system sustainability and food security: connecting the dots. Journal of Food Security, 2(1), 13-22.

Chalise, D., Kumar, L., & Kristiansen, P. (2019). Land degradation by soil erosion in Nepal: A review. *Soil Systems*, *3*(1), 12.

Challa, M., & Tilahun, U. (2014). Determinants and impacts of modern agricultural practise usage in west Wollega: the case of Gulliso district. *Journal of Biology, Agriculture and Healthcare*, *4*(20), 63-77.

Chatterjee, S., Goswami, R., & Bandopadhyay, P. (2015). Methodology of identification and characterization of farming systems in irrigated agriculture: case study in west Bengal State of India. *Journal of Agricultural Science and Technology*, *17*(5), 1127-1140.

Chowdhury, A. H., Hambly Odame, H., & Leeuwis, C. (2014). Transforming the roles of a public extension agency to strengthen innovation: Lessons from the National Agricultural Extension Project in Bangladesh. *The journal of agricultural education and extension*, *20*(1), 7-25.

Deressa, T. (2008) Measuring Ethiopian Farmers' Vulnerability to Climate Change Across Regional States. IFPRI Discussion Paper 806. Washington, DC: International Food Policy Research Institute (www.ifpri.org/pubs/dp.pdf).

Di Falco, S., Bezabih, M., & Yesuf, M. (2010). Seeds for livelihood: crop biodiversity and food production in Ethiopia. *Ecological Economics*, *69*(8), 1695-1702.

Doss, C. R., & Morris, M. L. (2000). How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana. *Agricultural economics*, *25*(1), 27-39.

Dyer, L., Oelbermann, M., & Echarte, L. (2012). Soil carbon dioxide and nitrous oxide emissions during the growing season from temperate maize-soybean intercrops. *Journal of Plant Nutrition and Soil Science*, *175*(3), 394-400.

Eleni T. (2008). Continued Use of Soil and Water Conservation Practices: A Case study in Tulla District, Ethiopia, MSc Thesis, Wageningen University. (pp 125)

FAO (2010). Climate-Smart Agriculture Sourcebook. Food and Agriculture Organization of the United Nations. Rome. Available from http://www.fao.org (Accessed 13/10/2017).

FAO, (2010). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2010 Key messages. Available from http://www.fao.org [Accessed 13/10/2017]

Fisher, M., Abate, T., Lunduka, R. W., Asnake, W., Alemayehu, Y., & Madulu, R. B. (2015). Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. *Climatic Change*, *133*(2), 283-299.

Garnett, T. (2012). Climate change and agriculture: Can market governance mechanisms reduce emissions from the food system fairly and effectively. *International Institute for Environment and Development, London*.

Ghimire, R., Wen-chi, H. U. A. N. G., & Shrestha, R. B. (2015). Factors affecting usage of improved rice varieties among rural farm households in Central Nepal. *Rice Science*, *22*(1), 35-43.

Gido, E. O., Sibiko, K. W., Ayuya, O. I., & Mwangi, J. K. (2015). Demand for agricultural extension services among small-scale maize farmers: Micro-level evidence from Kenya. *The Journal of Agricultural Education and Extension*, *21*(2), 177-192.

Goglio, P., Smith, W. N., Grant, B. B., Desjardins, R. L., Gao, X., Hanis, K., ... & Burgess, P. J. (2018). A comparison of methods to quantify greenhouse gas emissions of cropping systems in LCA. *Journal of Cleaner Production*, *172*, 4010-4017.

Greene, W. H. (2003), Econometric Analysis, fifth edition, Upper Saddle River, NJ, PrenticeHall.

Grossi, G., Goglio, P., Vitali, A., & Williams, A. G. (2018). Livestock and climate change: impact of livestock on climate and mitigation strategies. *Animal Frontiers*, *9*(1), 69-76.

Hassen, A., Talore, D. G., Tesfamariam, E. H., Friend, M. A., & Mpanza, T. D. E. (2017). Potential use of forage-legume intercropping technologies to adapt to climate-change impacts on mixed crop-livestock systems in Africa: a review. *Regional Environmental Change*, *17*(6), 1713-1724.

IPCC. (2014). Part A: Global and Sectoral Aspects. (Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Climate Change 2014: Impacts, Adaptation, and Vulnerability. 1132.

Kaliba, A. R., Verkuijl, H., & Mwangi, W. (2000). Factors affecting adoption of improved maize seeds and use of inorganic fertilizer for maize production in the intermediate and lowland zones of Tanzania. *Journal of Agricultural and Applied Economics*, *32*(1379-2016-113114), 35-47.

Kariyasa, K., & Dewi, Y. A. (2013). Analysis of factors affecting usage of integrated crop management farmer field school (icm-ffs) in swampy areas. *International Journal of Food and Agricultural Economics (IJFAEC)*, *1*(1128-2016-92015), 29-38.

Kassie, M., Jaleta, M., & Mattei, A. (2014). Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach. *Food Security*, *6*(2), 217-230.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Usage of interrelated sustainable agricultural practises in smallholder systems: Evidence from rural Tanzania. *Technological forecasting and social change*, *80*(3), 525-540.

Kaweesa, S., Mkomwa, S., & Loiskandl, W. (2018). Usage of Conservation Agriculture in Uganda: A Case Study of the Lango Subregion. *Sustainability*, *10*(10), 33-75.

Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World Development*, *66*, 695-706.

Lavison, R. K. (2013). Factors influencing the adoption of organic fertilizers in vegetable production in Accra, PhD Dissertation for Partial Fulfilment of PhD University of Ghana (Ghana) pp 290.

Lipper, L., & Zilberman, D. (2018). A short history of the evolution of the climate smart agriculture approach and its Links to climate change and sustainable agriculture debates. In *Climate Smart Agriculture* (pp. 13-30). Springer, Cham.

Loevinsohn M, Sumberg J, Diagne A (2012). Under what circumstances and conditions does usage of practise result in increased agricultural productivity? Protocol. London: EPPI Centre, Social Science Research Unit, Institute of Education, University of London.

Long, T. B., Blok, V., & Coninx, I. (2016). Barriers to the usage and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. *Journal of Cleaner Production*, *112*, 9-21.

Lugandu, S. (2013, April). Factors influencing the adoption of conservation agriculture by smallholder farmers in Karatu and Kongwa districts of Tanzania. In *A research paper presented at Research on Poverty Alleviation (EPOA) Eighteenth Annual Research Workshop. Kunduchi Beach Hotel, Dar es Salaam, Tanzania, April* (pp. 3-4).

Ma, Y., Schwenke, G., Sun, L., Li Liu, D., Wang, B., & Yang, B. (2018). Modeling the impact of crop rotation with legume on nitrous oxide emissions from rain-fed agricultural systems in Australia under alternative future climate scenarios. *Science of the Total Environment*, *630*, 1544-1552.

Manda, L. Z., & Wozniak, J. (2015). Farmer participation in radio campaigns for practise usage: Lessons from AFFRI's hybrid maize campaign in Mangochi, Malawi. *Journal of Development and Communication Studies*, *4*(1), 2-17.

Mashingo, M. S. H. (2010). Vulnerability assessment on pastoral livestock and pasture development to the extreme climatic events in Tanzania. *Paper presented under the study on economics of climate change in Tanzania Phase*, *3*.

Mathenge, M. K., Smale, M., & Olwande, J. (2012). *The Impact of Maize Hybrids on Income, Poverty, and Inequality among Smallholder Farmers in Kenya* (No. 1096-2016-88391).

Mbilinyi, A., Saibul, G. O., & Kazi, V. (2013). Impact of climate change to small scale farmers: voices of Farmers in village communities in Tanzania. *The Economic and Social Research Foundation Discussion Paper No, 47*.

Mittal, S., & Mehar, M. (2015). An assessment of farmer's information networks in India-role of modern ICT. *CGIAR. org*.

Mkonda, M. Y., & He, X. Conservation agriculture in Tanzania. *Sustainable agriculture reviews*. (pp. 309-324). Switzerland. Springer International Publishing.

Mmbando, F. E., & Baiyegunhi, L. J. (2016). Socio-economic and institutional factors influencing usage of improved maize varieties in Hai District, Tanzania. *Journal of Human Ecology*, *53*(1), 49-56.

Mwangi, M., & Kariuki, S. (2015). Factors determining usage of new agricultural practise by smallholder farmers in developing countries. *Journal of Economics and sustainable development*, *6*(5), 208 -216

Ngwira, A., Johnsen, F. H., Aune, J. B., Mekuria, M., & Thierfelder, C. (2014). Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. *Journal of Soil and Water Conservation*, *69*(2), 107-119.

Nkonya, E., Schroeder, T., & Norman, D. (1997). Factors affecting usage of improved maize seed and fertiliser in northern Tanzania. *Journal of Agricultural Economics*, *48*(1:3), 1-12.

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., & Mungai, C. (2017). Usage and dissemination pathways for climate-smart agriculture practises and practises for climate-resilient livelihoods in Lushoto, Northeast Tanzania. *Climate*, *5*(3), 63.

Obayelu, O. A., Adepoju, A. O., & Idowu, T. (2014). Factors influencing farmers' choices of adaptation to climate change in Ekiti State, Nigeria. *Journal of Agriculture and Environment for International Development*, *108*(1), 3-16.

Shetto, R., Owenya, M., 2007. Conservation Agriculture as Practised in Tanzania: Three Case Studies. African Conservation Tillage Network. Centre de Coope´ ration Internationale de Recherche Agronomique pour le De´veloppement, Food and Agriculture Organization of the United Nations, Nairobi, Kenya

Tanzania Food and Nutrition Centre (2014). Tanzania National Nutrition Survey 2014. Dar es Salaam, Tanzania. Available at https://www.unicef.org/esaro/ Tanzania_National_Nutrition_Survey_2014_Final_Report_18012015.pdf. (Accessed January 2017)

Teixeira, A. F. D. S., Weindorf, D. C., Silva, S. H. G., Guilherme, L. R. G., & Curi, N. (2018). Portable X-ray fluorescence spectrometry applied to the prediction of chemical attributes in Inceptisols under different land uses. *Ciência e Agrotecnologia*, *42*(5), 501-512.

Teklewold, H., Mekonnen, A., & Kohlin, G. (2019). Climate change adaptation: a study of multiple climate-smart practises in the Nile Basin of Ethiopia. *Climate and Development*, *11*(2), 180-192.

Teklewold, H., Mekonnen, A., Kohlin, G., & Di Falco, S. (2017). Does usage of multiple climate-smart practises improve farmers ‘climate resilience? Empirical evidence from the nile basin of Ethiopia. *Climate Change Economics*, *8*(01).

Tesfaye, B. (2008). Performance Efficiency Analysis of Livestock Marketing in Afar region, Ethiopia, PhD Thesis for Partial Fulfilment of PhD Mekelle University, 190pp.

Thuo, C. N., Nguluu, S. N., & Kisangau, D. P. (2017). Factors affecting usage of tissue culture bananas in the semi-arid areas of Lower Eastern region of Kenya.

Von Neumann, J. (1986). John von Neumann on technological prospects and global limits. *Population and Development Review*, *12*(1), 117-126.

Wooldridge, J., (2010), Econometric Analysis of Cross Section and Panel Data, MIT Press, Cambridge, MA.

CHAPTER FOUR

IMPACT OF THE COMBINATION OF CLIMATE SMART AGRICULTURE PRACTISES ON FOOD SECURITY: A COUNTERFACTUAL ANALYSIS FROM MBEYA AND SONGWE REGIONS IN TANZANIA

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Abstract

Climate change is a growing challenge to food security especial for the developing countries which depend agriculture production for their livelihood. Various agricultural approaches have been introduced to boost agricultural productivity and food security under the climate change era. One of be approach is the climate-smart agriculture (CSA) which proposed by Food and Agriculture Organization (FAO) as an appropriate approach to boost adaptive capacity, climate change mitigation and improve food security. Although the government and other stakeholders have promoted a number of CSA-practises, farming households have used them in their farms voluntarily and food insecurity is still a problem. The study used a multinomial endogenous switching regression model (MESR) to evaluate the impact of CSA-practises on household food security among farming households in Mbeya and Songwe regions in Tanzania. Primary data were collected from 1443 farming household in Mbarali, Mbeya, Momba and Mbozi districts. Three primary results were found. First, CSA-practises significantly increase food variety score per adult equivalent unit when used either singly or jointly. Second, the use of intercropping in isolation show the highest food variety score per adult equivalent unit among all the possible combinations of CSA-practises.

Third, the use of crop rotation in isolation also showed a high pay off after intercropping followed by a joint combination of crop rotation and residue retention. Therefore, a more comprehensive approach that focuses on joint usage of a combination of crop rotation, intercropping and residue retention was found to be the best food security portfolio. Consequently, the findings recommended that there is a need of promoting the usage of CSA-practises both in isolation and in combination of their positive impact on on food variety per adult equivalent unit as an indicator of food security.

Keywords: Usage, CSA- practises, Food, Security, Counterfactual, Analysis

4.1 Background Information

Climate change is a growing challenge to food security especial for the developing countries which depend agriculture production for their livelihood (FAO, 2019; FAO, 2017). To meet the global food human needs by 2050, the world's agricultural system must produce more food for a growing population, provide economic opportunities for the rural poor who depend on agriculture for their livelihoods and reduce the impact of climate change (Harvey *et al.,* 2018). Despite a reasonable food crop production worldwide, in 2018 still, 821 million people in the world were estimated to be food insecure, an increase up from 815 million in 2017 (FAO, 2019). Although, still a reduction from about 900 million in 2000 (FAO, 2015).

In African countries, a high proportion of the food insecure are smallholder farmers, who are simultaneously struggling to eradicate hunger and address many challenges impeding both supply and demand for food (Ochieng, 2018). Undernourished people in sub-Saharan Africa increase from 181 million in 2010 to 236 million in 2017 (FAO, 2018). This reflects that this region is highly affected malnutrition in the world and the problem of food insecurity is not declining (FAO, 2018). Studies show that 95 % of food production in this region depend on rainfall, low soil fertility and affected by climate change, hence affect agricultural productivity and food security (McGuire, 2015).

Tanzania, in particular, has been facing food insecurity problem because of climate change, environmental degradation, gender inequality, poverty and diseases (Maliondo *et al.,* 2012). The country is not drought-prone, but naturally the problem of food insecurity is both transitory and chronic. Similarly, malnutrition from food shortage, which is already seen as a direct consequence of climate change in the country decreases immunity and exposes the affected population to opportunistic diseases that would otherwise be resisted (Mwongera *et al.*, 2017).

The Food and Agriculture Organization (FAO) defines food security as a ‘‘situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life’’ (FAO, 2010).

Therefore, African agriculture needs to transform itself to improve the food security of the growing population and to provide a basis for economic growth and poverty reduction (Mwongera *et al.,* 2017). However, gradual climate change can threaten this transformation as it is predicted that climate change will potentially affect all aspects of food security, including food production, food accessibility, food utilization and price stability if local temperature increases by 2°C or above (IPCC, 2014).

These changes in temperature and other extreme weather events are expected to increase crop failures, pest and disease outbreaks, degradation of land and water resources (Nyasimi *et al.*, 2017). These lead to declining and uneven yield trends with significant effects on household food security (Maliondo *et al.*, 2012)

Tanzania's agriculture sector contributes nearly one-third of the country's GDP and employs 66.9 % of the population. Therefore, agriculture has the potential to increase incomes and improve livelihoods (URT, 2017). However, the country is among the thirteen countries in the world, which are mostly affected by the impacts of climate change and it is vulnerable to further climate variability (IPCC, 2014).

Average annual temperature in the country has increased by 1.0^0C while the annual rainfall has decreased by 2.8 mm per month per decade since the early 1960s. In addition, the climate change predictions indicate the mean daily temperatures will increase 3 to 5°C while the annual mean temperature is predicted to rise by 2 to 4°C by 2050 (Chambura and Macgregor, 2009).

Climate change in Mbeya and Songwe regions is quite evident with an increase of annual mean temperature by 0.27◦C/decade since the 1960s (Craparo *et al.*, 2015). Literature shows that the Mbeya and Songwe regions will be affected by declining rainfall, frequent droughts and increase in variability of rainfall (Craparo *et al.*, 2015). These and other climate change impacts add a critical dimension to Tanzania and therefore climate change mitigation and adaptation strategies are needed to boost agricultural production and household food security (Zeleke and Aberra, 2014).

According to FAO (2010), climate-smart agriculture (CSA) is seen as the means to boost adaptive capacity, climate change mitigation and improve food security to poor farm households. FAO defines climate smart agriculture as agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievement of national food security and development goal (FAO, 2010).

Climate smart agriculture is one of the approaches to transform agricultural systems so as to improve household food security, particularly in developing country Tanzania inclusive (Wekesa *et al.,* 2018). Food security in an era of climate change may be possible if farmers transform agricultural systems by use of means such as crop rotation, intercropping, residue retention, and fertilizer (Bryan *et al*. 2011).

Furthermore, various CSA-practises have been used by farming households to cope with impacts of climate change and improve food security. These includes the use of crop-rotation which increases the adaptation capacity of agricultural systems to climate change by improving soil fertility and structure, soil water holding capacity and water and nutrients distribution through the soil profile, helping to prevent pests and diseases, and increasing yield stability (Kuntashula *et al*., 2014).

Residue retention is another CSA-practise used in Tanzania which enables climate change adaptation by managing soil erosion, preserve soil moisture, avoid compaction of the soil, contain pest and diseases, reduce CO_2 emission and increase biodiversity in the agro-ecosystem (Chen *et al*., 2019). Intercropping and other practises that promote ecosystem management and biodiversity such as zero tillage and pest control, the use of organic manure as well as the cultivation of legumes are equally fundamental in strengthening the resilience of farming household (Thornton and Lipper, 2013). In general, these CSA-practises have an effect on food security and assist farming households to increase food crop productivity and protect them to decrease the rate of climate change (Lipper and Zilberman, 2018).

In Tanzania, CSA-practises the government is working hard to addressing the impact of climate change, as well as improving economic growth and agricultural development (Mkonda and He, 2017). The government of Tanzania in collaboration with other local and international organisations, like African Green Revolution Alliances (AGRA), SNV-Tanzania, Technoserve Tanzania, Tanzania Agriculture Research Institutes (TARI) and ADP Mbozi are promoting the implemention of CSA-practises to cope with climate change (URT, 2017). In addition, Tanzania Climate-Smart Agriculture Alliance (TCSAA) was established to coordinate CSA initiatives within the framework of the National CSA Programme (URT, 2017). This study aimed to investigate the impact of CSA-practises on household food security in Mbeya and Songwe regions in Tanzania.

Despite the work done by the Tanzanian government and non-governmental organisations, the impacts of climate change still causes challenges to food production and farming household wellbeing resulting in malnutrition, hunger, and persistent poverty in Mbeya and Songwe regions in Tanzania (TFNC, 2014). However, CSA have been considered as an appropriate approach to ensure food security in the face of climate change (FAO, 2010). The approach is imperative as it has triple benefits of improved productivity and high income, improve adaptation to climate change and reduction or removal of greenhouse gases (FAO, 2010).

Although the government of Tanzania and other agricultural practitioners have been working hard to promote CSA-practises, some farm households have used these practises on their farms voluntarily (Tenge *et al.,* 2004). This is true for Mbeya and Songwe Regions in Tanzania, where there are considerable efforts to promote various CSA-practises but the usage is minimal and climate change impacts remains a major challenge for agricultural production (Maliondo *et al* 2002). As a result, food security prevalence in Mbeya and Songwe Regions is still high with statistics showing, 37.7 % of children below 5 years are stunted compare to the national level which is 34 % (TFNC, 2014). Surprisingly, the dietary diversity for children aged 6 – 23 months is documented to be an average of 2.1 in Mbeya and Songwe Regions.

Therefore, there is a dearth of knowledge on the constraints that condition farming households' usage behaviour for CSA-practises as it is necessary in designing pro-poor policies that could encourage their use and boost agricultural productivity and food security. Additionally, past research on the usage and the impact of farm household welfare (i.e. Pantaleo and Chagama, 2016; Nkhoma *et al.*, 2017; Dhraief *et al.*, 2018) concentrated on the usage of different practises individually, but in reality farming households use more than one practises as complements or substitutes that deal with their production constraints such as challenges of climate change (Teklewold *et al.,* 2013).

For example, Wu and Babcock (1998) argued the analysis of usage and effect of the practises or technologies on welfare without controlling for interdependence and simultaneous between them, there is a possibility of overestimate or underestimate the effect of several factors on the practises or technologies used.

Furthermore, farming households may decide to use multiple combinations of CSA-practises but it is not known which combinations result into highest payoffs in terms of household food security. There are various researches that examined the determinants and the effect of using multiple combinations of agriculture practises on household welfare have used a multiple setting framework elsewhere such a Teklewold *et al.,* 2020; Wekesa *et al.*, 2018; Khonje *et al.*, 2018; Ng'ombe *et al.,* 2017; Manda *et al.,* 2015; Teklewold *et al.,* 2013).

However, despite the potential of these studies, there are few studies in Tanzania, particularly in Mbeya and Songwe regions which analysed the simultaneous usage and impacts of CSA-practises on household food security (Teklewold *et al.*, 2020; Mwungu, *et al.,* 2019 and Kim *et al.,* 2019). Nevertheless, in the Southern Highlands of Mbeya and Songwe might have different ecological set up; hence, the usage and impacts of CSA-practises could be different.

Additionally, in this study, the crop rotation, intercropping and residue retention were used as CSA-practises mostly practised in the study area and little is known on the impact of these practises (especially when used in combination) on household food security. Therefore, this study aimed to fill these knowledge gaps by evaluating the impact of combination of CSA- practises on household food security in Mbeya and Songwe regions using multinomial endogenous switching regression framework.

The main contribution of this study to the body of knowledge is as follows. First, it articulates the importance of synergetic effects arising from the combination of CSA-practises in helping to achieve household food security in Tanzania. Second, the study investigated whether usage of CSA-practises in combination would improve food security than using them in isolation. This knowledge is appropriate to the on-going discussions on whether farming households in Tanzania and elsewhere should use CSA-practises in piecemeal or in the package so as to improve household food security. The third is that, the study extends the empirical and methodological approach in the literature through evaluating the impact of CSA-practises on food security while controlling for the selection bias, particularly in the Tanzanian context. Finally, the study is relevant for designing effective extension policy by identifying the combination of CSA-practises that deliver the highest payoff specifically on food security.

The rest of the study is structured as follows: Section 4.3 of this study give a brief literature review while section 4.4 presents the conceptual, econometric framework, and definition of variables, section 4.5 presents the study areas, sampling and data. Section 4.6 presents the results and discussions. The last section summarizes and concludes, highlighting key findings and policy implications.

4.2 Literature Review

Pantaleo and Chagama (2016) used an evaluation method called propensity score matching method (PSM) to evaluate the impact of microfinance on household welfare between borrowers and non-borrowers' households in Tanzania. The results revealed that borrowing from the microfinance institution has an impact (positive) on household income compared to non-borrowers. A study by Amare *et al.* (2012) evaluated the effect of maize-pigeon intensification on household income using propensity score matching and endogenous switching regression and found a positive impact.

The generalized propensity score matching method was employed by Kassie *et al. (*2014) to estimate the effect of drought tolerant maize seed on household food security in the

rural households of Tanzania and found a positive impact on household food security. Asfaw *et al.* (2010) examined the impact of using improved chickpea technologies on market integration in Ethiopia using the augmented double hurdle model. The study found a positive impact of using the improved chickpea technologies on marketed surplus.
Dhraief *et al.* (2018) investigated the determinants of using innovative technologies for livestock keepers in Tunisia. The study found that education level of the head of household, number of livestock owned, and number of occupation influenced the usage of innovative technologies. Additionally, age of the head of the household and the experience of the head of the household head in farming activities influenced the usage of innovative technologies negatively.

Nkhoma *et al.* (2017) used a propensity score matching method to evaluate the impact of conservation agriculture (CA) practises (i.e. crop rotation, residue retention and reduced tillage). The study found that agricultural extension services (advisory) and wetlands had a positive but insignificantly impact on crop productivity and income.

Manda *et al.* (2015) estimated the usage and the effect of sustainable agricultural practises (SAPs) on household income and maize yield in the rural farming households in Zambia. The study found that the usage of a combination of SAPs have a positive effect on maize yields and incomes of farming households. The study by Ng'ombe *et al.* (2017) examined the determinants of using conservation farming (CF) and its impact on crop revenue. The study found that factors influencing the usage of CF practises depend on the combinations used by farming households. The study found that the usage of CF has a significant positive impact on crop revenue per acre when used individually or in combination.

Wekesa *et al.* (2018) estimated the effect of CSA-practises on household food security in Kenya. The study revealed that the combination of CSA-practises such as field management, risk reduction practises and specific soil management practises showed the highest payoff in terms of food security compared to the CSA-practises used individually. Another study examined the impact of combinations of CSA-practises on risk on risk exposure and cost of risk in Ethiopia. The study found that usage of combinations of practises is widely viewed as a risk-reducing insurance strategy that can increase farmers' resilience to production risk.

Majority of these studies concentrated on the analysis of single practises or technologies while farming households are using CSA-practises which are used jointly as complements, substitutes or supplements to deal with the production constraints such as pest and diseases, drought, soil erosion and soil fertility (Teklewold *et al.*, 2013). This study employed a multinomial endogenous switching regression framework to estimate the determinants of using CSA-agriculture technologies in isolation or in combinations and evaluate its effect on household food security in Mbeya and Songwe region in the Southern Highlands of Tanzania.

4.2.1 Conceptual and econometric framework

According to Feder *et al.* (1985), agricultural practises can be introduced to farm households in packages and can be used either in combination or in isolation. This study examined whether the use of CSA-practises (crop rotation, intercropping and residue retention) either in isolation or in combination can improve household food security. In practise, farming households usually use a combination of CSA-practises to tackle production constraints like low yields, droughts, weeds, pests and diseases resulted from climate change. The usage of CSA-practises either individual or in combination can be influenced by several factors such as household characteristics, resource constraints, plot characteristics, institution characteristics and geographical location as illustrated in Figure 4.1. The decision to use CSA-practises either in isolation or in combination can improve agricultural productivity; hence increase the availability of food. This can affect food prices in the local markets then affect household's food expenditure. Because of increased production and/or productivity, household can sell the surplus crop, which will lead in increased household income. Increased income in turn could raise expenditures on different variety of food, which are not produced by the household. This could improve the consumption of variety of food needed by the body.

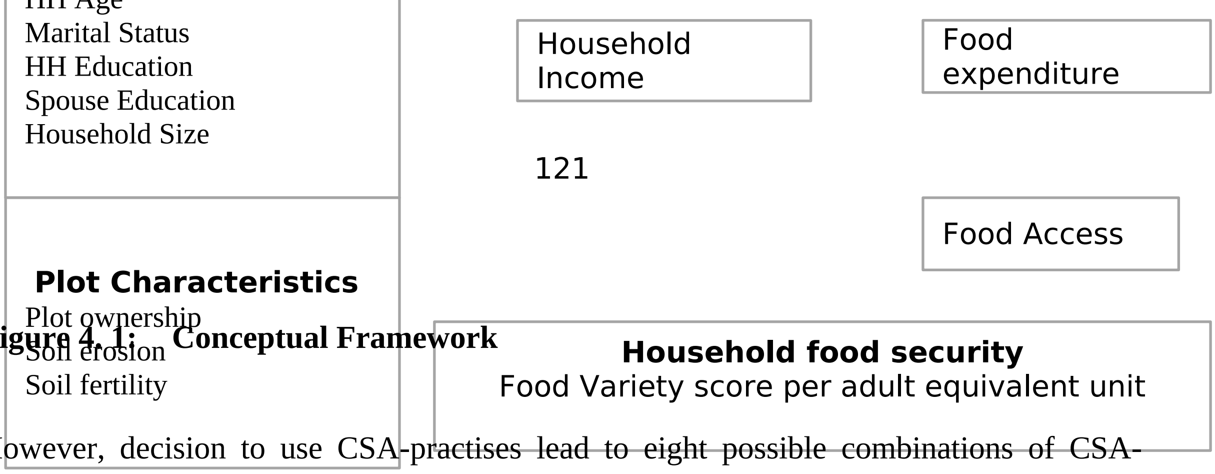

Figure 4.1: Conceptual Framework

However, decision to use CSA-practises lead to eight possible combinations of CSA-practises. The use of these combinations by farming households may not be random as a result they might endogenously self-select either using or not using the decisions. This implies that farming households which decide to use a specific CSA-practise can have different characteristics compare to the households that did not use. This is because those households which use a specific CSA-practise are not a random sample of the population, as our study is not based on a controlled experiment but an observational study.

Therefore, unobservable characteristics such as motivation, managerial skills or expected food security improvement can influence the decisions. There is a possibility of characteristics which are unobservable to correlate with the outcomes variable of interest, i.e., CSA-practises used (either in isolation or in combination) and household food security can be correlated hence endogenous problem.

To eliminate with this problem a model which deals with the interaction in the usage of multiple agricultural practises was developed by Feder (1982). In the current years, various studies have examined the joint estimation of multiple combinations of agricultural practises (e.g., Teklewold *et al.*, 2020; Wekesa *et al.*, 2018; Khonje *et al.*, 2018; Ng'ombe *et al.*, 2017; Manda *et al.*, 2015; Teklewold *et al.*, 2013). In this study, a randomized utility framework was used to model the usage of CSA-practises by focusing on the usage of these practises where eight alternatives which involve three CSA-practises (crop rotation, intercropping and residue retention) as shown in Table 4-1.

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Table 4. 1: Combination of usage of crop residue retention, residue retention and intercropping

SN	CSA	Description
1	$C_0R_0I_0$	$C_0R_0I_0$ = 1 if a farmer is a non-user
2	$C_1R_0I_0$	$C_1R_0I_0$ = 1 if a farmer only uses crop rotation; 0 otherwise
3	$C_0R_1I_0$	$C_0R_1I_0$ = 1 If a farmer uses residue retention; 0 otherwise
4	$C_0R_0I_1$	$C_0R_0I_1$ = 1 If a farmer uses intercropping; 0 otherwise

5	$C_1R_1I_0$	$C_1R_1I_0$ = 1 If a farmer uses crop rotation and residue retention; 0 otherwise
6	$C_1R_0I_1$	$C_1R_0I_1$= 1 If a farmer uses crop rotation and intercropping; 0 otherwise
7	$C_0R_1I_1$	$C_0R_1I_1$= 1 If a farmer uses residue retention and intercropping; 0 otherwise
8	$C_1R_1I_1$	$F_1P_1I_1$= 1 If a farmer uses crop rotation, residue retention and intercropping; 0 otherwise

The assumption is that farming households use CSA-practises (either in isolation or in combination) that maximize utility subject to production constraints such as climate change impacts and variability. The aim of the farm households is to maximize utility V_{ij} by comparing the utility provided by alternative CSA-practises. A farm household i can use CSA-practise j over any alternative CSA-practise$m$, if $V_{ij} > V_{ik}, k \neq j$.

However, farming households always self-select into the user or non-user categories and endogeneity problems may arise because unobservable characteristics may be correlated with the outcome variables (food security). For instance, farm household can decide to use a CSA-practise based on unobservable characteristics such as their innate managerial, influences of policymakers and technical abilities in understanding and using the practise (Abdulai and Huffman, 2014). Therefore, failure to account for unobservable characteristics may overstate or understate the true impact of the CSA-practises (Kim *et al.,* 2019).

The study applied multinomial endogenous switching regression model developed by Bourguignon *et al.* (2007) to account for interactions between uses of alternative CSA-practises and self-selection bias. The model is an appropriate technique compared to other evaluation techniques like propensity score mating because it enables the construction of a counterfactual based on returns to characteristics of user and non-user of CSA-practises (Kim *et al.,* 2019; Mansur *et al.,* 2008).

Additionally, the model allows the set of treatment variables to intermingle with observable variables and unobserved characteristics. This indicates that the effect of CSA-practise used is not limited to the intercept of the outcome equations, but can also have a slope effect (Zeng *et al.,* 2015). The model permits the interaction by estimating separate regressions for users and non-users. The study used the multinomial logit selection model to model the decisions to use CSA-practises and recognizing the inter-relationships among the choices of CSA-practises. The impact of CSA practises on household food was estimated in the second stage where the ordinary least square was applied with selectivity correction.

4.3 Methodology

4.3.1 A Multinomial logit selection model

To examine the factors motivating farming households to use specific CSA-practises in isolation or in combination(s) (crop rotation, residue retention and intercropping) a multinomial logit selection model was employed. Assume that a latent variable $A^{¿}$ capture the expected food security (Food Variety Score per adult equivalent unit) from using combination j $(j=1\ldots m¿$ with respect to the usage of any other combination$k$. Therefore, the latent variable can be specified as follows:

$A^{¿}=\overline{V}_{ij}+\eta_{ij}=Z_i\alpha_j+\eta_{ij}$ …………………………………………………………………….. (1)

$A=¿$ ……………………………………………… (2)

This is to say, farm household i can choose a combination j if combination j provides expected food variety score per adult equivalent unit (FVS/AEU) as an outcome which is greater than any other combination ($\varepsilon_{ij}=\max_{k\neq j}(A¿¿ik^{¿}-A_{ij}^{¿})<0¿$. A deterministic component $(V¿¿ij=Z_i\alpha_j)¿$ and the idiosyncratic unobservable stochastic component(η_{ij}) are shown in equation 1.

The later captures variables which are essential to farm household decision maker but are not known to the researcher such as skills or motivation. The deterministic component $(V¿¿ij)¿$ is the function of the factors¿) that affect the likelihood of using a combination j. The¿) variables includes farm characteristics household (household size, education of the household head, gender of the of the household, age of the household head, marital status of the household head and farming experience of the household head); households resource endowment (livestock ownership, mobile phone ownership, radio ownership, television ownership, income diversification, access to loan); plot characteristics (average plot distance, number of plots cultivated, soil erosion, production diversity and total plot size); institutional factors (access to demonstration plots, extension services, distance from home to the extension office, availability of tarmac road, membership in the multiple organizations); and geographical location (Mbozi, Momba and Mbarali districts).

It is assumed that covariate vector Z_i is uncorrelated with the idiosyncratic unobservable stochastic component η_{ij}. For example, $E(\eta_{ij}|Z_i)=0$ is under the assumption that $\eta_{ij}$are Independent and Identically Gumble distributed, that is under the Independence of Irrelevant Alternative (IIA¿hypothesis. Selection model (1) leads to a multinomial logit model (McFadden, 1974) where the probability of choosing a combination j (P_{ij}) is given as:

$P_{ij}=Pr$ ¿ ……………………………………………………….. (3)

The second stage the study used the MESR to estimate the relationship between the outcome variables and a set of exogenous variables for used combinations. Based on the CSA-practises specification, the base category was the non-user of CSA-practises (i.e., $C_0R_0I_0$), is denoted as $j=1$. In the remaining packages ($j=2,\ldots,8$), at least one CSA-practise is used. The outcome equation for each possible regime j is given as:

$$\begin{cases} Regime\,1: Y_{i1} = X_i\beta_1 + \mu_{i1} \; if \; A=1 \\ \quad\quad\quad\quad . \\ \quad\quad\quad\quad . \\ Regime\,M: Y_{ij} = X_i\beta_j + \mu_{ij} \; if \; A=j \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

X_i set of exogenous variables (household characteristics, households resource endowment, plot, household, institution factors and geographical location) for the chosen combination and μ_{ij} is unobserved stochastic component which verifies $E(\mu_{ij}|X_{ij}, Z_{ij})=0$ and $var(\mu_{ij}|x_{ij}, z)=\sigma_j^2$. Note that, the outcome equations were estimated separately when estimating OLS models. If the error term of the selection model (2) η_{ij} are correlated with the error term of the outcome equation μ_{ij} conditionally on the sample selection are non-zero and the OLS estimates are inconsistent. To correct for the potential inconsistent, the study employed the model by Bourguignon *et al*, (2007), which takes into account the correlation between error terms from each outcome equation μ_{ij}. This is a Multinomial endogenous switching regression model. According to Bourguignon *et al.* (2007), the following selection bias corrected outcome equation was used to get consistent estimation of β_j in the outcome equation.

$$\begin{cases} Regime\,1: Y_{i1}=X_i\beta_1+\sigma_1\left[\rho_1 m(P_{i1})+\sum_j \rho_j m(P_{ij})\frac{P_{ij}}{P_{ij}-1}\right]+V_{i1}\, if A=1\, 5a \\ \vdots \\ Regime\,M: Y_{\Im}=X_i\beta_M+\sigma_j\left[\rho_1 m(P_{\Im})+\sum_j \rho_j m(P_{ij})\frac{P_{ij}}{P_{ij}-1}\right]+V_{ij}\, if\ A=j\,5b \end{cases}$$

4.3.2 Estimation of average treatment effects

Based on Bourguignon *et al.* (2007) the expected FVS/AEU of the farming household that used a combination of $CSA\ practise_j$ can be derived as follows:

$$\begin{cases} E(Y_{i2}|A_i=2)=X_i\beta_2+\sigma_2\left[\rho_2 m(P_{i2})+\sum_{k\neq 2} P_{ik} m(P_{ik})\frac{P_{ik}}{P_{ik}-1}\right](6a) \\ E(Y_{\Im}|A_i=M)=X_i\beta_M+\sigma_M\left[\rho_M m(P_{\Im})+\sum_{k\neq 2} P_{ik} m(P_{ik})\frac{P_{ik}}{P_{ik}-1}\right](6b) \end{cases}$$

Then the FVS/AEU of farming household that use combination $_j$ was derived in the hypothetical counterfactual case that did not use $(j=1)$ as follows:

$$E(Y_{i1}|A_i=2)=X_i\beta_1+\sigma_1\left[\rho_1 m(P_{i2})+\rho_2 m(P_{i1})\frac{P_{i1}}{P_{i1}-1}+\sum_{k=3-M}\rho_k m(P_{ik})\frac{P_{ik}}{P_{ik}-1}\right](7a)$$

$$E(Y_{i1}|A_i=M)=X_i\beta_1+\sigma_1\left[\rho_1 m(P_i m)+\sum_{k=2\ldots M}\rho_k m(P_{ik-1})\frac{P_{ik-1}}{P_{ik-1}-1}\right](7b)$$

Therefore, the difference between equations $(6a)$ and $(7a)$ or Eqs. $(6b)$ and $(7b)$ give the average treatment effect (ATT).

4.3.3 Construction of food variety score per adult equivalent unit (FVS/AEU)

The households indicated whether they consumed one of the food items within a particular food group in the previous seven days. If the household indicated YES, the household received a value of one score and zero for NO response. The list based on the 12 food groups, namely vegetables, fruits, meat, eggs, cereals, white tubers and roots, fish and other seafood, legumes and nuts, milk and milk products, oil and fats, sweets, and spices condiments and beverages (FAO, 2011). FVS refers to the individual food items consumed over particular period; a day, a week, or a month. In this study, FVS was computed based on a list comprising 47 individual food items within the same 12 food groups. The respondent indicated whether the household consumed or not within the previous 7 days.

The adult equivalent scale constant for East Africa standards (Massawe, 2016) was employed to compute households of different sizes with members of different sex and age groups. An adult equivalent unit was assigned to each household member by multiplying each age category by respective adult equivalent scale with respect to gender of each household member. The fact that households with different sizes have different requirements in terms of resources, the sum of adult equivalent was adjusted based on the economies of scale constants (Mbwana *et al.,* 2016). The values were multiplied by the average costs subject to household sizes. The computed variable was then used as one of the predictors replacing the household size.

4.3.4 Definition of variables

The empirical model of this study was specified based on the literature review of the similar studies (Dhraief *et al.,* 2018; Nkhoma *et al.,* 2017; Ng'ombe *et al.,* 2017; Pantaleo and Chagama, 2016; Kassie *et al.,* 2014). According to this literature, many factors affect usage and thus affect our outcome variables.

Table 4. 2: Variable definitions

Variable	Definition
Dependent Variable	
Food Variety Score	Food Variety Score per adult equivalent Unit (FVS/AEU)
$C_0R_0I_0$	$C_0R_0I_0$ = 1 if a farmer is a non-user

$C_1R_0I_0$	$C_1R_0I_0$ = 1 if a farmer only uses crop rotation; 0 otherwise
$C_0R_1I_0$	$C_0R_1I_0$ = 1 If a farmer uses residue retention; 0 otherwise
$C_0R_0I_1$	$C_0R_0I_1$ = 1 If a farmer uses intercropping; 0 otherwise
$C_1R_1I_0$	$C_1R_1I_0$ = 1 If a farmer uses crop rotation and residue retention; 0 otherwise
$C_1R_0I_1$	$C_1R_0I_1$= 1 If a farmer uses crop rotation and intercropping; 0 otherwise
$C_0R_1I_1$	$C_0R_1I_1$= 1 If a farmer uses residue retention and intercropping; 0 otherwise
$C_1R_1I_1$	$F_1P_1I_1$= 1 If a farmer uses crop rotation, residue retention and intercropping; 0 otherwise
Explanatory Variables	
Household Characteristics	
The household size	Number of household members
Education	Level of education of household head in years
Gender	1 if a household head is male, 0 otherwise (Dummy)
Age of the household head	Age of head of the household (years)
Marital status of the household head	1 if a household head is married, 0 otherwise (Dummy)
Farming experience	Farming experience of the household head (years)
Households resource endowment	
Livestock ownership	Tropical Livestock Unit (TLU)
Mobile phone ownership	1 if a household head owned mobile phone, 0 otherwise (Dummy)
Radio ownership	1 if a household head owned radio, 0 otherwise (Dummy)
Television ownership	1 if a household head owned television, 0 otherwise (Dummy)
Ownership of productive assets	Asset index
Income diversification	Number of income sources
Land ownership	1 if head of the household owned land, 0 otherwise (Dummy)
Institutional services	
Access to demonstration plots	1 if head of the household has access to demonstration plot, 0 otherwise (Dummy)
Extension services	1 if head of the household has received extension services, 0 otherwise (Dummy)
Distance to the extension office	Distance in minutes
Access to tarmac road	Distance in Minutes
Membership of multiple organizations	1 if a household head joined multiple organisations, 0 otherwise (Dummy)
Access to credit	1 if household head had access to agricultural credit, 0 otherwise (Dummy)

4.3.5 Study areas, sampling, data collection

The data used in this study was obtained from the household survey conducted in the Southern Highlands of Mbeya and Songwe in Tanzania under the Integrated Project to Improve Agriculture Productivity and Food Security in the Bread Basket area of Southern Highlands.

The study was conducted during the period of September–December 2017. The study aimed to evaluate the impact of the simultaneous usage of several CSA practises on household food security. The sample covers 1443 farm households. A multistage sampling was used to select farmer organisations (FOs) from each district, and households from each FO.

First, based on their food production potential crops (maize, paddy, common beans, and soya beans), four districts were selected purposively from two regions of the Southern Highlands of Tanzania (Mbeya and Songwe Regions). Second, 51 wards were randomly selected out of 92 wards. Third, FOs from each ward were identified then a proportionate random sampling was applied to choice farm households from all FOs to get a total of 1443 households.

4.4 Empirical Results

4.4.1 Descriptive statistics

Table 4-3 shows the descriptive statistics of the CSA-practises used in combination or in isolation disaggregated by district. Residue retention (3.95%) and intercropping (3.15%) were the most popular CSA practises among farming households which use individual components. The results showed lower usage of CSA practises across all districts. This implies that farming households used more of combinations of CSA practises than in isolation on their farms. This is the evident that farmhouse households use CSA practises as a complement to each other.

The three CSA practises (crop rotation, residue retention and intercropping) were used simultaneously in which 62.96 % of the farming households used the combination of the three CSA-practises ($C_1R_1I_1$). This indicates the farming households used multiple combinations of CSA practises to combat the production constraints and climate change risks. The results also showed that the usage of combination of crop rotation, residue retention and intercropping ($C_1R_1I_1$) was more used in Momba district (76.1%) than Mbozi district (67.02%) and Mbeya district (62.05%).

The lower usage of combination of crop rotation, residue retention and intercropping ($C_1R_1I_1$) in Mbarali district is because the majority of faming households cultivate more rice throughout the year, hence crop rotation and intercropping is not common. The study found that 14.62% of farming households used the combination of residue retention and intercropping ($C_0R_1I_1$) while Mbozi District had the highest %age of farming households (19.66%) that used a combination of residue retention and intercropping ($C_0R_1I_1$).

Table 4. 3: CSA-practises used in isolation or in combination

CSA practises	Pooled	Mbozi DC	Momba DC	Mbarali DC	Mbeya DC
$C_0R_0I_0$	7.07	1.90	1.674	17.95	7.88
$C_1R_0I_0$	0.83	0.21	0.000	2.88	0.48
$C_0R_1I_0$	3.95	5.71	2.929	2.24	3.82
$C_0R_0I_1$	3.19	1.06	0.418	6.73	4.53
$C_1R_1I_0$	4.02	4.23	12.134	0.64	1.67
$C_1R_0I_1$	3.40	0.21	1.674	11.54	1.91
$C_0R_1I_1$	14.62	19.66	5.021	10.26	17.66
$C_1R_1I_1$	62.92	67.02	76.151	47.76	62.05

4.4.2 Impacts of CSA-practises usage on food security

The treatment effect was determined to find the impact of the usage of CSA-practises in isolation or in combination on food security as an outcome variable. The ordinary least squares regression of Food Variety Scores per adult equivalent Unit (FVS/AEU) of the households were estimated for each combination of CSA-practises, taking care of the selection bias correction terms.

At this stage, treatment effects were reported. Different combinations were identified; crop rotation only ($C_1R_0I_0$), residue retention only ($C_0R_1I_0$) intercropping only ($C_0R_0I_1$) combination of crop rotation and residue retention ($C_1R_1I_0$), combination of crop rotation and intercropping ($C_1R_1I_0$), combination of residue retention and intercropping ($C_0R_1I_1$) and the crop rotation, residue retention and intercropping combination ($C_1R_1I_1$).

The simplest approach is to look at the actual FVS/AEU by farm household CSA-practises used. The result shows that farming households that used crop rotation in isolation have food variety score of 2.0179/AEU. Another option is to check the effect of each CSA-practise on FVS/AEU. The result shows that all combinations were negative and have insignificant effect on Food Variety Scores per adult equivalent Unit (FVS/AEU).

The observed and unobserved characteristics that might influence food variety score per adult equivalent Unit (FVS/AEU). To address for both observed and unobserved characteristics, the study used the counterfactual analysis as explained in section 4.5.2. That is the difference in the FVS/AEU that might be caused by unobservable characteristics, such as household head skills.

The analysis helps to examine which combinations of CSA-practises have a higher impact on FVS/AEU as the indicator of food security. Table 4-4 presents the FVS/AEU under actual and counterfactual situations. The study compared the expected FVS/AEU under the actual case of the farm households that used a particular CSA-practise and the counterfactual case that the farm household did not use the said CSA-practise. The column (3) of Table 4-4 shows the usage effect of each CSA-practise on FVS/AEU, which is the treatment effect, calculated as the difference between column (1) and (2) based on equation (6a – 7a) and 6b – 7b) as shown in section 4.3.2.

The results show that the impacts of CSA-practises on food security (FVS/AEU) are both positive and negative but differ in magnitude depending on the practise used. Farm household that used CSA-practises such as crop rotation, residue retention and intercropping in isolation increases the FVS/AEU by a magnitude of 2.6213, 0.9349 and 3.7076 respectively.

The finding is similar with the study by Al-Shater *et al*. (2017) in Syria, which found that farm household which used zero tillage in isolation as a conservation agriculture practise earned on the average 9494 SYP or US$189 per ha (33% higher) net income. The result is also inconsistent with that of Beyene *et al.* (2017) in Ethiopia which found that farm household which used soil conservation practises in isolation reduces net revenue by a magnitude of 101.7Birr per hector.

The study found that usage of crop rotation and residue retention ($C_1R_1I_0$) in combination does not guarantee the maximum return. This is because farm household that used a combination of crop rotation and residue retention, their FVS/AEU increase by a magnitude of 0.3517 compared to non-users. However, the usage of crop rotation ($C_1R_0I_0$), residue retention ($C_0R_1I_0$) and the intercropping ($C_0R_0I_1$) increases FVS/AEU of a magnitude of 2.6213, 0.9349 and 3.7076, which are higher than the usage of combination of crop rotation and residue retention ($C_1R_1I_0$).

This means that using CSA-practises in isolation improves household food security than used in combination. The finding is inconsistent with that of Beyene *et al.* (2017) which found that the usage of a combination of soil conservation and intercropping increased the net revenue per hector. The result of this study cautions about the conclusion that multiple use is not always the best CSA-agriculture to improve household food security. It is possible to use a combination of CSA-agriculture, relative to using one practise a time, places burdens on farming household in terms of expenditure and risk.

The study found that usage of combination of all three practises simultaneously was positive and highly significant increased FVS/AEU. Again, using all three practises simultaneously ($C_1R_1I_1$) does not guarantee maximum improvement of household food security as has a lower magnitude compared to the practises used in isolation. The study found that farming households that used a combination of crop rotation, residual retention and intercropping ($C_1R_1I_1$) increased food variety score by a magnitude of 0.0005 per AEU. However, the usage of combination of crop rotation and residue retention ($C_1R_1I_0$) increases the food variety score by a magnitude of 0.3517 per AEU which is higher than using crop rotation, residue retention and intercropping in combination ($C_1R_1I_1$).

The finding is similar with the study by Di Falco and Veronesi (2013), who found that a combination of soil conservation and changing crop varieties yielded better return than the usage of three strategies crop rotation, water conservation, and soil conservation in rural Ethiopia. Result of this study indicate that the payoff from combinations of CSA-practises depends on the type of practises considered in the analysis, as there is a possibility that using CSA-practises in isolation may yield a better payoff than combinations of practises.

Table 4. 4: Impact on Food Variety Score by Climate Smart Agriculture practises

CSA-practise	FVS/AD if farm households did	Counterfactual FVS/AD if farm households didn't use	Usage Effects (FVS/AD)

	use		
Crop rotation only	1.9458	-0.6756	2.6213***
	(0.2792)	(0.1433)	(0.1631)
Residue retention only	0.2410	-0.6939	0.9349***
	(0.0112)	(0.0188)	(0.0150)
Intercropping only	0.1077	-3.5999	3.7076***
	(0.0152)	(0.0855)	(0.0807)
Combination of crop rotation and	0.1062	-0.2455	0.3517***
residue retention	(0.0110)	(0.0209)	(0.0186)
Combination of crop rotation and	-10.2866	-1.0341	-9.2526***
Intercropping	(0.1628)	(0.0943)	(0.2247)
Combination of residue retention	0.1736	0.4655	-0.2918***
and Intercropping	(0.0029)	(0.0064)	(0.0056)
Combination of crop rotation,	0.2417	0.2412	0.0005***
residue retention and intercropping	(0.0025)	(0.0028)	(0.0018)

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.7 Conclusion, Recommendations and Policy Implications

Usage of CSA-practises and evaluation of their potential impacts on household welfare have received considerable attention from policy analysts. Low rates of usage among farmers continue to be recorded despite substantial investments in their promotion by governments and other stakeholders. Furthermore, prior research has ignored joint usage and interdependence of multiple CSA-practises and their potential impacts on household food security. Using cross-sectional data collected from Mbeya and Songwe regions in Tanzania, the study evaluated the impact of using combination of CSA-practises on food security among farming households. A multinomial endogenous switching regression model was used to account for self-selection.

With respect to the causal effects findings, the study recommend as follows. First, usage of CSA-practises both in isolation and in combination should be encouraged because all possible combinations result in significant positive effects on food variety per adult equivalent unit as an indicator of food security expect of crop rotation and intercropping and residue retention and intercropping combination. Second, more promotional efforts should focus on usage of CSA-practises in isolation since these generally increase food varieties score per adult equivalent compare CSA-practises used in combinations.

Further, regardless of unobserved and observed effects, using crop rotation, residue retention and intercropping in isolation results into the highest food variety score per adult equivalent among all possible combinations. Therefore, efforts to improve food variety score per adult equivalent unit should focus on usage of crop rotation and residue retention and intercropping in isolation.

The findings of this study are grounded on cross sectional data. Therefore, better data sets such as panel data methods with time dimension should be considered in the future studies for more rigorous evidence about the role and implications of CSA-practises. Additionally, the data used in this study are not ideally rich in agronomic and shock variables.

Admittedly, this is an important limitation, plus our study is restricted to evaluating potential contribution of the usage of CSA-practises on household food security; perhaps these results could be different under a single crop or when all input costs are ideally observed. Besides, CSA-practises could be dynamic or agro-ecological location specific: may be some practises are more effective in the short run while others yield more payoffs in the long run or maybe their impacts vary by agro-ecological location. These should be investigated and future research should be conducted to address these issues.

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References

Abdulai, A., & Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Economics*, *90*(1), 26-43.

Al-Shater, T. (2017). Measuring the Impacts of Conservation Tillage (CT) on Household Income and Wheat Consumption: A Syrian Case.

Amare, M., Asfaw, S., & Shiferaw, B. (2012). Welfare impacts of maize–pigeon pea intensification in Tanzania. *Agricultural Economics*, *43*(1), 27-43.

Aryal, J. P., Jat, M. L., Sapkota, T. B., Khatri-Chhetri, A., Kassie, M., & Maharjan, S. (2018). Adoption of multiple climate-smart agricultural practises in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies and Management*. 10 (3), 407-427.

Asfaw S, Shiferaw B, Simtowe F (2010). Does Technology Adoption Promote Commercialization? Evidence from Chickpea Technologies in Ethiopia. Paper presented at Centre for the Study of African Economies Conference Economic Development in Africa from 21st to 23rd March 2010. St-Catherine, Oxford

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural practises on smallholder welfare: Evidence from Tanzania and Ethiopia. Food policy, 37(3), 283-295.

Beyene, A. D., Mekonnen, A., Kassie, M., Di Falco, S., & Bezabih, M. (2017). Determinants of Usage and Impacts of Sustainable Land Management and Climate-Smart Agricultural Practises (SLM-CSA): Panel Data Evidence from the Ethiopian Highlands. *Environment for Development Discussion Paper Series*, (17-10).

Bourguignon, F., Fournier, M., Gurgand, M., 2007. Selection bias corrections based on the multinomial logit model: Monte-Carlo comparisons. *Journal of Economic Surveys* 21, 174–205.

Bryan, B. A., King, D., & Ward, J. R. (2011). Modelling and mapping agricultural opportunity costs to guide landscape planning for natural resource management. *Ecological Indicators*, *11*(1), 199-208.

Chambura, M., & Macgregor, J. (2009). Cultivating success: the need to climate-proof Tanzanian agriculture.

Chen, F., Chen, J., Huang, W., Chen, S., Huang, X., Jin, L., & Zhao, Y. (2019). Westerlies Asia and monsoonal Asia: Spatiotemporal differences in climate change and possible mechanisms on decadal to sub-orbital timescales. *Earth-science reviews*, *192*, 337-354.

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

Dhraief, M. Z., Bedhiaf-Romdhania, S., Dhehibib, B., Oueslati-Zlaouia, M., Jebali, O., & Ben-Youssef, S. (2018). Factors affecting the adoption of innovative technologies by livestock farmers in arid area of Tunisia. *FARA Res. Rep*, *3* (5), 22.

Di Falco, S., & Veronesi, M. (2013). How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia. *Land Economics*, *89*(4), 743-766.

Feder, G. (1982). Adoption of interrelated agricultural innovations: Complementarity and the impacts of risk, scale, and credit. *American Journal of Agricultural Economics, 64*(1), 94-101.

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic development and cultural change*, *33*(2), 255-298.

Food and Agriculture Organization (FAO), (2010). The State of Food Insecurity in the World: Addressing food insecurity in protracted crises. Rome: Food and Agriculture Organization of the United Nations (FAO) and World Food Programme (WFP). Available from http://www.fao.org [Accessed 13/10/2017]

Food and Agriculture Organization (FAO), (2011). The state of food insecurity in the world. Available from http://www.fao.org [Accessed 16/5/2018]

Food and Agriculture Organization (FAO), (2015). The state of food insecurity in the world. Available from http://www.fao.org [Accessed 14/1/2018]

Food and Agriculture Organization (FAO), (2017). The state of food insecurity in the world. Available from http://www.fao.org [Accessed 10/2/2018]

Food and Agriculture Organization (FAO), (2018). The state of food insecurity in the world. Available from http://www.fao.org [Accessed 14/2/2019]

Food and Agriculture Organization (FAO), (2019). The state of food insecurity in the world. Available from http://www.fao.org [Accessed 29/5/2019]

Gido, E. O., Sibiko, K. W., Ayuya, O. I., & Mwangi, J. K. (2015). Demand for agricultural extension services among small-scale maize farmers: Micro-level evidence from Kenya. *The Journal of Agricultural Education and Extension*, *21*(2), 177-192.

Harvey, L. D. (2018). *Climate and global environmental change*. Routledge.

International Panel for Climate Change (IPCC). (2014). Global and Sectoral Aspects. (Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Climate Change 2014: Impacts, Adaptation, and Vulnerability., 1132.

Kassie, M., Jaleta, M., & Mattei, A. (2014). Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach. *Food Security*, *6*(2), 217-230.

Khonje, M. G., Manda, J., Mkandawire, P., Tufa, A. H., & Alene, A. D. (2018). Adoption and welfare impacts of multiple agricultural practises: evidence from eastern Zambia. *Agricultural economics*, *49*(5), 599-609.

Kim, J., Mason, N. M., Snapp, S., & Wu, F. (2019). Does sustainable intensification of maize production enhance child nutrition? Evidence from rural Tanzania. *Agricultural Economics*, *50*(6), 723-734.

Kuntashula, E., Chabala, L. M., & Mulenga, B. P. (2014). Impact of minimum tillage and crop rotation as climate change adaptation strategies on farmer welfare in smallholder farming systems of Zambia. *Journal of Sustainable Development*, *7*(4), 95.

Lipper, L., & Zilberman, D. (2018). A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates. In *Climate Smart Agriculture* (pp. 13-30). Springer, Cham.

Lugandu, S. (2013). Factors influencing the adoption of conservation agriculture by smallholder farmers in Karatu and Kongwa districts of Tanzania. In *A research paper presented at Research on Poverty Alleviation (EPOA) Eighteenth Annual Research Workshop. Kunduchi Beach Hotel, Dar es Salaam, Tanzania, April* (pp. 3-4).

Maliondo, S. M. S., Mpeta, E. J., & Olson, J. (2012). Climate change and food security in Tanzania: an analysis of current knowledge and research gaps and recommendations for a research agenda. *iAGRI Reference Background Paper*.

Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2015). Adoption and impacts of sustainable agricultural practises on maize yields and incomes:

Evidence from rural Zambia. *Journal of Agricultural Economics, 67*(1), 130-153.

Mansur, E.T., Mendelsohn, R., Morrison, W., 2008. Climate change adaptation: a study of fuel choice and consumption in the US energy sector. *Journal of Environmental Economics and Management 55*, 175–193.

Massawe, G. D. (2016). Farming systems and household food security in Tanzania: the case of Mvomero and Kishapu districts, PhD Thesis for Partial Fulfilment of PhD University College Dublin (Ireland) pp 296.

Mbwana, H. A., Kinabo, J., Lambert, C., & Biesalski, H. K. (2016). Determinants of household dietary practises in rural Tanzania: Implications for nutrition interventions. *Cogent Food & Agriculture*, *2*(1), 1224046

McFadden, D. (1974), 'Conditional logit analysis of qualitative choice behavior', in P. Zarembka, ed., Frontiers in Econometrics, Academic Press, New York, pp. 105– 142.

McGuire, S. (2015). FAO, IFAD, and WFP. The state of food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress. Rome: FAO, 2015.

Mkonda, M. Y., & He, X. Conservation agriculture in Tanzania. *Sustainable agriculture reviews*. (pp. 309-324). Switzerland. Springer International Publishing.

Mmbando, F. E., & Baiyegunhi, L. J. (2016). Socio-economic and institutional factors influencing adoption of improved maize varieties in Hai District, Tanzania. *Journal of Human Ecology, 53*(1), 49-56.

Mwongera, C., Shikuku, K. M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., & Winowiecki, L. A. (2017). Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. *Agricultural Systems*, *151*, 192-203.

Mwungu, C.M., Shikuku, K.M., Kinyua, I. and Mwongera, C. (2019). Impact of adopting prioritized climate-smart agricultural technologies on farm income and labor use in rural Tanzania. Invited paper presented at the 6th African Conference of Agricultural Economists, September 23–26, 2019, Abuja, Nigeria

Ng'ombe, J. N., Kalinda, T. H., & Tembo, G. (2017). Does adoption of conservation farming practises result in increased crop revenue? Evidence from Zambia. *Agrekon*, *56*(2), 205-221.

Ngwira, A., Johnsen, F. H., Aune, J. B., Mekuria, M., & Thierfelder, C. (2014). Adoption and extent of conservation agriculture practises among smallholder farmers in Malawi. *Journal of Soil and Water Conservation*, *69*(2), 107-119.

Nkhoma, S., Kalinda, T., & Kuntashula, E. (2017). Adoption and impact of conservation agriculture on smallholder farmers' crop productivity and Income in Luapula Province, Zambia. *Journal of Agricultural Science*, *9*(9), 168-181.

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., & Mungai, C. (2017). Adoption and dissemination pathways for climate-smart agriculture technologies and practises for climate-resilient livelihoods in Lushoto, Northeast Tanzania. *Climate*, *5*(3), 63.

Obayelu, O. A., Adepoju, A. O., & Idowu, T. (2014). Factors influencing farmers' choices of adaptation to climate change in Ekiti State, Nigeria. *Journal of Agriculture and Environment for International Development*, *108*(1), 3-16.

Ochieng, J., Afari-Sefa, V., Karanja, D., Kessy, R., Rajendran, S., & Samali, S. (2018). How promoting consumption of traditional African vegetables affects household nutrition security in Tanzania. *Renewable Agriculture and Food Systems, 33*(2), 105-115.

Pantaleo, I. M., & Chagama, A. M. (2016). Impact of Microfinance Institutions on Household Welfare in Tanzania: Propensity Score Matching Approach. *The African Review*, *45*(2), 168-204.

Tanzania Food and Nutrition Center (TFNC). (2014). Ministry of Health and Social Welfare Tanzania National Nutrition Survey 2014. Available from http:// http://www.tfnc.go.tz/ [Accessed 15/11/2017].

Teklewold, H., Adam, R. I., & Marenya, P. (2020). What explains the gender differences in the adoption of multiple maize varieties? Empirical evidence from Uganda and Tanzania. *World Development Perspectives*.

Teklewold, H., Kassie, M., & Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practises in rural Ethiopia. *Journal of Agricultural Economics*, *64*(3), 597-623.

Tenge, A. J., De Graaff, J., & Hella, J. P. (2004). Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands, Tanzania. *Land Degradation & Development*, *15*(2), 99-114.

Tesfaye, A., Bogale, A., Namara, R. E., & Bacha, D. (2008). The impact of small-scale irrigation on household food security: The case of Filtino and Godino irrigation schemes in Ethiopia. *Irrigation and Drainage Systems*, *22*(2), 145-158.

Thornton PK, Lipper L. (2013) How does climate change alter agricultural strategies to support food security? Background paper for the conference "Food Security Futures: Research Priorities for the 21st Century", 11-12 April 2013, Dublin

United Republic of Tanzania (URT). (2017). *Annual agriculture sample survey*. Dodoma: Government printer.

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). Effect of climate-smart agricultural practises on household food security in smallholder production systems: micro-level evidence from Kenya. *Agriculture & Food Security*, *7*(1), 80.

Wu, J., & Babcock, B. A. (1998). The choice of tillage, rotation, and soil testing practises: Economic and environmental implications. *American Journal of Agricultural Economics, 80*(3), 494-511.

Zeleke, M. T., & Aberra, Y. (2014). Determinants of the adoption of land management strategies against climate change in Northwest Ethiopia. Ethiopian Renaissance Journal of Social Sciences and the Humanities, 1, 93-118.

Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M. and Yirga, C, 2015. Ex post impacts of improved maize varieties on poverty in rural Ethiopia', *Agricultural Economics, Vol. 46,* pp. 515–526.

CHAPTER FIVE

COMBINING CLIMATE SMART AGRICULTURE PRACTISES PAYS OFF: EVIDENCE ON FOOD SECURITY FROM SOUTHERN HIGHLAND ZONE OF TANZANIA

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Abstract

Concerns of food insecurity and climate change are the serious global challenges, Tanzania inclusive. In response, farm households are using various climate smart agricultural practises (CSA-practises) which are believed to play a vital role to increase agricultural productivity, increase resilience to climate change and reduce mitigation costs for greenhouse gas (GHG) emission while improving households' food security. Despite these benefits of CSA-practises but the usage of these practises is still voluntary and its impact on household welfare specifically food security is not well documented in Tanzania, particularly in Mbeya and Songwe Region. Therefore, the determinants of using of CSA-practises (in particular organic manure, drought-tolerant maize seeds and irrigation) and the impact of the usage of household food security were examined. The cross-sectional study design was used to collect information from from farming households in the Southern Highlands of Tanzania (Mbeya and Songwe regions). To evaluate the impact of combination of CSA-practises on household food security the study used a multinomial endogenous treatment effect model. A counterfactual analysis was conducted to compare the impacts from different combinations of climate smart agriculture practises considered. The findings show that household, plot, and institutional characteristics have significant effects on the usage of a different combination of CSA-practises. The study also found that the highest payoff of food security is achieved when climate smart agriculture practises are used in combination rather than in isolation. The package that contains combination of drought-tolerant maize seeds and Irrigation ($Or_0Dt_1Ir_1$) gave higher payoff than the combination of all three CSA-practises. The study suggests that based on the practises considered in this study, the usage of a combination of various practises result in better food security compared to the usage of these practises individually. This indicates that promoting combination of CSA-practises could enhance household food security.

Keywords: Climate smart agriculture practises, food security, and multinomial endogenous treatment effect.

5.1 Introduction

Food insecurity is a serious global challenge for many households (Sibhatu *et al.,* 2015). Despite reasonable food crops production worldwide, more than 820 million individuals are food insecure with a number of obstacles to attain zero hunger by 2030 (FAO, 2019). It is projected that 1.3 billion people of the global population are suffering from food security at moderate levels. This implies that they are not suffering from hunger but they suffer from access to nutritious and enough food which expose them to high risk of malnutrition and poor health (FAO, 2019). Statistics show that 1.2 billion people are in extremely poor whereby 75 % of these reside in rural areas and are primarily dependent on agricultural production (Tiberti and Tiberti, 2015). In the last few decades, African agriculture production increased but did meet the demand for food of the growing population (Sibhatu *et al*., 2015). As a result of this mismatch, African farming households in the rural area are continuing suffering from food and nutritional insecurity due to poor access to sufficient protein and energy from their diet (Gouel and Guimbard, 2019). However, agriculture is still an important sector to improve household food security (Godfray *et al*., 2010). FAO defined food security as a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for active and healthy life (FAO, 2010a).

Because of the high demand for food as the consequences of rapid population growth in Africa, there is a need to transform African agriculture to improve food and nutrition security; however, climate change can impede this transformation since it increases temperatures and decreases annual rainfall which results in the increase of droughts and salinity (IPCC, 2014). It is estimated that, growing periods of crops in western and southern Africa might be shorten by an average of 20 % by 2050, causing a 40 % decrease in cereal yields and a decrease in cereal biomass for livestock as the consequences of climate change (FAO, 2010b).

Subsequently, it is important to simultaneously improve agricultural productivity and reduce yield variability overtime under adverse climatic conditions (Sibhatu *et al*., 2015). There are various options have been proposed to address the challenge of food insecurity under climate change, including closing the yield gap through increasing productivity and addressing the structural causes of persistent poverty (Aggarwal *et al*., 2012). Previous studies in Africa indicate the importance of investigate the impact of climate change and agricultural practises at the household level, rather than focusing on aggregated results that hide a large amount of variability (Thornton *et al*., 2010; Baethgen, 2010).

An anticipated means to achieve this is increased usage of climate-smart agriculture (CSA) approach as proposed by FAO (2010b). CSA is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change (FAO, 2013). CSA approach is vital as it contain three scopes of sustainable development which are mutually addressing ecosystems management, food security, and climate change challenges (Lipper and Zilberman, 2018).

Usage of CSA-practises by farming households either in combination or in isolation can lead to increase agricultural productivity, improve adaptation to climate change and reduce mitigation costs for greenhouse gas (GHG) emission (Shirsath *et al.*, 2017). However, a work to promote CSA in Africa are proceeding at the policy level as African leaders endorsed the inclusion of CSA in the NEPAD program on agriculture and climate change to improve food security in the region (Zougmoré *et al.*, 2015).

Many initiatives related to CSA have been taken in Tanzania. For example, the establishment of climate smart agriculture program (2015 – 2025) is one of the initiatives aimed at enhancing the usage of CSA-practises and food security (URT, 2015). Various government and non-governmental organisations such as District Councils, Tanzania Agricultural Research Institutes (TARI), Sokoine University of Agriculture (SUA), African Green Revolution Alliance (AGRA), SNV-Tanzania, One Acre Funds, Ruvuma Commercialisation and Diversification of Agriculture (RUCODIA), African Conservation Tillage Network (ACTN) implemented CSA-practises projects and programs in different regions (Mbeya and Songwe Regions inclusive) aimed at improving food crop productivity and food security (AGRA, 2016; Lipper and Zilberman, 2018).

However, according to Mugabe (2019) the majority of the CSA-practises projects and programmes are ongoing but CSA-practises are not broadly diffused in the different parts of the country. This is due to limiting factors such as capacity, funds and policy support. However, a number of CSA-practises have been implemented and used by farming households in different parts of the country to fight against climate change impacts. These include the use of reduced tillage, which provides ecosystem services such as water regulation, carbon storage, soil stability, prevent soil erosion, improve infiltration of water, and improve soil health (Bhatt, 2017).

Crop rotation is another CSA-practise which improves the adaptation to climate change through the improvement soil health and structure, improve soil water holding capacity, helping to break the circle of pests and diseases and play a major role in increasing yield stability (Kuntashula *et al*., 2014). Residue retention enables climate change adaptation by soil erosion control, conserve soil moisture, reduce soil compaction, decrease CO_2 emission and improve biodiversity (Chen *et al*., 2019). In general, these CSA-practises have an effect on food security and assist farming households to increase food crop productivity and protect farming households from the climate change (Lipper and Zilberman, 2018).

Despite the benefits of CSA-practises, the usage of these practises is still voluntary and its impact on household welfare specifically food security is not fully documented in Tanzania; particularly, in Mbeya and Songwe region (Beyene *et al.*, 2015; Tenge *et al.*, 2004). A Study by TCNC (2014) found that the prevalence of food insecurity in Mbeya and Songwe Region is high; with 37.7 % of children below five years are stunted, higher than the national level which is 34 %. There are various pieces of literature (Giller *et al*., 2015, Pittelkow *et al*., 2015, Kirkegaard *et al.*, 2014) which examined the link between the usage of CSA-practises and food security in Tanzania and elsewhere. However, there are scarce empirical studies which examined the determinants of usage of individual and combination of CSA-practises.

In addition, the discussions of the impact of the usage of individual and combination of these practises on household food security are virtually non-existent in Tanzania, particularly in Mbeya and Songwe region. This study will fill these gaps by examining the determinants of the usage of individual or combination of CSA-practises, and how usage impact farming household's food security in Mbeya and Songwe regions in Tanzania.

The study is important because a comprehensive large farming household survey of food crops (maize, paddy, common-bean and soya beans farming households) farming systems of Tanzania was used. Additionally, the interdependence between different CSA-practises and jointly analyse the decision to use a combination of practises identified using a multinomial endogenous treatment effect model.

This is relevant because knowledge on the interrelationships among multiple combinations of CSA-practises could give a good contribution to the ongoing discussion on whether farming households should use CSA-practises individually or in combination. Finally, this study is relevant because by identifying a good combination of CSA-practises with a highest payoff could be important in designing effective agricultural extension policy.

5.2 Literature Review

5.2.1 Concept of climate-smart agriculture (CSA)

According to FAO (2010b), CSA is defined as an approach which is used to "develop technical, policy and investment conditions in achieving sustainable agricultural development for food security under climate change". The approach is imperative in attaining the national food security through its goals of improving agricultural productivity and income, improve adaptation to climate change and reducing or remove the greenhouse gases emission (FAO, 2014).

In addition, the aims of CSA are to improve food security and bigger development goals under a changing climate (Lipper and Zilberman, 2018). According to Ali and Erenstein (2017), there is a need to improve CSA planning for the purpose of addressing the synergies and trade-offs between the increase of agricultural productivity, improve adaptation to climate change and mitigation of greenhouse gases. The trade-off and synergies of CSA (i.e. productivity, adaptation and mitigation) lead to address economics, environment and social challenges, hence achieving more efficient, effective, and equitable food systems (Lipper and Zilberman, 2018).

There are various options of CSA-practises such as micro-level options, which include crop diversification and the timing of planting (Deressa *et al.*, 2009). Another option is the market responses, which involves access to agricultural loans and different sources of household income (Ekwere *et al.*, 2014). Improvement of subsidy scheme together with the access to input and output markets are CSA-practises under the option of institutional change as explained by Mendelsohn (2001).

The last option is the technological developments which include practises like the drought-tolerant maize seeds, crop rotation, use of irrigation, residues retention, reduced tillage, crop rotation drought-tolerant seeds (Page *et al.*, 2020; Li *et al*., 2019; Blanco-Canqui *et al.*, 2018; Deressa *et al.*, 2009). However, some of the CSA-practises are localized and are not directly used and implemented in other regions or agriculture settings.

This study considered organic manure, drought-tolerant maize seeds and irrigation as CSA-practises used in the study area. According to Khaitov *et al.* (2019) the use of organic manure is considered as climate smart because it improves soil structure and its water holding capacity with minimum leaching, it reduces the need for synthetic fertilisers and related greenhouse gases emissions.

Food security in an era of climate change may be possible if farmers use stress-tolerant seeds as they help farming household to increase productivity and yield stability under the era of climate change and variability (Fisher *et al.*, 2015). According to Masuka *et al.* (2017), drought-tolerant Maize Seeds are one of the promising stress tolerant-seeds which have the ability to withstand an abiotic stress like drought. These seeds increase production per unit area, reduce costs of production, increases and/or maintains above- and below-ground biomass during drought periods (Masuka *et al.*, 2017).

The use of irrigation is best CSA-practise because of enabling the production during the dry season, improves water infiltration, reduces water loss due to runoff and evaporation and improves the quality and availability of ground and surface water (Arslan, 2013). Additionally, the use of irrigation is more efficient when it is accompanied by other CSA-practises such as drought-tolerant seeds and organic manure that can use moisture more efficiently (Arslan, 2013).

5.2.2 The Concept of food security

According to Capone *et al*. (2014), food security has four pillars which include food availability, food accessibility, food affordability and food stability. Food availability is about the availability of food which can be obtained through agricultural production exchange and distribution. Food accessibility is referred to as the appropriate methods of obtaining food which can be influenced by affordability, allocation and consumer preference while food utilization is considered as the proper way of food consumption through consideration of requirements of human nutrition (Capone *et al*., 2014). Generally, development specialists face difficult to identify the appropriate indicators for food security due to the lack of a standard measure (Coates, 2004). The indicators of food security such as consumption, poverty, and malnutrition are used as proxy measures, while indicators of assets and income are used as determining factors (Maxwell *et al.*, 1999).

These measures are related to food security, but none of them captures the concept accurately or completely. This is due to the fact that food security is actually a complex concept, hence difficult to measure using a single indicator (Ndobo, 2013). It is, therefore, important to search for reliable and cost-effective indicators to use based on four pillars of food security. The study concentrates on measuring the impact of the usage of CSA-practises on household dietary diversity score per adult equivalent unit as an indicator of food security.

5.2.3 Theoretical Framework

The theoretical framework by Singh and Strauss (1986) was used in this study. The model is referred to as agriculture household model (AHM) which is applied in a developing country where markets are imperfect. Because of imperfect input and output markets there is an interaction of household production and consumption which indicates that farming households both producers and consumers of goods and services with the objective of maximizing expected utility (Mutenje *et al.*, 2016).

For example, market imperfection can cause the farming household to allocate labour into different activities, whereby the allocation decisions can be determined endogenously by the rate of shade wage rather than the rate of market equilibrium. Furthermore, farming household depends on their savings and assets as a result of imperfect credit market which impedes them to use CSA-practises, hence food insecurity (Mutenje *et al.,* 2016).

Barrett (2008) argued that the information asymmetry, market imperfections and transaction costs could push farming households to produce food for own consumption rather than for market. Furthermore, according to Tessema *et al.* (2016), farming households cannot use CSA-practises such as organic manure, drought-tolerant maize seeds and irrigation because of the market imperfections and high transaction costs.

Hence, a non-separable household model which combines input and output market imperfections is preferred as a suitable to model decisions of the household and allocation of resources. The study followed Fernandez-Cornejo *et al.* (2005) and Weersink *et al.* (1998), the utility (U), is a function of the consumption of purchased goods (G) and leisure (L), subject to human capital $(H)$and other household characteristicsZ_h as exogenous factors. Therefore:

$$Max\, U\left[G, L, H, Z_h\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The utility is maximized subject to time, production and income constraints as:

Time constraint: $T = L_f[d_j] + L_e + L, L_e \geq 0$ …………………………... (2)

Production constraint: $Q = Q\lfloor X[d_j], L_f[d_j], H, d_j, R \rfloor d_j \geq 0$ ………………………. (3)

Income constraint: $P_g G = P_g Q - W_x X + W_e L_e + A$ …………………………... (4)

The constraint relates to household labour decisions into leisure L working on the farm L_f or off-farm work$L_e$which cannot exceed the total households' time endowment (T). Another constraint is a convex continuous production function, assuming that the quantity of crops produced (Q) depends on, farm inputs(X), household labour deployed in agricultural production processL_a, human capital (H), the choice of CSA-practises used d_j and a vector of exogenous factors that shift the production function (R).X and L_f are functions of d_j since some of the CSA-practises affect directly the input or labour demand of farm households.

For example, organic manure affects the labour supply of the farm household as some amount of labour is needed when applying organic manure. Households' characteristics $(H¿¿x)¿$, plot characteristics$(P¿¿x)¿$, institutional characteristics$(I¿¿x)¿$ and household assets$(H¿¿a)¿$ determine the choice of CSA- practise (d_j) in turn.

$d_j = [H_x, P_x, I_x, H_a]$ ……………………………………………………………… (5)

The final constraint is shown in equation (iv), where, the farming household has a budget constraint whereby a total household expenditure (the price of purchased goods (Pg) times quantity of purchased goods) should be less than the net income from agriculture, off-farm income (wage rate (W_e) times (L_e) - total off farm labour supplied by the household and other income sources such as remittances and pension (A). Plug in equation 3 into equation 4 yields a farm practise-constrained measure of household income:

$$P_g G = P_q Q \lfloor X(d_j), L_f(d_j), H, d_j, R \rfloor - W_x X + W_e L_e + A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (6)}$$

The Kuhn-Tucker first order conditions can be obtained by maximizing the Lagrangean expression (ι)over (G, L) and minimising it over (λ, η):

$$\iota = U ¿$$

$$+\lambda \left\{ P_q Q \left[X(d_j), L_f(d_j), H, d_j, R \right] - W_x X + W_e L_e + A - P_g G \right\}$$

$$+\eta \left[T - L_f(d_j) - L_e - L \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (7)}$$

λ and ηrepresent the Lagrange multipliers for the marginal utility of income and time, respectively. Following Tambo and Wünscher (2014), Fernandez-Cornejo *et al*. (2005) solving the Kuhn-Tucker conditions, reduced-form expression of the optimal level of household income $Y^{¿}$ can be obtained by:

$$Y^{¿} = Y(d_j), P_q, P_g, A, H, T, R, Z_h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (8)}$$

and household demand for consumption goods (G) can be expressed as:

$$G = G(d_j, P_g, Y^{¿}, H, T, Z_h) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (9)}$$

Therefore, the reduced forms of $Y^{¿}$ and G are affected by a set of explanatory variables, includingd_j. The main objective of this paper is therefore, to evaluate the impact of organic manure, drought-tolerant maize seeds and irrigation on household dietary diversity score per adult equivalent unit (HDDS/AEU) as food security indicator.

5.2.4 Empirical review

Earlier studies have focused on the relationship between the usage of CSA-practises and crop productivity but there are scarce literatures on the impact of combination of CSA-practises on household welfare such as household food security; therefore, is still an area where researchers need to focus on. However, there are some studies which employed different impact evaluation methods to evaluate the impact of the usage of different agriculture practises on household welfare in Tanzania and elsewhere. For example, Bezu *et al.* (2014) used instrumental variable regression to evaluate the effect of farming household usage of improved maize seed on household welfare in Malawi.

The study found female-headed farming households which were the users of improved maize seeds have better household welfare compared to male-headed households. A propensity score matching method (PSM) was employed by Allotey *et al.* (2019) to evaluate the effect of fertilizer subsidy programme on income of the household. The study found that fertilizer subsidy programme has a direct contribution to household income.

The impact studies of CSA-practises usage were conducted in different regions of Tanzania by Mkonda and He (2017). Results showed that the impact of the usage of planting basins, terraces, reduced tillage, cover crops and crop rotation has same variations. For example, in Arusha, farming households used terraces, in Dodoma they used reduced tillage while the Ruvuma they used *Matengo pits*, but all have shown a positive impact on productivity of maize and coffee.

Furthermore, in the Southern Agricultural Growth Corridor, planting basins have doubled maize yields compared to that of conventional tillage. Mkonda and He (2017) found that farming households which used irrigation, reduced tillage and crop rotation have improved food crop productivity from an average of 0.5-ton Ha^{-1} to 1.5-ton Ha^{-1} in the northern zone of Tanzania. Subsequently, maize yields have increased from 2,500 kg to 4,166 kg per Hectare and 3750 kg per Ha when intercropped with lablab.

In Pakistan, Imran *et al*. (2018) investigated the impact of CSA on cotton production. The study found that users of water and drainage management reduced tillage, crop rotation and improved seed varieties have increased productivity compared to non-users. In Kenya, Mwabu *et al*. (2006) conducted a study on the determinants of the usage of drought tolerant maize seeds and its impact on poverty in Laikipia and Suba districts.

The study revealed that the price of maize, education level, and distance to the roads are the main determinants of hybrid maize usage by farmers and the usage reduce household poverty. In their study, Ouma *et al*. (2006) analysed factors influencing the usage of maize practises and fertilizer. They found that education, access to credit, access to extension and agro-ecological differences had a significant influence on fertilizer usage on maize.

A study by Ariga *et al*. (2008) examined the usage of chemical fertilizers by peasant maize growers in Kenya using probit and logit models. The results revealed location as the dominant determinant factor affecting peasants' decisions to use chemical fertilizer on maize production. Furthermore, the result found that the decision to buy chemical fertilizer was positively related to land ownership but not with household wealth.

In addition, closeness to the agro-dealer influenced peasants' decision to use chemical fertilizer for maize production. Pittelkow *et al*. (2015) found that the usage of reduced tillage in isolation reduces yields. Surprisingly, when crop rotation is combined with cover crops and reduced tilage, its negative impacts on yield are minimized.

Moreover, usage of a combination of reduced tillage, cover crop and crop rotation has a significant yield increase in rain-fed crop production which implies that it may become a good combination of CSA-practises for the dry land regions. Even though, the reduced tillage found to reduce crop yield by 5.7%, but it increases yield equal to or even higher yield than conventional tillage.

Most of the relevance of these studies have a long focus on the use and impact of single CSA-practise (Mwabu *et al*., 2006; Imran *et al*., 2018), even though farming households use more than one practise to address their overlapping constraints. Furthermore, these studies do not consider the combination of different CSA-practises. Therefore, modelling usage and impact analysis on multiple combinations of CSA-practises in order to capture information on interdependence and simultaneous usage decision and its impact on household food security.

5.2.5 Conceptual framework

Farming households' decisions to use drought-tolerant maize seeds, organic manure and irrigation lead to eight possible combinations of CSA-practises. Usage of these combinations by farming households may not be random as a result they might endogenously self-select either using or not using the decisions. This indicates that farming households which use a specific CSA-practise may have systematically different characteristics from those households that did not use different CSA-practise packages; because farm households that use a particular CSA-practise are not a random sample of the population as our study is not based on a controlled experiment but an observational study.

Therefore, unobservable characteristics such as motivation, managerial skills or expected yield can influence the decisions. There is a possibility of the unobserved characteristics to correlate with the outcomes of interest. Therefore, a multinomial endogenous treatment effect model proposed by Deb and Trivedi (2006) was employed in this study to account for observed and unobserved heterogeneity. The model is an appropriate framework for evaluating CSA-practises used both in isolation and in combination as it captures the interactions among choices of alternative CSA-practises (Wu and Babcock, 1998).

Two steps are used in the estimation where the first stage a mixed multinomial logit selection model was applied to model the farming household's choice of combination or individual CSA-practise. In the second stage of estimation, the ordinary least square (OLS) with selectivity correction terms was used to estimate the impact of outcome variables. For the case of this study, the outcome variable is Household Dietary Diversity Score per Adult Equivalent Unit (HDDS/AEU) as an indicator of household food security.

5.3 Methodology of the Study

5.3.1 Study area

The study was conducted in Mbeya and Songwe Region were four district were involved i.e. Mbozi, Mbarali, Momba and Mbeya Districts. These study area is in the Southern Highlands, which is the breadbasket area of Tanzania where a different of food crops are cultivated such as maize, beans, soya beans and paddy rice. The study selected two regions and four districts based on the presence of food crops such as maize, paddy rice, beans and soya beans. In addition, food and nutritional security vulnerability was another selection criterion because 37.7% of children below five years are stunted (TFNC, 2014), and there have been absence of integrated interventions in recent years.

The study area was also regarded best since farmers from these regions/districts primarily rely on food crop production for their livelihoods. The difference in geographical location (i.e. Mbeya and Songwe Regions) was another reason for the selection of these study areas as it would enable to generalize the results. Furthermore, mixed agronomic practises also were the main driver for the selection of this study area.

5.3.2 Sampling and data collection

The cross-sectional study design was used to collect information from the farming households in the Southern Highlands Zone of Mbeya and Songwe in Tanzania. The Sokoine University of Agriculture in collaboration with the Integrated Project to Improve Agriculture Productivity and Food Security in the Bread Basket area of Southern Highlands of Tanzania conducted the survey during the period of September –December 2017.

A multistage sampling was employed to select farmer organisations (FOs) from each district and households from each FO. First, based on their food production potential crops (maize, paddy, common beans, and soya beans), four districts were selected purposively from two regions of the Southern Highlands of Tanzania (Mbeya and Songwe Regions). Second, 51 wards were randomly selected out of 92 wards. Third, FOs in each ward were identified then a proportionate random sampling was applied to choose farming households from all FOs to get a total of 1443 households.

A structured male and female questionnaires were used to capture information using open data kit (ODK) was used. Information like household demographics, socioeconomic characteristics, different CSA-practises used, food consumption, and other farm/plot characteristics were collected.

5.3.3 Estimation strategies

A multinomial endogenous treatment effects model involves two stages. First; farming household choose one of the eight combinations as shown in the first column of Table 5.1. Following Deb and Trivedi (2006), let U_{ij} denote the indirect utility associated with the j^{th} CSA-practise, j = 0, 1, 2 ..., J for farming household$i$:

$$U_{ij}^{¿}=Z_i^{'}\alpha_j+\sum_{k=1}^{j}\delta_{jk}l_{ik}+\eta_{ij} \text{ ………………………………………………………..(10)}$$

Zi was used to denote the vector of household characteristics, plot characteristics, institutional factors and location with the associated parametersα_{ij}; $\eta_{ij}$are independently and identically distributed error terms. The $U_{ij}^{¿}$ includes a latent factor l_{ik} that incorporates unobserved characteristics common to farming households$i$’s treatment choice and outcome variables. Outcome variables in this analysis are the combinations of different CSA-practises which include organic manure, drought-tolerant maize seeds and irrigation. Management and technical abilities of farming households in understanding CSA-practises were considered as unobserved characteristics that may have an impact on outcome variables (Khonje *et al.*, 2015).

The assumption is that the l_{ik} is independent ofη_{ij}. Following Deb and Trivedi (2006), let $j=0$ denote the control group and$U_{i0}^{¿}=0$. During the analysis, the non-users of CSA-practises (organic manure, drought-tolerant maize seeds and irrigation) were considered as the control. Let d_j be the observable binary variables representing the choice of different combination of CSA-practises and as a vector of:

$l_i = (d_{i1}, d_{i2}, ..., d_{ij}$¿. …………………………………………………………………. (11)

let $l_i = (l_{i1}, l_{i2}, ..., l_{ij}$¿ ……………………………………………………………....(12)

The probability of treatment can be represented as:

pr ¿ ………………………(13)

g stands as multinomial probability distribution which is expected to have a mixed multinomial logit (MMNL) structure, defined as:

Pr ¿ ………………………………………… (14)

Then second stage was undertaken to evaluate the effect of CSA-practises usage on household food security where the FVS/AEU and HDDS/AEU were used as indicators of food security. Equation 14 shows the expected outcome:

E ¿ ………………………………………. (15)

y_i stand for the HDDS/AEU as the outcome variable and an indicator of household food security for farming household i ,a set of exogenous variables are presented by x_i with a parameter vectors β, and γ_i represent the treatment effects relative to the control group i.e., non-users of CSA-practises. If $d_{ij}$is treated to be exogenous but there is a possibility endogeneity in usage decision of CSA- practises which resulted into inconsistent estimates $\gamma.E¿$, is a function of each of the latent factorsl_{ij}.

This means that the outcome variable is affected by the unobservable characteristics which also affect selection into treatment. Whenλ_j, is the factor-loading parameter and when is positive, the treatment and outcome are positively correlated through unobserved characteristics and vice versa. This implies that there is positive (negative) selection, with γ and λ the associated parameter vectors, respectively. The study assumes a normal (Gaussian) distribution function because the outcome variable (HDDS/AEU) is a continuous variable where a Maximum Simulated Likelihood (MSL) approach was deployed for estimation.

In the next step, the valid instruments were included, following Deb and Trivedi (2006) that the parameters of the model are estimated even if the explanatory variables in the treatment equation are the same as the ones used in the outcome equation. Therefore, the use of exclusion restrictions or instruments can provide more robust estimates. In the analysis, additional variables which are not correlated with the HDDS/AEU were included in the treatment equation.

The main challenge empirically is to find valid instruments. However, the age difference between household head and spouse, farm experience, the main information sources (extension services) access to the tarmacked road and agricultural extension services were used as instrumental variables. The extension services might have effect on the usage decisions of CSA-practises but is hardly expected to influence the outcomes such as HDDS/AEU as an indicator of household food security. Different studies on usage and impact of practises have utilised information from extension services as an instrument variable (i.e. Khonje *et al.,* 2018; Di Falco and Bulte, 2011).

5.3.4 Measuring food security (outcome variables)

Household dietary diversity score per adult equivalent unit (HDDS/AEU) was used as an indicator of food security to evaluate the impact of CSA-practises on household food security. The household dietary diversity score per adult equivalent unit is suggested to be a suitable measure in assessing diets quality and nutritional adequacy at household level (Assenga *et al.,* 2016; Kinabo, *et al.,* 2016).

The HDDS/AEU was computed by aggregating food varieties that households reported consuming over the previous 24 hours as suggested in other studies (Mbwana *et al.,* 2016; Kinabo *et al.,* 2016). The households indicated whether they consumed one of the food items within a particular food group in the previous 24 hours. If the household indicated YES, the household received a value of one score and zero for NO response. The list included 12 food groups, namely: cereals, white tubers and roots, vegetables, fruits, meat, eggs, fish and other seafood, legumes and nuts, milk and milk products, oil and fats, sweets, and spices condiments/beverages (FAO, 2011).

The scores ranging from 1-12 were summed up as HDDS. Greater dietary diversity scores are suggested to be associated with better food security adequacy. The adult equivalent scale is commonly used in household consumption analysis because it is more meaningful in expressing food consumption profiles in households with different size and composition by age and sex. This study employed the adult equivalent scale constant for East Africa standards (Massawe, 2016) to compute households of different sizes with members of different sex and age groupings. An adult equivalent unit was assigned to each household member by multiplying each age category by a respective adult equivalent scale with respect to the gender of each household member. The fact that households with different sizes have a different requirement in terms of resources, the sum of adult equivalent was adjusted based on the economies of scale constants.

5.3.5 Variables and data description

Organic manure, drought-tolerant maize seeds and irrigation are the CSA-practises considered in this study as they help to protect the environment and to reduce both the impacts of climate change on agricultural systems (adaptation) and the contribution of the agricultural practises to greenhouse gases (GHG) emissions (mitigation) (Shirsath *et al.*, 2017). The study examined the determinants of the usage of combinations of CSA-practises before evaluating its effect on household food security.

The different combinations of the three CSA-practises were used as dependent variables as shown in Table 5-1. The organic manure, drought-tolerant maize seeds and irrigation were denoted asO_r, D_r and I_r respectively. Several explanatory variables such as the age of the head of the household, gender of the head of the household, education level of head the household, education level of the spouse, production diversity, income diversity, household size, access to extension services, asset, household expenditure locations and plot size were specified in the model.

The study hypothesized that household head age and sex significantly influence the usage of CSA-practises either in isolation or in a combination (Khonje *et al.*, 2018). Similarly, farming household economic status such as asset ownership, household expenditure and their resource endowment such as land size have a positive association with the usage of

CSA-practises (Deressa *et al.*, 2011). In addition, farming households which use CSA-practises differ based on their locations such those located (Taneja *et al.*, 2014).

5.4 Results

5.4.1 Descriptive statistics

CSA-practises might be used in a wide range of different combinations, and this has implication on household's food security status. Given the set of available combinations, understanding what motivates an individual to select specific combinations is important for policy direction. Table 1 presents different combinations. The results show that, 18.02% of the farming households were nonusers of any CSA combinations while 26.8% of the farming households used the combination $Or_0Dt_1Ir_0$. This combination comprised the use of drought-tolerant maize seeds only. Another 7.21% of the farming households used the organic manure ($Or_1Dt_0Ir_0$) while 26.8 and 12.06% used combination of drought-tolerant maize seeds and irrigation respectively ($Or_0Dt_1Ir_1$).

Further, 24.81% of the farming households used a combination of $Or_1Dt_1Ir_0$ that contained organic manure and drought-tolerant maize seeds practises. Another 6.65% of farming households used a combination of $Or_1Dt_0Ir_1$ that contained a combination of organic manure and irrigation practises. The study found that 2.08% used a combination of $Or_0Dt_1Ir_1$ that contained drought tolerant maize seeds and irrigation practises. Approximately, 2.08% of the farming households used the combination of $Or_1Dt_1Ir_1$ that contained a combination of all three CSA-practises.

Table 5.1: Combination of the usage of organic manure, drought tolerant maize seeds and irrigation

SN	Choices	Description	Or_0	Dt_0	Ir_0	Frequency	%ages
1	$Or_0Dt_0Ir_0$	Non-users				260	18.02
2	$Or_1Dt_0Ir_0$	1 if a farmer only uses organic manure; 0 otherwise	√			104	7.21
3	$Or_0Dt_1Ir_0$	1 If a farmer uses drought tolerant maize seeds; 0 otherwise		√		385	26.68
4	$Or_0Dt_0Ir_1$	1 If a farmer uses irrigation; 0 otherwise			√	174	12.06
5	$Or_1Dt_1Ir_0$	1 If a farmer uses organic manure and DTMS; 0 otherwise	√	√		358	24.81
6	$Or_1Dt_0Ir_1$	1 If a farmer uses organic manure and irrigation; 0 otherwise		√	√	96	6.65
7	$Or_0Dt_1Ir_1$	1 If a farmer use DTMS and irrigation; 0 otherwise	√		√	30	2.08
8	$Or_1Dt_1Ir_1$	1 If a farmer uses organic manure, DTMS and irrigation; 0 otherwise	√	√	√	36	2.49
Total						**1443**	**100.00**

The mean age of sampled farm households surveyed in the study area is 54 in Mbeya and 53 in Songwe regions respectively. These findings agree with the study of Chavanapoonphol *et al.* (2005) that found out that Thailand rice farmers were quite old of average age of 51 years, and also agrees with the study of Nwaru and Onuoha (2010) that the respondents were a bit old with average age of about 52 and 55 years for smallholder food crop farmers using credit and those not using credit respectively in Imo State, Nigeria. But this disagrees with the findings of Otitoju (2008) which found out that small and medium-scale soybean farmers in Benue State, Nigeria had average age of about 33 and 39 years respectively.

The findings show that (50%) of household heads in Songwe region were male while 49 % of household head in Mbeya region were male. The findings show that the average years of attending school were 10 years where by education of the household head from Mbarali district was on average of 8 years of schooling, Momba district was 4 years, in

Mbozi 3 years and in Mbeya district was 5 years. The household size in Mbarali was found to be 7 members while in Momba 4 members, 7 members in Mbozi and 5 members in Mbeya district. Otitoju and Arene (2010) in their study found the similar results that the respondents used modern variety of soya- beans have an average household size of 7 people. It was found that the average number of different sources of income was 2.2. In Mbeya region the average source was 2 same as in Songwe region. This implies that farm households have income obtained from different sources apart from agriculture. However, as the majority of the farm households depend mostly on agriculture, having different sources of income of the farmer does not necessarily helped farmer to use CSA-practices.

5.4.2 Mixed Multinomial Logit Regression Model Results and Discussions

The findings of the mixed multinomial logit model are presented in Table 2. The findings showed the different variables that determine the usage of single or combination CSA-practises where the non-user of any of the CSA-practises ($Or_0Dt_0Ir_0$) was taken as base category. The model fits the data with the Wald test, Wald χ^2 (186) = 1890.39; p > χ^2 = 0.000 which implies that the null hypothesis that all the regression coefficients are jointly equal to zero should be rejected.

5.4.3 Determinants of using CSA-practises

This section presents the determinants of using organic manure, drought-tolerant maize seeds and irrigation, either in isolation or in combination. The results of the mixed multinomial logit model which identified the main determinants of the usage of CSA-practises either in isolation or in combination or in isolation are presented in Table 5.2. As explained before, the valid instruments such as the age difference between household head and spouse, farm experience, the main information sources (access to extension services) access to tarmacked road and access to agricultural extension services were included in the selection equation but not in the outcome equation. Similar to Beyene (2017), the study use as selection instruments in the food security functions the variables related to past experience such as household characteristics (age difference between the household head and spouse and farm experience) and the main information sources (access to extension services).

Results in Table 5.2 show that gender of the household head has negatively related with the usage of irrigation in isolation ($Or_0Dt_0Ir_1$). This means that female headed households were more likely to use of irrigation in isolation ($Or_0Dt_0Ir_1$) by 1.7181 units at 5% significant level relative to non-use of CSA-practices ($Or_0Dt_0Ir_0$) compared to male household head. Use of irrigation practise by female headed households can support them to generate income through higher-value produce and cultivate varieties of horticultural crops for home consumption, hence improve household dietary diversity. The result was contrary to the results of Wekesa (2017), which found that male-headed household used CSA-practises compared to female-headed households in Kenya.

The results show that age has a significant negative effect in using a combination of organic manure, drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$) at the household level usage decision. This indicates that a unit increase of the household head by one unit lead to decrease likelihood of using combination of $Or_1Dt_1Ir_1$ by 0.0298 units at 5 % significant level relative to non-use of CSA-practices ($Or_0Dt_0Ir_0$). This implies that, younger farming household heads in the study area are more likely to use a combination of organic manure, drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$) than older household heads. It might be that older household heads are more risk-averse than younger farming household heads and they are less willing to gather information about CSA-practises. However, in some cases, older farming household heads may have more experience in farming, hence are more likely to use the CSA-practises. Similar results were found by Beyene (2017), Di Falco and Verona (2013), Teklewold *et al.* (2013) but contrary to the findings of Kassie *et al.* (2015)

who find that age have a positive effect on the usage of Sustainable Agricultural Practises (SAPs).

Table 5.2: Parameter estimates of the mixed multinomial logit model

Variables	$Or_1Dt_0Ir_0$	$Or_0Dt_1Ir_0$	$Or_0Dt_0Ir_1$	$Or_1Dt_1Ir_0$	$Or_0Dt_1Ir_1$	$Or_1Dt_0Ir_1$	$Or_1Dt_1Ir_1$
Production diversity	-1.3426**	0.1962	-0.9502	-0.4034	-0.3987	-1.4869	-1.3060***
	(0.5414)	(0.8937)	(1.1554)	(0.6070)	(0.4949)	(1.1295)	(0.5063)
Gender of the household head	-0.6629	0.2997	-1.7181**	-0.1635	-0.7889	-0.1431	0.1187
	(0.5237)	(0.8611)	(0.7255)	(0.6117)	(0.5605)	(0.8345)	(0.5174)
Age of the Household head	0.0094	-0.0158	0.0104	-0.0150	-0.0186	-0.0153	-0.0298**
	(0.0132)	(0.0270)	(0.0243)	(0.0152)	(0.0126)	(0.0304)	(0.0129)
Marital status of the household head	-0.2348	-0.4191	0.6465	0.5337	1.0051*	2.2525**	0.2841
	(0.5123)	(0.7437)	(0.5938)	(0.5845)	(0.5619)	(1.1269)	(0.5038)
Occupation	0.1428	-0.1449	-0.7055	0.2026	0.0496	-0.5757	0.2014
	(0.1937)	(0.3075)	(0.5243)	(0.2202)	(0.1852)	(0.4255)	(0.1841)
Education of the household head	-0.0449	-0.0006	-0.0396	-0.0675	-0.0243	-0.1937***	-0.0585
	(0.0517)	(0.0885)	(0.1156)	(0.0615)	(0.0530)	(0.0747)	(0.0519)
Education of the spouse	0.0742	0.0815	0.1278	0.2267	0.1412	0.2001	0.2527**
	(0.1253)	(0.2601)	(0.2109)	(0.1430)	(0.1257)	(0.1906)	(0.1277)
Household size	0.0892	0.0954	0.1457	0.0496	0.1241**	0.1158	0.1089*
	(0.0648)	(0.0922)	(0.1164)	(0.0689)	(0.0632)	(0.1154)	(0.0614)
Tropical livestock Unit	0.0089	-0.0140	0.0249	0.0276	0.0220	0.1215	-0.0129
	(0.0824)	(0.0866)	(0.1020)	(0.0852)	(0.0788)	(0.0950)	(0.0796)
Total plot size	-0.0304	0.0359	0.0675***	0.0495**	0.0329	0.0203	0.0516**
	(0.0285)	(0.0302)	(0.0252)	(0.0244)	(0.0226)	(0.0451)	(0.0221)
Plot ownership	-1.2965***	-1.7524***	-0.6741	-0.3657	-1.2289***	-0.0183	-0.4528
	(0.3521)	(0.5420)	(0.7081)	(0.4578)	(0.3593)	(0.7199)	(0.3494)
Land title	0.2836	0.2672	0.2762	-0.0348	0.1176	-0.0139	-0.0793
	(0.4358)	(0.4365)	(0.4360)	(0.5616)	(0.4333)	(0.8041)	(0.4321)
Log of asset	0.3840***	0.2145	0.1934	0.2482**	0.2561**	0.3259	0.5120***
	(0.1123)	(0.1779)	(0.2295)	(0.1200)	(0.1047)	(0.2146)	(0.1033)
Soil fertility	0.3817	0.0244	0.1750	0.6757**	0.3995*	0.2353	0.4230*
	(0.2414)	(0.4149)	(0.5156)	(0.2792)	(0.2332)	(0.4337)	(0.2292)
Soil erosion	-0.0979	0.3915	-0.0062	0.1316	0.0803	0.3512	0.3370
	(0.2744)	(0.4319)	(0.5691)	(0.3047)	(0.2630)	(0.4428)	(0.2563)
Access to loan	0.8603**	-0.1258	-0.0532	1.2705***	0.8653**	-0.2504	0.6204*
	(0.3434)	(0.6065)	(0.7365)	(0.3661)	(0.3458)	(0.7299)	(0.3307)
Region dummy	0.2162	-0.3531	-1.1488*	-0.7991**	1.3049***	-0.7875	0.3159
	(0.2872)	(0.4131)	(0.6025)	(0.3365)	(0.2767)	(0.4866)	(0.2651)
Age difference	-0.0144	0.0254	-0.0073	0.0091	0.0165	0.0444	0.0127
	(0.0146)	(0.0177)	(0.0231)	(0.0161)	(0.0152)	(0.0472)	(0.0142)
Farm experience	0.0022	0.0456**	-0.0039	0.0152	0.0087	-0.0056	0.0225*
	(0.0126)	(0.0225)	(0.0239)	(0.0137)	(0.0118)	(0.0215)	(0.0118)
Average farm distance	-0.0105	0.0113	-0.0009	-0.0166**	-0.0141*	0.0120	-0.0039
	(0.0065)	(0.0075)	(0.0103)	(0.0084)	(0.0075)	(0.0107)	(0.0061)
Access to extension	0.2172	0.9698*	-0.1903	0.4647	0.1762	-0.5242	0.7720**
	(0.3728)	(0.5455)	(0.8157)	(0.4116)	(0.3448)	(0.8770)	(0.3367)

Distance to extension office	-0.0094**	-0.0002	-0.0209**	-0.0176***	-0.0256***	-0.0226**	-0.0354***
	(0.0038)	(0.0052)	(0.0100)	(0.0044)	(0.0041)	(0.0096)	(0.0040)
Access to tarmac road	0.0010	-0.0036	0.0011	-0.0009	0.0014	-0.0015	0.0009
	(0.0017)	(0.0043)	(0.0017)	(0.0023)	(0.0017)	(0.0045)	(0.0017)
Constant	-2.8306	-4.5114	-2.1100	-3.7509**	-2.1926	-5.4589*	-5.3263***
	(1.7307)	(2.8564)	(3.3451)	(1.8333)	(1.6097)	(3.1843)	(1.5886)

The study found a positive effect of land ownership on the usage of organic manure ($Or_1Dt_0Ir_0$), drought-tolerant maize seeds ($Or_0Dt_1Ir_0$) and combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$). Farming households which owned land were less likely to use a combination drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.2965 units at 1 % significant level. Furthermore, land owners are less likely to use a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.2289 units at 1 % significant level. Finally, land owners are less like to use drought tolerant maize seeds ($Or_0Dt_1Ir_0$) by 1.7524 units at 1 % significant level. This is because the land renters are less likely to apply new practises on rented plots because of the absence of security of tenure in the farm. Similar result was found Maguza-Tembo *et al.* (2017), who found that land renters are less likely to apply new practises because of the lack of security of tenure in the farm. The result, however, is inconsistent with the findings of Tran *et al.* (2019) whose findings show that land ownership was found to be significant and had positive influence in the usage of CSA packages in Vietnam.

The study found that marital status of the household head was positively related with the usage of drought tolerant maize seed and irrigation in combination ($Or_0Dt_1Ir_1$). This means that marriage headed households were more likely to use the combination of maize tolerant maize seeds by 1.0051 units at 5% significant level relative to non-use of CSA-practices ($Or_0Dt_0Ir_0$) compared to single household head. In addition, the study found that marital status of the household head positively related with the usage of combination of organic manure and irrigation. Thus, marriage households are also likely to have more labour so they are likely use practices which are labour intensive compare to single households. These results agrees with the findings of Tambo and Abdoulaye (2012) in their study of adoption of drought tolerant maize in northern Nigeria.

The study found a positive and significant relationship between the household size and the usage of a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$). This means that a unit increase of the household size is likely to increase the usage of combination of $Or_0Dt_1Ir_1$ by 0.1241 units at 5 % significant level. In addition, units increase of household size increase the probability of using the combination of organic manure, drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$) by 0.1089 units at 10 % significant level. This is due to the fact that application of organic manure, operation of irrigation activities in the farms and planting of drought-tolerant maize seeds which require a specific spacing are labour-intensive and hence positively associated with household size. The result is consistent with the findings of Kassie *et al.* (2015) whose findings show that farming households with large household size are likely to use crop rotation in Tanzania.

Surprisingly, the study found a negative and significant effect of education on the usage of a combination of organic manure and irrigation ($Or_1Dt_0Ir_1$). The study found that one more year of education decrease the probability of using the combination of organic manure and irrigation ($Or_1Dt_0Ir_1$) by 0.1937 units at 1% significance level. This is because the educated farming household heads might spend part of their time on off-farm activities and have less time to spend on the farm. This makes the opportunity cost of working on farm higher for the educated household heads. Kassie *et al*. (2012) found the same result in his study of the usage of cereal-legume in Tanzania. However, it is expected that the more educated the household heads are, the more innovative they are and able to access and understand information, hence, increasing the likelihood of using CSA-practises (Gido *et al*., 2015).

The study found a negative effect of land ownership on the usage of organic manure ($Or_1Dt_0Ir_0$), drought-tolerant maize seeds ($Or_0Dt_1Ir_0$) and combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$). Farming households which owned land were less likely to use a combination drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.2965 units at 1 % significant level. Furthermore, land owners are less likely to use a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.2289 units at 1% significant level. Finally, land owners are less like to use drought tolerant maize seeds ($Or_0Dt_1Ir_0$) by 1.7524 units at 1% significant level. This is because the land renters are less likely to apply new practises on rented plots because of the absence of security of tenure in the farm. Similar result was found Maguza-Tembo *et al.* (2017), who found that land renters are less likely to apply new practises because of the lack of security of tenure in the farm. The result, however, is inconsistent with the findings of Tran *et al.* (2019) whose findings show that land ownership was found to be significant and had positive influence in the usage of CSA packages in Vietnam.

Agricultural extension is the system of learning and building the human capital of farmers by giving information and exposing them to farm practises which can increase agricultural productivity and food security. The study used access to government and non-government extension agents, and distance to the nearest agricultural office as proxies for access to information. The study found that farming households with access to agricultural extension services were more likely to use drought-tolerant maize seeds ($Or_0Dt_1Ir_0$) by 0.9698 units at 10% significant level. The use of DTMS is mainly due to farm input subsidy programme which has over the years disseminated DTMS. The DTMS has been an integral component in the government subsidy package and this has made it easy for farming households to access and use the seeds. In addition, farming household exposure to drought respond by using risk reducing practices such as drought tolerant maize seeds.

Furthermore, the agricultural extension services were found to be significant at 5% significant level and positively correlated with the combination of organic manure, drought-tolerant maize seeds and irrigation (Or1Dt1Ir1). The positive relationship implies that farming households with access to agriculture extension service may get the courage to use and continuously apply CSA-practises. Similar results were found by studies conducted by Solomon *et al.* (2011), Namwata *et al.* (2010); Odoemenem and Obinne (2010) and Matata *et al.* (2010) which found farming households which are frequently visited by extension officer use agricultural practises compare to farming households with no access to extension visits. This finding is contrary to Gebremariam and Wünscher, (2016) who noted that agriculture extension service is negative and statistically significant with the usage of cereal-legume diversification only. However, Bamire et al. (2002) argued that, farming households with few extension visits are less likely to use agricultural practices compare to their counterparts.

The distance to an agricultural extension office is negative and significant to all combination expect the usage of drought tolerant maize seed suggesting that farmer-proximity to an agricultural extension office increases the propensity to use CSA-practises in isolation and in combination. The intuition drawn from such a finding is that formal ways of promoting the using CSA-practises such as through a government extension system are quite relevant. Indeed, longer distances are associated with higher transportation costs, especially in developing countries such as Tanzania where rural transport infrastructures are poorly developed.

Access to credit was important in influencing usage of the four combinations of CSA-practises under consideration in this study. The study found that households whose heads had access to credit had 0.8603 units at 5% significant level higher chance to use organic manure in isolation ($Or_1Dt_0Ir_0$), than the household heads with no access to credit. Households with access to credit were more likely to use a combination of organic manure and drought-tolerant maize seeds ($Or_1Dt_1Ir_0$) by 1.2705 units at 1% significant level. Furthermore, the study found that households whose heads had access to credit had higher chance to use a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) than their household heads with no access to credit by 0.8653 units at 5% significant level. Finally farming households whose heads had access to credit had higher chance to use a combination of organic manure, drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$) than the farming households with no access to credits by 0.6204 units at 10% significant level. Positive correlation between access to credit and usage of agricultural practices was also noted by Ogada *et al.* (2014).

As expected, the distance of farm from homestead has a negative and significant effect on usage of the combination of organic manure and drought tolerant maize seeds ($Or_1Dt_1Ir_0$) and the combination of drought tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$). The study found that a household which is one minute closer to the farm/plot had higher chance of using a combination of organic manure and drought-tolerant maize seed at 0.0166 units at 5% significant level. In addition, the study found that one minute close to the farm/plot increase the probability of using a combination of drought-tolerant maize seeds and irrigation by 0.0141 units at 10% significant level. The negative relationship implies that farmers may feel tired by the time they get to the farm or may have to spend extra money to commute from the house to the farm field, hence led to not to use the practises. Similar result was found by Gebremariam and Wünscher (2016) who concluded that, the farm distance from homestead has a negative and significant effect on the usage of the comprehensive package of sustainable agricultural practises. Region dummies included in the models are found to be highly statistically significant (the point of reference is the Mbeya region).

The coefficient for region dummy was found to be negative sign and statistically significant for the usage of irrigation ($Or_0Dt_0Ir_1$) and the combination of organic manure and drought-tolerant maize seeds ($Or_1Dt_1Ir_0$). The study found that farming households from Songwe region are less likely to use irrigation as a CSA-practise ($Or_0Dt_0Ir_1$) by 1.15 units at 10 % significant level. This is due to the availability of few irrigation schemes in Songwe Region compare to number of irrigation schemes in Mbeya Region such as Madibila, Kongolo Mswisi, Kapunga irrigation scheme just to mention a few. In addition, the study found that farming households from Songwe Region were less like to use a combination of organic manure and drought-tolerant maize seeds. This indicates that Mbeya Region may have been targeted more than Songwe Region by agricultural interventions and extension services. The finding is similar to the study by Kassie *et al.* (2012) in Tanzania who found that district dummy for Arumeru, Babati, and Kondoa were statistically significant and negatively correlated with the usage of improved maize varieties.

Plot size was found to be significantly at 1% is positively influence the usage of irrigation (Or0Dt0Ir1) in isolation and significant at 5% level positively associated with the adoption of the combination of organic manure and drought tolerant maize seeds (Or1Dt1Ir0). Furthermore, plot size was found to be significant at and positively associated with the usage of the combination of organic manure, drought-tolerant maize seeds and irrigation

(Or1Dt1Ir1). This implies that farming households with larger plot sizes are usually practice commercial farming and will usually adopt agricultural technologies such as CSA for profit maximization. This result is different from the study conducted by Lunduka *et al.* (2012), which reported a farm size is negative and significant effects of farmland holdings and opened pollinated variety of maize in Malawi.

Household assets were found to be one of the important determinants in the usage of CSA-practises. It is found that household's asset holding is positively and significantly correlated with the usage of organic manure ($Or_1Dt_0Ir_0$), organic manure with drought-tolerant maize seeds ($Or_1Dt_1Ir_0$), drought-tolerant maize seeds with irrigation ($Or_0Dt_1Ir_1$) and organic manure with drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$). The livestock holding (TLU) was another asset considered but the study did not find its significant impact on the usage of CSA-practises, either in combination or in isolation.

5.6.4 Estimation of the treatment effects

The estimates of the impact of CSA-practises used in isolation and in combination on household dietary diversity per adult equivalent units (HDDS/AEU) as an indicator of food security were presented on Table 5.3. Remarkably, the study found that majority of the CSA-practises have a positive effect on HDDS /AEU, both when used in isolation and in combination (with the exception of the impact of organic manure ($Or_1Dt_0Ir_0$) in isolation). Generally, CSA-practises used as combination had shown a strong and positive impact HDDS/AEU compared to practises used in isolation. Additionally, some of the factor loadings show evidence of negative selection bias, suggesting that unobserved characteristics that increase the probability of using CSA-practises are allied with lower levels of welfare than those expected under random assignment to the CSA-practises usage status. Positive selection bias is also evident in the outcome equation, suggesting that unobserved variables increasing the likelihood of using organic manure ($Or_1Dt_0Ir_0$), drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$), organic manure and irrigation ($Or_1Dt_0Ir_1$) and organic manure, drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$) are associated with higher HDDS/AEU.

The study found that farm households that used organic manure ($Or_1Dt_0Ir_0$) alone was negatively impact HDDS/AEU at 10% significant level. The usage of organic manure in isolation decreases the HDDS/AEU by 7.35% in comparison with non-user ($Or_0Dt_0Ir_0$). Similar result was found by Martey (2018) in Ghana, who found that usage of organic fertilizer significantly decreases household food expenditure by US$174. However, when organic manure is used with drought-tolerant maize seeds ($Or_0Dt_1Ir_0$), the HDDS per AEU increase to 19.14%. In addition, when organic manure is used with irrigation, again the HDDS/AEU increased to 24.15%.

The usage of drought-tolerant maize seeds ($Or_0Dt_1Ir_0$) and irrigation ($Or_0Dt_0Ir_1$) in isolation were found to have positive and insignificant impact on HDDS/AEU. Sileshi *et al.* (2018) found a similar result that, the usage of soil and water conservation positively and significantly increased the per capita food consumption expenditure. In addition, the study found that the usage of soil and water conservation increases significantly the probability of farming household being food insecure. Khonje *et al.* (2015) found the drought tolerant maize seed to have the strongest impact when used in isolation than when it is implemented with any other SAPs in Zambia. However, when drought-tolerant maize seeds ($Or_0Dt_1Ir_0$) are used in combination with organic manure, there was positive and significant impact HDDS/AEU. The combination of drought-tolerant maize seeds with irrigation also had positive and significant impact HDDS/AEU. The usage of drought-tolerant maize seed in combination with organic manure leads to increase HDDS/AEU by 19.14%. It is somewhat lower compare to the impact of drought-tolerant maize seed found elsewhere. For example, Khonje *et al.* (2015) and Mutenje, *et al.* (2016) found a 90% and 24.6% impacts of improved maize varieties in Zambia and Malawi, respectively. The usage of the combination of drought-tolerant maize seeds with irrigation was found to increase HDDS/AEU by 25.25%.

Interestingly, the study found a 20.27% impact on HDDS/AEU when organic manure, drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$) were used in combination. This implies that usage of a combination of CSA-practises (organic manure, drought-tolerant maize seeds and irrigation) provide a higher payoff than the usage of these practises in isolation. Therefore, the finding verifies the complementarity of the CSA-practises and their synergetic effect.

Besides, the usage of a combination of drought-tolerant maize seeds and Irrigation ($Or_0Dt_1Ir_1$) gave higher payoff than the combination of all three CSA-practises. This is similar to the study by Beyene (2017), which found that a combination of two strategies (intercropping and tree planting) yielded a better return than the usage of three strategies in rural Ethiopia. Mutenje *et al.* (2016) in Malawi also reported that usage of a combination of drought tolerant maize seeds and improved storage facilities gave the highest payoff than when the combination of all three practises they considered in their study (drought tolerant maize seeds, improved storage facilities, and soil and water conservation). The similarities between these findings and earlier studies could be due to the reason that the agro-ecological between our study area and the other studies.

Although, according to the multinomial nature of modelling in this study, it is not possible to elicit the real complementarity effects figure of the CSA-practise considered among each other. One can reveal that there is a strong complementary effect among the CSA-practises used in this study. For example, usage of organic manure and drought-tolerant seeds lead to a -7.35 and 3.37 % increase of HDDS/AEU when used in isolation. But when they are used together, the marginal effect increases to 0.1914%. This shows that there is a strong complementary effect, more than even their individual arithmetic summations (-7.35% +3.37%= -3.98%). The same applies when the drought-tolerant maize seed and irrigation are used in isolation; lead to increase HDDS/AEU by 3.37 and 1.74 % respectively. But when they are used in combination, the HDDS/AEU increased to 25.25%. Again, this shows a complementary effect, more than the individual arithmetic summations (3.37% +1.74%=5.11%).

Table 5.3: Multinomial endogenous treatment affects model estimates of CSA-practises impacts on Household Dietary Diversity per adult equivalent unit

Climate Smart Agriculture Practises	HDDS/AEU	Standard errors
Organic manure ($Or_1Dt_0Ir_0$)	-0.0735*	0.0412
DTMS ($Or_0Dt_1Ir_0$)	0.0337	0.0718
Irrigation ($Or_0Dt_0Ir_1$)	0.0174	0.0778
Organic manure and DTMS ($Or_1Dt_1Ir_0$)	0.1914***	0.0462
DTMS and Irrigation ($Or_0Dt_1Ir_1$)	0.2525***	0.0609
Organic Manure and Irrigation ($Or_1Dt_0Ir_1$)	0.2415***	0.0653
Organic manure, DTMS and Irrigation ($Or_1Dt_1Ir_1$)	0.2027***	0.0424
Selection terms		
Organic manure ($Or_1Dt_0Ir_0$)	0.1095***	0.0119
Drought Tolerant Maize seed ($Or_0Dt_1Ir_0$)	0.0882***	0.0151
Irrigation ($Or_0Dt_0Ir_1$)	0.0288**	0.0118
Organic manure and DTMS ($Or_1Dt_1Ir_0$)	-0.0469***	0.0095
DTMS and Irrigation ($Or_0Dt_1Ir_1$)	-0.1486***	0.0238
Organic Manure and Irrigation ($Or_1Dt_0Ir_1$)	-0.0757***	0.0151
Organic manure, DTMS and Irrigation ($Or_1Dt_1Ir_1$)	-0.0691***	0.0190

5.4.5. Exclusion restriction

The economic theory and empirical studies were used for the selection of the exclusion restriction. Earlier studies such as Di Falco *et al.* (2011), Shiferaw *et al*. (2014) and Khonje *et al.* (2015) used variables such as extension service, farmer-to-farmer extension, radio information, market and climate information and distance to inputs as exclusion restrictions. In this study the age differences between household head and spouse, farming experience, plot distance from resident, extension visit and the distance to the extension office to the farmers' residents were used. For example, extension service is considered as the primary source of knowledge and information about new and improved practises for farmers, especially when the cost of information and knowledge is prohibitive (e.g. Genius *et al.*, 2014; Krishnan and Patnam, 2014).

In addition to its role in developing skills and knowledge of farmers to use new and improved practises, an extension could play a vital role in the facilitation of linkages with other institutional support services such as input supply, output marketing, and credit. Second, development or extension agents are usually assigned at the administrative level and their assignment is less likely to be influenced by households' behaviour. Besides, the presence of the extension agent in the village or community is determined outside the farmer's improved storage practise use decision (Kadjo *et al.*, 2013). A falsification test for admissibility of the exclusion restriction following Di Falco *et al.* (2011) confirms that it is a possible selection instrument, since the variable is significantly correlated with CSA-practises at less than 1% level, but not correlated with the outcomes for non-user households. Additional tests for the exclusion instrument were conducted as shown in Table 5.4.

Table 5.4: Tests for the exclusion restriction

Test	Null hypothesis/Test type	Test results
Durbin test	Exclusion instrument is exogenous	F= 0.268607, p = 0.6043
Wu–Hausman test	Exclusion instrument is exogenous	F =0. 264908, p = 0.6068
Anderson canonical correlation statistic	Under identification	LM= 125.301, p = 0.000
Cragg-Donald statistic	Under identification	χ2= 7.844, p = 0.0975

The result from Durbin and Wu–Hausman (DWH) tests for exogeniety of the selection instrument were found to be highly insignificant while the Wooldridge's (2010) score test of exogeniety, which can tolerate heteroskedastic errors also fails to reject the null hypothesis of exogeneity. The study computed the Anderson canonical correlation statistic (Baum *et al.,* 2007) to test for identification of the model. The test rejects the null hypothesis of under identification of the model at less than 1% and justifies that the excluded instrument is relevant. The robustness of the results was checked by estimating the Cragg-Donald chi-square statistic which also rejects the null of weak identification at less than 1% level of significance. Furthermore, the study assessed the weak instrument robust inference using the Anderson–Rubin's test (Baum *et al.,* 2007), which also confirmed the validity of the selection instrument.

5.5 Conclusion and Policy Implications

This study examines the determinants of usage of CSA-practises in isolation or in combination and its impact on food security. Cross-sectional data collected in the Southern Highlands of Tanzania (Mbeya and Songwe region) were used for the empirical analysis. The determinants of CSA- practises used and the various factors affecting food security in each regime were identified using a multinomial endogenous treatment effect model. Through this model, the heterogeneity in the decision to use a combination of CSA-practises as opposed to individual usage were taken into account as well as unobserved characteristics of the farming household.

Findings show that there are various variables which are important in influencing usage of CSA-practises, either in isolation or in combination. Household characteristics are important in the decision to use CSA-practises. For example, spouse education, the size household, gender of the head of the household, age of the head of the household and farm experience have shown the different effects on the probability of using CSA-practises considered in this study. The findings show that loan acquisition and agricultural extension services were positively associated with some, but not all, of the combination of CSA-practises.

Household assets were found to be one of the important determinants in the usage of CSA-practises. The study found that household asset holding is positively and significantly correlated with the usage of organic manure ($Or_1Dt_0Ir_0$), organic manure with drought-tolerant maize seeds ($Or_1Dt_1Ir_0$), drought tolerant-maize seeds with irrigation ($Or_0Dt_1Ir_1$) and organic manure with drought-tolerant maize seeds and irrigation ($Or_1Dt_1Ir_1$). Plot characteristic such as the distance of the plot, total plot size and soil fertility of the cultivated plots also show different effects on the probability of using CSA-practises.

Policy-makers and other agriculture stakeholders may use the information to influence the usage of different CSA-practises. Results from this study generally show that CSA-practises have a positive and significant effect on household dietary diversity score per adult equivalent unit. The package that contains combination of drought-tolerant maize seeds and Irrigation ($Or_0Dt_1Ir_1$) gave the higher payoff than the combination of all three CSA-practises. This implies that future interventions that aim to increase agricultural productivity and enhance household dietary diversity score per adult equivalent unit as an indicator of food security should combine use of drought-tolerant maize seeds and irrigation with other best CSA-practises that enhance agronomic practises.

5.6 Ethics Statement

The study ensured confidentiality of the information provided to the respondents, including their own personal information. Where applicable, especially for secondary data, the sources of information were acknowledged. The respondents were aware of the aim of the study. This created an environment of trust, necessary to gain reliable information that is correct and accurate at the same time, in order to guarantee the quality of this study on one hand and allowing them to provide the information without any suspicion on the other hand.

5.7 Author Contributions

All authors contributed to manuscript revision, read and approved the submitted version.

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References

African Green Revolution Alliance (AGRA) (2016). Tanzania Annual Report. Available from https://agra.org/2016AnnualReport/. Accessed (11/07/2018)

Aggarwal, V. S., & GGS, I. (2012). Female-headed households and feminisation of Poverty. *Research journal of social science and management*, *4*(02), 57-62.

Ali, A., & Erenstein, O. (2017). Assessing farmer use of climate change adaptation practises and impacts on food security and poverty in Pakistan. *Climate Risk Management*, *16*, 183-194.

Allotey, S. S. K., Adam, H., & Hudu, Z. (2019). Impact of Fertilizer Subsidy Programme on Maize Income in the Northern Region of Ghana.

Ariga, J., Jayne, T.S., Kibaara B. and Nyoro, J.K. (2008). Trends and Patterns in Fertilizer Use by Smallholder Farmers in Kenya, 1997-2007. Tegemeo Working Paper No.32: Tegemeo Institute, Egerton University. Nairobi.

Arslan, H. (2013). Application of multivariate statistical techniques in the assessment of groundwater quality in seawater intrusion area in Bafra Plain, Turkey. *Environmental monitoring and assessment*, *185*(3), 2439-2452.

Assenga, E. A., & Kayunze, K. A. (2016). Food Security Incidences Based on Dietary Energy Consumption, Dietary Diversity and Household Food Insecurity Access Scale in Chamwino District, Tanzania. *International Journal of Asian Social Science*, *6*(11), 644-658.

Baethgen, W.E., 2010: Climate risk management for adaption to climate variability and change. *Crop Science*, 50(2), 70-76

Bamire, A. S., Fabiyi, Y. L., & Manyong, V. M. (2002). Adoption pattern of fertiliser technology among farmers in the ecological zones of south-western Nigeria: A Tobit analysis. *Australian journal of agricultural research*, *53*(8), 901-910.

Barrett, C. B. (2008). Poverty traps and resource dynamics in smallholder agrarian systems. *Economics of poverty, environment and natural-resource use*, 17-40.

Baum, C. F., Schaffer, M. E., & Stillman, S. (2007). Enhanced routines for instrumental variables/generalized method of moments estimation and testing. *The Stata Journal*, *7*(4), 465-506.

Beyene, A. D., & Kassie, M. (2015). Speed of adoption of improved maize varieties in Tanzania: An application of duration analysis. *Technological Forecasting and Social Change*, *96*, 298-307.

Beyene, A. D., Mekonnen, A., Kassie, M., Di Falco, S., & Bezabih, M. (2017). Determinants of Usage and Impacts of Sustainable Land Management and Climate-Smart Agricultural Practises (SLM-CSA): Panel Data Evidence from the Ethiopian Highlands. *Environment for Development Discussion Paper Series*, (17-10).

Bezu, S., Kassie, G. T., Shiferaw, B., & Ricker-Gilbert, J. (2014). Impact of improved maize adoption on welfare of farm households in Malawi: a panel data analysis. *World Development*, 59, 120-131.

Bhatt, R. (2017). Zero tillage for mitigating global warming consequences and improving livelihoods in South Asia. In Environmental Sustainability and Climate Change Adaptation Strategies (pp. 126-161). IGI Global.

Blanco-Canqui, H., Ruis, S.J., 2018. No-tillage and soil physical environment. Geoderma 326, 164–200.

Capone, R., Bilali, H. El, Debs, P., Gianluigi, C., & Noureddin, D. (2014). Food System Sustainability and Food Security: Connecting the Dots. *Journal of Food Security*, *2*(1), 13–22.

Chaovanapoonphol, Y., Battese, G. E. & Chang, H. (2005). The Impact of Rural Financial Services on the Technical Efficiency of Rice Farmers in the Upper North of

Thailand. Contributed Paper at the Annual Conference of the Australian Agricultural and Resource Economics Society at Coffs Harbour, 9-11 February 2005.

Chen, J., Gong, Y., Wang, S., Guan, B., Balkovic, J., & Kraxner, F. (2019). To burn or retain crop residues on croplands? An integrated analysis of crop residue management in China. Science of the Total Environment, 662, 141-150.

Coates, J., 2004. Experiences and expression of food insecurity across cultures: Practical implications for valid measurement. Available from http://www.ifpri.org/ [Accessed 27/5/2019].

Deb, P., & Trivedi, P. K. (2006). Specification and simulated likelihood estimation of a non-normal treatment-outcome model with selection: Application to health care utilization. *The Econometrics Journal*, *9*(2), 307-331.

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *The Journal of Agricultural Science*, *149*(1), 23-31.

Deressa, Temesgen Tadesse, Rashid M. Hassan, Claudia Ringler, Tekie Alemu, and Mahmud Yesuf. (2009) "Determinants of farmers’ choice of adaptation methods to climate change in the Nile Basin of Ethiopia." *Global environmental change* 19 (2) 248-255.

Di Falco, S., & Bulte, E. (2013). The impact of kinship networks on the adoption of risk-mitigating strategies in Ethiopia. *World Development*, *43*, 100-110.

Di Falco, S., & Veronesi, M. (2013). How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia. *Land Economics*, *89*(4), 743-766.

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829-846.

Ekwere, G. E., & Edem, I. D. (2014). Effects of agricultural credit facility on the agricultural production and rural development. *International Journal of Environment, 3*(2), 192-204.

Fernandez-Cornejo, J., Hendricks, C., & Mishra, A. (2005). Technology adoption and off-farm household income: the case of herbicide-tolerant soya beans. *Journal of Agricultural and Applied Economics*, *37*(3), 549-563.

Fisher, R. A., Muszala, S., Verteinstein, M., Lawrence, P., Xu, C., McDowell, N. G., ... & Spessa, A. (2015). Taking off the training wheels: the properties of a dynamic vegetation model without climate envelopes, CLM4. 5 (ED). *Geoscientific Model Development*, *8*(11).

Food and Agriculture Organization of the United Nations (FAO), (2014). Success stories on climate-smart agriculture. Available from http://www.fao.org [Accessed 21/7/2018].

Food and Agriculture Organization of the United Nations (FAO). (2010b). “Climate-Smart” Agriculture. The Hague Conference on Agriculture, Food Security and Climate Change. Available from http://www.fao.org [Accessed 3/8/2018].

Food and Agriculture Organization of the United Nations (FAO). (2013). Review of food and agricultural policies in the united republic of Tanzania. Available from http://www.fao.org [Accessed 3/8/2018].

Food and Agriculture Organization of the United Nations (FAO). (2010a). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2010 Key messages. Available from http://www.ifpri.org/ [Accessed 20/5/2018].

Food and Agriculture Organization of the United Nations (FAO). (2019). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2019 Key messages. Available from http://www.ifpri.org/ [Accessed 29/1/2019].

Food and Agriculture Organization of the United Nations (FAO). (2011). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2011 Key messages. Available from http://www.ifpri.org/ [Accessed 10/6/2018].

Gebremariam, G., & Wünscher, T. (2016). Combining sustainable agricultural practises pays off: evidence on welfare effects from Northern Ghana (No. 310-2016-5382) Available at: https://ideas.repec.org/p/ags/aaae16/246452.html. (Accessed 23 May 2019)

Genius, M., Koundouri, P., Nauges, C., & Tzouvelekas, V. (2014). Information transmission in irrigation technology adoption and diffusion: Social learning, extension services, and spatial effects. *American Journal of Agricultural Economics*, *96*(1), 328-344.

Gido, E. O., Sibiko, K. W., Ayuya, O. I., & Mwangi, J. K. (2015). Demand for agricultural extension services among small-scale maize farmers: Micro-level evidence from Kenya. *The Journal of Agricultural Education and Extension*, *21*(2), 177-192.

Giller, K. E., Andersson, J. A., Corbeels, M., Kirkegaard, J., Mortensen, D., Erenstein, O., & Vanlauwe, B. (2015). Beyond conservation agriculture. *Frontiers in plant science*, *6*, 870.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, 327(5967), 812–818.

Gouel, C., & Guimbard, H. (2019). Nutrition transition and the structure of global food demand. *American Journal of Agricultural Economics*, *101*(2), 383-403.

Imran, M. A., Ali, A., Ashfaq, M., Hassan, S., Culas, R., & Ma, C. (2018). Impact of Climate Smart Agriculture (CSA) practises on cotton production and livelihood of farmers in Punjab, Pakistan. *Sustainability*, *10*(6), 2101.

IPCC. (2014). Part A: Global and Sectoral Aspects. (Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Climate Change 2014: Impacts, Adaptation, and Vulnerability., 1132.

Kadjo, D., Ricker-Gilbert, J., Alexander, C., & Tahirou, A., (2013). Effects of Storage Losses and Grain Management Practices on Storage: Evidence from Maize Production in Benin. In 2013 Annual Meeting, August 4-6, 2013, Washington, DC (No. 150522). Agricultural and Applied Economics Association.

Kassie M, Jaleta M, Shiferaw B, Mmbando F, Mekuria M (2012) Interdependence in farmer technology adoption decisions in smallholder systems: joint estimation of investments in sustainable agricultural practices in rural Tanzania. Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguac¸u, Brazil, 18–24 August

Khaitov, B., Yun, H. J., Lee, Y., Ruziev, F., Le, T. H., Umurzokov, M., and Park, K. W. (2019). Impact of Organic Manure on Growth, Nutrient Content and Yield of Chilli Pepper under Various Temperature Environments. *International Journal of Environmental Research and Public Health*, *16*(17), 3031.

Khonje, M. G., Manda, J., Mkandawire, P., Tufa, A. H., & Alene, A. D. (2018). Adoption and welfare impacts of multiple agricultural practises: evidence from eastern Zambia. *Agricultural Economics*, *49*(5), 599-609.

Kinabo, J., Mamiro, P., Dawkins, N., Bundala, N., Mwanri, A., Majili, Z., & Ngowi, M. (2016). Food intake and dietary diversity of farming households in Morogoro region, Tanzania. *African Journal of Food, Agriculture, Nutrition and Development*, *16*(4), 11295-11309.

Kirkegaard, J. A., Hunt, J. R., McBeath, T. M., Lilley, J. M., Moore, A., Verburg, K., Whitbread, A. M. (2014). Improving water productivity in the Australian grains industry - A nationally coordinated approach. *Crop and Pasture Science*, 65(7), 583–601.

Krishnan, P., & Patnam, M. (2014). Neighbors and extension agents in Ethiopia: Who matters more for technology adoption. *American Journal of Agricultural Economics*, *96*(1), 308-327.

Kuntashula, E., Chabala, L. M., & Mulenga, B. P. (2014). Impact of minimum tillage and crop rotation as climate change adaptation strategies on farmer welfare in smallholder farming systems of *Zambia. Journal of Sustainable Development*, 7(4), 95.

Li, Y., Li, Z., Cui, S., Jagadamma, S., & Zhang, Q. (2019). Residue retention and minimum tillage improve physical environment of the soil in croplands: A global meta-analysis. *Soil and Tillage Research*, *194*, 104-292.

Lipper, L., & Zilberman, D. (2018). A short history of the evolution of the climate smart agriculture approach and its Links to climate change and sustainable agriculture debates. In Climate Smart Agriculture (pp. 13-30). Springer, Cham.

Lunduka, R., Fisher, M., & Snapp, S. (2012). Could farmer interest in a diversity of seed attributes explain adoption plateaus for modern maize varieties in Malawi? *Food Policy*, *37*(5), 504-510.

Maguza-Tembo, F., Edriss, A.K. and Mangisoni, J. (2017), “Determinants of climate smart agriculture technology adoption in the drought prone districts of Malawi using a multivariate probit analysis”, *Asian Journal of Agricultural Extension, Economics and Sociology*, 16 (3), pp. 1-12.

Martey E (2018) Welfare effect of organic fertilizer use in Ghana. *Heliyon* 4, 1– 26.

Massawe, G. D. (2016). Farming systems and household food security in Tanzania: the case of Mvomero and Kishapu districts, PhD Thesis for Partial Fulfilment of PhD University College Dublin (Ireland) (pp 296).

Masuka, B., Atlin, G. N., Olsen, M., Magorokosho, C., Labuschagne, M., Crossa, J., and Macrobert, J. (2017). Gains in maize genetic improvement in Eastern and Southern Africa: I. CIMMYT hybrid breeding pipeline. *Crop Science*, *57*(1), 168-179.

Matata, P. Z., Ajay, O. C., Oduol, P. A., & Agumya, A. (2010). Socio-economic factors influencing adoption of improved fallow practises among smallholder farmers in western Tanzania. *African journal of agricultural research*, *5*(8), 818-823.

Maxwell, D., C. Ahiadeke, C. Levin, M. Armar-Klemesu, S. Zakariah and G.M. Lamptey, (1999). Alternative food security indicators: Revisiting the frequency and severity of coping strategies. *Journal of Food Policy*, 24(4): 411 – 429

Mbwana, H. A., Kinabo, J., Lambert, C., & Biesalski, H. K. (2016). Determinants of household dietary practises in rural Tanzania: Implications for nutrition interventions. *Cogent Food & Agriculture*, *2*(1), 1224046

Mendelsohn, R. (ed.) (2001), Global Warming and the American Economy: A Regional Assessment of Climate Change, Cheltenham: Edward Elgar Publishing

Mkonda, M. Y., & He, X. Conservation agriculture in Tanzania. *Sustainable agriculture reviews*. (pp. 309-324). Switzerland. Springer International Publishing.

Mugabe PA. (2019). Assessment of information on successful climate-smart agricultural practices/innovations in Tanzania. In: Leal Filho W. (eds) Handbook of Climate Change Resilience. Springer, Cham

Mutenje, M., Kankwamba, H., Mangisonib, J., & Kassie, M. (2016). Agricultural innovations and food security in Malawi: Gender dynamics, institutions and market implications. *Technological Forecasting and Social Change*, *103*, 240-248.

Mwabu, G., Mwangi, W., & Nyangito, H. (2006, August). Does adoption of improved maize varieties reduce poverty? Evidence from Kenya. In *International Association of Agricultural Economists Conference, Gold Coast, Australia* (pp. 12-18).

Namwata B.M.L, Lwelamira J, Mzirai O.B. (2010). Adoption of Improved Agricultural Technologies for Irish potatoes (Solanum tuberosum) among Farmers in Mbeya Rural District, Tanzania: A Case of IIungu Ward. *J. Anim. Plant Sci*. 8(1):927-935.

Ndobo, F.P., (2013). Determining the food security status in a South African township. Available from http://dspace.nwu.nwu.ac.za/bitstream/handle/10621/Ndobo FP. (Accessed 10/6/2019].

Nwaru, J. C., & Onuoha, R. E. (2010). Credit use and technical change in smallholder food crop production in Imo State of Nigeria. *New York Science Journal*, *3*(11), 144-151.

Odoemenem, I. U., & Obinne, C. P. O. (2010). Assessing the factors influencing the utilization of improved cereal crop production practises by small-scale farmers in Nigeria. *Indian Journal of Science and technology*, *3*(1), 180-183.

Ogada, M. J., Mwabu, G., & Muchai, D. (2014). Farm technology adoption in Kenya: a simultaneous estimation of inorganic fertilizer and improved maize variety adoption decisions. *Agricultural and food economics*, *2*(1), 12.

Otitoju, M. A. (2008). Determinants of technical efficiency in small and medium-scale soybean production in Benue State, Nigeria. Unpublished M. Sc dissertation submitted to the Dept. of Agricultural Economics, University of Nigeria, Nsukka.

Otitoju, M. A., & Arene, C. J. (2010). Constraints and determinants of technical efficiency in medium-scale soybean production in Benue State, Nigeria. *African journal of agricultural research*, *5*(17), 2276-2280.

Ouma, J O, Hugo de Groote and George O. (2006). "Determinants of Improved Maize Seed and Fertilizer Use in Kenya: Policy Implications." Paper presented at the 2006 Annual Meeting of the International Association of Agricultural Economists, Queensland, Australia, August 12-18, 2006

Page, S. J., & Connell, J. (2020). *Tourism: A modern synthesis*. (5th Edition) Routledge.

Pittelkow, C. M., Linquist, B. A., Lundy, M. E., Liang, X., van Groenigen, K. J., Lee, J., van Kessel, C. (2015). When does no-till yield more? A global meta-analysis. *Field Crops Research*, 183, 156–168.

Ranganathan, D. S., & Selvaseelan, D. A. (1997). Mushroom spent rice straw compost and composted coir pith as organic manures for rice. *Journal of the Indian Society of Soil Science*, *45*(3), 510-514.

Sharma, A. R., & Mitra, B. N. (1990). Complementary effect of organic material in rice-wheat crop sequence. *The Indian Journal of Agricultural Sciences*, *60*(3), 163-168.

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *44*, 272-284.

Shirsath, P. B., Aggarwal, P. K., Thornton, P. K., & Dunnett, A. (2017). Prioritizing climate-smart agricultural land use options at a regional scale. *Agricultural Systems*, 151, 174–183.

Sibhatu, K.T., Krishna, V.V., Qaim, M., (2015). Farm Production Diversity and Dietary Diversity in Developing Countries. PNAS 112, 10657–10662

Sileshi, M., Kadigi, R., Mutabazi, K., & Sieber, S. (2019). Impact of soil and water conservation practises on household vulnerability to food insecurity in eastern Ethiopia: endogenous switching regression and propensity score matching approach. *Food Security*, *11*(4), 797-815.

Singh, I., Squire, L., & Strauss, J. (1986)., (eds). Agricultural Household Models: Extensions, Applications and Policy. Baltimore: Johns Hopkins University. Press.

Tambo, A.J. & Wünscher, T. (2014). More than adopters: the welfare impacts of farmer innovation in rural Ghana. Selected Paper prepared for presentation at the Agricultural & Applied Economics Association’s 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29.

Taneja, G., Barun, P. D., Pramod, K. J., & Aggarwal, P. K., & Tyagi, N., K., (2014) Farmers‟ Preferences for Climate-Smart Agriculture: An Assessment in the Indo-Gangetic Plain. IFPRI Discussion Paper (1337). International Food Policy Research Institute, Washington, D.C., USA

Tanzania Food and Nutrition Centre (2014). Tanzania National Nutrition Survey 2014. Dar es Salaam, Tanzania. Available at https://www.unicef.org/esaro/

Tanzania_National_Nutrition_Survey_2014_Final_Report_18012015.pdf. (Accessed January 2017)

Teklewold, H., Kassie, M., & Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practises in rural Ethiopia. *Journal of agricultural economics*, *64*(3), 597-623.

Tenge, A. J., De Graaff, J., & Hella, J. P. (2004). Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands, Tanzania. Land Degradation & Development, 15(2), 99-114.

Tessema, Y. M., Asafu-Adjaye, J., Kassie, M., & Mallawaarachchi, T. (2016). Do neighbours matter in technology adoption? The case of conservation tillage in northwest Ethiopia. African *Journal of Agricultural and Resource Economics*, 11(311-2016-5659), 211-225.

Thornton, Philip K., Peter G. Jones, Gopal Alagarswamy, Jeff Andresen, and Mario Herrero. "Adapting to climate change: agricultural system and household impacts in East Africa.*Agricultural systems*, 103 (2) 73-82.

Tiberti, L., & Tiberti, M. (2015). Rural policies, price change and poverty in Tanzania: An agricultural household model-based assessment. *Journal of African Economies*, 24(2), 193–229.

Tran, N. L. D., Rañola, R. F., Sander, B. O., Reiner, W., Nguyen, D. T., & Nong, N. K. N. (2019). Determinants of adoption of climate-smart agriculture practises in rice production in Vietnam. *International Journal of Climate Change Strategies and Management*.

United Republic of Tanzania (URT), (2015). Tanzania Climate-Smart Agriculture Program. Dar es salaam.

Weersink, A., Nicholson, C., & Weerhewa, J. (1998). Multiple job holdings among dairy farm families in New York and Ontario. *Agricultural Economics*, *18*(2), 127-143.

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). Effect of climate-smart agricultural practises on household food security in smallholder production systems: micro-level evidence from Kenya. *Agriculture & Food Security*, *7*(1), 80.

Wooldridge, J., (2010), Econometric Analysis of Cross Section and Panel Data, MIT Press, Cambridge, MA.

Wu, J., & Babcock, B. A. (1998). The choice of tillage, rotation, and soil testing practises: Economic and environmental implications. *American Journal of Agricultural Economics*, *80*(3), 494-511.

Zougmoré, R., Partey, S., Ouédraogo, M., Omitoyin, B., Thomas, T., Ayantunde, A., and Jalloh, A. (2016). Toward climate-smart agriculture in West Africa: a review of climate change impacts, adaptation strategies and policy developments for the livestock, fishery and crop production sectors. *Agriculture & Food Security*, *5*(1), 26.

CHAPTER SIX

UNDERSTANDING THE IMPACT OF CLIMATE SMART IRRIGATION ON HOUSEHOLD FOOD SECURITY: A COUNTERFACTUAL ANALYSIS OF SOUTHERN HIGHLAND ZONE OF TANZANIA

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Abstract

The object of this study was to examine the impact of using irrigation as a climate-smart agriculture practises (CSA-practises) on household food security in Mbeya and Songwe Regions in Tanzania. The endogenous switching regression model was applied to control for the self-select bias problem. A cross-sectional study design was applied to collect information from a sample of 1443 farming households in Mbeya and Songwe Regions in Tanzania. The objective of the study was to evaluate the impact of irrigation as CSA-practise on household food security. The study found that radio ownership, education of the household head, farm experience, production diversity and livestock ownership were the determinants of using irrigation in the study area. Additionally, the average treatment effect of the treated (ATT) and the average treatment effect of untreated (ATU) were positive and highly significant for both irrigator and non-irrigator farming households. This implies that the use of irrigation as a CSA-practise has a positive impact on household food security. The study recommended policymakers to consider rehabilitating the existing irrigation schemes and constructing new schemes to widen the impacts of irrigation to household food security. However, despite the positive impact of irrigation, the study recommended the use of other irrigation practises such as drip irrigation, sprinkler irrigation in the areas where construction of small-scale irrigation is not possible. The study used cross-sectional data which has some limitations. Therefore, the use of panel data in future studies may give results that are more robust.

Keywords: Food security, Impact, Irrigation, Climate change

6.1 Background of the Study

In the last few decades, global communities have been working hard to reduce food insecurity and poverty challenges (FAO, 2017). Despite the global increase in food crop production but 821 million people worldwide were found food insecure in 2018 and their livelihood depend on agriculture (FAO, 2019; Capone *et al.,* 2014). It is reported that the climate change can threaten food production, food accessibility, food utilization and food price stability if the local temperature increases by 2°C or above (Ochieng, 2018, FAO, 2014; IPCC, 2014). In addition, it is projected that in arid and semi-arid countries, if the temperatures rise by 1%, the irrigation demand is likely to increase by 10 % (IFAD, 2007).

Farming households which are more vulnerable to climate change are those from tropic and semi-tropic regions, because they have fewer adaptation strategies, compared to the temperate regions (Brown & Funk, 2008). Apart from the problem of climate change, tropic and semi-tropic regions are facing challenges on soil infertility, increased soil degradation and increasing population, which cause food insecurity (Oldeman *et al.* 1990; Godfray *et al.* 2010). Likewise, the climate change impacts on agricultural production and food supply are controlled by the climate-induced soil degradation, drought and heat stress at the flowering stage, while the extraordinary seasonal heat can worsen future food security (Miao *et al.,* 2011).

In Tanzania, the frequency of dry spell and rising in temperature is likely to increase and the country is one of the thirteen countries worldwide, affected by the climate change (Nyasimi *et al.,* 2014). The annual temperature has increased by 1.0^{0}C, while the annual rainfall has decreased by 2.8 mm per month per decade since the early 1960s (Chambura and Macgregor, 2009). In addition, the forecasts of climate change designate that the mean daily temperatures will increase 3 to 5°C and by the year 2050, the mean annual temperature is predicted to increase by 2 to 4°C (Chambura and Macgregor, 2009). The increase in temperature is expected to increase drought, especially in the dry seasons, resulting to evapotranspiration, hence depletion of plant-available soil moisture (Zeleke and Aberra, 2014).

The climate change and variability are predicted to affect agriculture productivity and household food security, especially to developing countries, Tanzania inclusive (Nyasimi *et al.,* 2017). Food and Agricultural Organization (FAO) defined food security as ‘‘situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, 2010a). FAO explained that, to overcome the effect of climate change on agriculture, using CSA-practises can help farming households to improve agricultural productivity and ultimately resulting in higher household food security (FAO, 2010a). Some of CSA-practises involved water management improvement through use of small scale irrigation, use of drought-tolerant seeds, use of conservation agriculture among others (Mango *et al.,* 2018).

The use of CSA-practises that will enable farming households to increase farm productivity, achieve climate resilience, improve food security, nutrition, and income and achieve other developmental goals is therefore key (FAO, 2010a). According to Lipper *et al.* (2014), CSA may be defined as an approach for transforming and reorienting agricultural development under the new realities of climate change. Food and Agriculture Organization (FAO) provided a commonly used definition which defines “CSA as agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes greenhouse gases (mitigation) where possible, and enhances achievement of national food security and development goals”.

In this definition, the principal goal of CSA is identified as food security and development while productivity, adaptation, and mitigation are identified as the three interlinked pillars necessary for achieving this goal (FAO, 2010b). This study examined the determinants of using irrigation, one of CSA-practises and its implication on farming households in Southern Highlands of Mbeya and Songwe in Tanzania. Woldeab (2003), defined "irrigation as an artificial application of water to soil for the purpose of supplying the moisture essential in the plant root zone to prevent stress that may case reduced yield or poor quality of harvest crops".

In Tanzania, the agriculture sector continues to be driven by rain-fed practises, resulting in low agricultural productivity and food security problems (URT, 2010). Available data show that, the suitable land for agriculture production is about 44 million hectares of which about 29.4 million hectares are potential for irrigation agriculture (URT, 2012). Among the land potential land for irrigation about 2.3 million hectares are characterized as high potential, 4.8 million hectares as medium potential while 22.3 million hectares are characterized as low potential; however, only 1.6 % of the potential land have been developed for irrigation agriculture (URT, 2012). To improve irrigation agriculture in the country , a three-year strategic plan have been developed, aiming at increasing the area under irrigation from 111,000 hectare to 572,326 hectare by the year 2018 (Mwongera *et al.*, 2017). This could decrease the effectof climate change through increased agriculture productivity and income; hence, improve food security at household level and at the nation level. The expansion of irrigable land is vital, as agriculture is the main source of livelihood. Agriculture contributes to about 25 % of Gross Domestic Product, 30 per cent of export earnings and about 75 % of labour force comes from agriculture sector (URT, 2016).

The government of Tanzania has been working hard to improve the potential area for irrigation, but food security prevalence is still high, with statistics showing 34.7 % of children below five years are stunted (short of their age), 14 % are underweight (thin for their age) and 5 % are wasted (thin for their weight) (TFNC, 2014). In 2017, the country ranked the 95th out of 113 countries in the Global Food Security Index, indicating overall slow progress towards achieving food security target (EIU, 2017). It is reported that 8.3 per cent of all households in Tanzania were classified as having Poor Dietary Intake (PDI) in 2011 (WFP, 2011). Furthermore, Mbeya and Songwe regions are among the top five regions with a high supply of food with good number of irrigation infrastructures, such as Madibira, Kongolo Mswisi, Njalalila, Kapunga irrigation schemes, just to mention a few. However, statistics from TNFC showed that food insecurity is high in these regions. For example, in 2016 household dietary diversity score (HDDS) and children dietary diversity score were 6.18 and 1.74 respectively (Ochieng *et al.*, 2017). In addition, 37.7 per cent of children aged 0-59 months are stunted, the figure being higher than that of the national level of 34.7 % (TFNC, 2014).

There are several literatures on the usage and impact of irrigation practise, but the majority of these literatures have evaluated the impact of using irrigation practise on aggregate welfare measures (Mnyenyelwa, 2008; Lipton *et al.* 2003; Magrini and Vigani (2016); Maestre *et al.* 2017). However, studies that evaluated the impact of irrigation practise on the household food security are scarce, especial in the Southern Highlands of Mbeya and Songwe regions in Tanzania (i.e. Hagos *et al.* (2017) Bacha *et al.,* 2011; Tesfaye, *et al.*, 2008). The scarcity is even worse when analysing the use of irrigation practise on household food security by controlling both observed and unobserved characteristics. This is because many studies did not control sample selection biases in their evaluations.

According to Di Falco *et al.* (2011), sample selection bias can arise due to systematic differences in unobserved characteristics between farming households participating in irrigation and non-participating farming households. For example, highly motivated farming households are likely to participate in irrigation agriculture and probably they can be more food secure through having higher food variety score per adult equivalent unit compared to farming households which are less motivated.

Therefore, if the selection bias caused by unobservable characteristics is not controlled, it may result into overstated or understated estimates of the impact of using irrigation practise on household food security (i.e. Food Variety Score per Adult equivalent Unit (FVS/AEU). Therefore, this knowledge gap is filled by this study by valuating the impact of using irrigation practise on food security of the farming households using endogenous switching regression models. This model is suitable for this study as it controls both observables and unobserved characteristics.

This study can improve the available information regarding the topic and helps to conduct further interventions in the area of study. The findings of this study can also be used in guiding policymakers and development planners, who are concerned about irrigation development for household food security. Moreover, the research findings could be used as an input for researchers to further knowledge generation in concepts related to irrigation development and food security. This study explores the potential for irrigation practise as CSA-practises to impact household food security in Tanzania.

6.2 Literature Review

6.2.1 The concept of irrigation

Rainfall dependence agriculture under the climate change and variability led to low crop productivity, household food insecurity (Brown and Funk 2008). The use of irrigation as a CSA-practise was considered by this study as the appropriate practise, especially during the dry seasons and areas with unreliable rainfall (Kamwamba-Mtethiwa *et al.,* 2016). This practise is vital in increasing agriculture productivity/income, improves adptation to climate change and improves household food security and national developmental goals (Mango *et al.,* 2018; Akrofi *et al.,* 2019).

Previous studies have revealed that, climate change will lead to changes in yield and area growth, with overall lower yield growth (Brown and Funk 2008). This will lead to larger expansion, higher food prices which will result into lower affordability of food, reduced calorie availability, and growing childhood under nutrition in Africa south of the Sahara. Irrigation is a particularly robust climate smart agricultural (CSA) practise practise in the semi-arid and arid areas of SSA and is often essential to the deployment of any other CSA-practises (Akrofi *et al.*, 2019).

6.2.2 The concept of food security

Different pieces of literature have defined the term food security since the 1960s and 1970s, and the definition has been changed periodically ending up with 200 definitions including about 450 indicators (Hoddinott, 1999). FAO (2010a) food security is defined as a ‘‘situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life’’ According to Capone *et al*, (2014) food security has four pillars which includes, food availability, food accessibility, food affordability and food stability. Food availability is about the availability of food which can be obtained through agricultural production, exchange and distribution. Food accessibility is referred to as the appropriate methods of obtaining food which can be influenced by affordability, allocation and consumer preference while food utilization is considered as the proper way of food consumption through consideration of requirements of human nutrition (Capone *et al*,. 2014).

6.2.3 Linkages among irrigation and household food security

According to Domènech (2015), irrigation agriculture is vital in improving agriculture productivity and livelihood of the people, both at household and at the national level. The food availability, access, utilization, and stability are considered as pillars of food security are likely to change as a result of increased water availability for crop production and other uses. Nonvide (2017) argued that the use of irrigation has a direct effect on food availability as it leads to increased agriculture productivity and changes in cropping patterns. Staatz, *et al.* (2009) revealed that through irrigation, there is a possibility of increasing the food supply as the main role of irrigation is to enhance water control; therefore, reducing potentially hostile impacts on production from little rain. Furthermore, irrigation agriculture is important as it can increase food amount to the household through multiple crop cultivated because of the access to irrigation water and the household can purchase more food, which they cannot produce on their own. In addition, the income obtained from the sales of the irrigated crops can improve household food security (Domènech, 2015).

6.2.4 Theoretical framework

In this study, it is emphasized that farming household which used irrigation practise were self-selected themselves into irrigation. Therefore, it is difficult to compare the Food

Variety Score per Adult Equivalent Unit (FVS/AEU) as a food security indicator and outcome variable for the farming household who use irrigation and non-users because of selection bias which can be caused by observed and unobserved characteristics of the farming households (Di Falco *et al.,* 2011). This section explains the theory and methods used to carry out a counterfactual analysis so as to control for the self-select bias. The counterfactual analysis is used to estimate the outcome variable (i.e. FVS/AEU) if a farming household would not use irrigation.

The usage of a certain practise is a function of the benefits obtained from that particular pracise and that benefit can either improving the outcome or in the utility of the users (Di Falco *et al.*, 2011). Therefore, the usage decision of the farming household in irrigated farming is grounded on the utility difference they obtain between the usage of irrigation and not using irrigation. Therefore, the expected utility theory is the appropriate theory in this particular study.

Based on this study, using irrigation or not depends on the expected utility of using and not to use irrigation in crop production. Farming households can use irrigation practise if the expected utility of using the practise if higher than the expected utility of not using (Debertin, 2012).

Then, if the expected utility from using irrigation practice is lower than the expected utility from not using, then the decision of the farming household will be non-user of irrigation. The utility is assumed to depend on household food security (i.e. FVS/AEU), but also can be a function of characteristics of the household, plot characteristics and institutional factors which might affect food security of the household (Di Falco *et al.*, 2011).

The objective of any producer (i.e. farming household) is to maximize profit, subject to production constraints, but profit obtained from production can purchase goods and services that maximise the utility of the producer (Debertin, 2012). The expected utility theory based on production choice was used as a theoretical basis for the usage decision of the farming household in irrigation comparing to the utility of non-user (status quo) with usage (the new state). In this study, the utility for the status quo is denoted as follows:

$$U_{0j} = u(Y_j, Z_j, q^0 \varepsilon_{0j}) \quad \text{...(1)}$$

The utility for the new state is denoted as:

$$U_{1j} = u(Y_j, Z_j, q^1 \varepsilon_{1j}) \quad \text{...(2)}$$

In this model, the farming household j can use irrigation practise if the utility of using the irrigation practise exceeds utility of not using.

$$U_1(Y_j, Z_j, q^1 \varepsilon_{1j}) > U_0(Y_j, Z_j, q^0 \varepsilon_{0j}) \quad \text{..(3)}$$

U_0 indicates the utility function of the farm households without irrigation (status quo), U_1 indicates the farming households which irrigate, Y stands for food security indicator (FVS/AEU), q^0 and q^1 represents the levels alternative of good indexes for farming households with and without irrigation practise respectively. If $q^1 > q^0$, then q^1 refers to improved food security of the farming household after using irrigation practise. Z_j denotes a vector of exogenous variables.

Assuming the farming households can maximise utility, the decision by farming household j to use irrigation practise ($Irrigation = 1$) or not using ($Irrigation = 0$) is grounded through a comparison of expected utilities of both situations. The difference in the expected utilities can be expressed by the following decision rule:

$$Irrigation = \begin{cases} 1, ifE\left[U_j^1 - U_j^0 \middle| Z_j\right] > 0 \\ 0, ifE\left[U_j^1 - U_j^0 \middle| Z_j\right] \leq 0 \end{cases} \quad \ldots\ldots(4)$$

Here, E denote the expectation operator. Farming households have different characteristics, therefore they also differ in their expected utility levels of both choices. The vector Z_j stands for variables with an effect on the utilities of both choices and how expectations are formed on these utilities.

6.2.5 Empirical studies on impact of irrigation

Previous studies have shown mixed results of the impact of irrigation as a CSA-practise on farming households' welfare. The study conducted by Mnyenyelwa (2008) found that farming households that used traditional irrigation scheme in Same District in Kilimanjaro Tanzania had high crop productivity, and they had higher production diversity compared to non-irrigators. Haji *et al.,* (2013) used matching technique to measure the impact of Mede Telilasmall-scale irrigation scheme on household poverty. The study found that the use of irrigation as a CSA- practise reduce the depth incidence and severity of the household poverty in Ethiopia.

The study by Fan *et al.* (2000) found the use of irrigation farming for food crop production has shown impact on agriculture productivity and even less on the rural household poverty. Mango *et al*, (2018) show that the usage of irrigation practise has positive impact on household income.

Pender *et al.* (2002), argue that benefit obtained from modern irrigation to date have been relatively small. Likewise, Jin *et al.* (2002) and Rosegrant and Evenson (1992) found no linkage between irrigation, agricultural productivity and poverty reduction in Asia, in general, and in China and India in particular. Gebregziabher *et al.,* (2008) found that the income of non-irrigators is less than that of the irrigator households by about 50%. The income gain due to access to irrigation ranges from 4000 Birr to 4500 Birr per household per annum.

Hagos *et al.* (2017) employed mean difference to test for the use of irrigation practise on household nutrition status in Ethiopia. The result showed that use of irrigation did not have significant impact on household nutritional status. Similar results was found by Shively and Hao (2012), who found a non-significant effect of using irrigation practises on household food security. In Tanzania and Ethiopia, the study conducted by Passarelli *et al*. (2018), found that the use of irrigation to better household dietary diversity was mainly through the pathway of increasing household incomes in Ethiopia but not in Tanzania.

Another study conducted by Hagos *et al.* (2009) also indicated that irrigation in Ethiopia increased yields per hectare, income, consumption and food security. The study conducted by Tesfaye *et al.* (2006) in eastern. Shoa using Heckman two stage analyses revealed that those households with access to irrigation are at better position in securing enough food than their counterparts.

Mudima (2002) evaluated the impact of five irrigation schemes on the household welfare in Tanzania. The study found that the use of irrigation practise improve the food security at the community level compared to the communities without irrigation. Similar results was found in the study by Passarelli *et al*, (2018) which evaluated the pathways from small-scale irrigation to household incomes in Tanzania and Ethiopia.

Tedros (2014) evaluated the impact of irrigation practise also studied food security and economic impact of irrigated agriculture in Gum-selasa and Shilena Irrigation Scheme, Hintalowejerat, South-Estern Zone of Tigray, Ethiopia. The study found a positive impact of the use of irrigation practise on food security in all schemes. The study by Shiferaw and Mengistu (2015 use PSM to evaluate the impact of irrigation practises and found a positive impact on household income and poverty reduction.

Woldegebrial *et al.* (2015) also used PSM and reported the impact of irrigation practice usage on household income, expenditure and accumulation of assets. The study found a positive impact for the outcome variable in question. Dillon (2011) used a combination of PSM and Difference-in-Difference to evaluate the impact of irrigation practise use in Northern Mali. The study found a significant increase of total household consumption and agricultural productivity.

The main weakness in previous studies is that lack appropriate impact evaluation methods that can deal with the self-selection issue as use and no-users of the practises in question were not random (Kuwornu and Owusu (2012). This can underestimate or overestimate the impacts of irrigation on household welfare, such as food security. To correct this bias. Therefore, this study employed the endogenous switching regression model to correct for the problem of observed and unobserved characteristics in which other evaluation methods such PSM cannot do due to its ability to control only observed characteristics.

6.2.6 The conceptual framework

This section gives a brief explanation of the conceptual framework of this study. Climate change is one of the major challenges in developing countries as its impact affect agriculture development and food security. The impact of climate change could be reduced if the majority of farmers use irrigation as one of CSA-practises (FAO, 2010b).

However, irrigation has both biophysical as well as socio-economic requirements, and similarly, each household has specific biophysical and socio-economic characteristics. The study hypothesized that the usage of irrigation as a CSA-practise has a positive impact on household food security Mbeya and Songwe Regions in the Southern Highlands of Tanzania. Following Saleth *et al.* (2003), it is imperative to illustrate the linkages between irrigation and household's food security.

There are a chain of variables which influences the farming households to use irrigation as a CSA- practise. These are such as the age of the head of the household, age of the spouse, gender of the head of the household, marital status of the head of the household, education of the head of the household, household size, farm experience, own a television, own a radio, own a mobile phone, livestock ownership (TLU), production diversity, number of group membership. The usage of irrigation could result in an increase in agricultural productivity and income, ultimately resulting in higher household food security. The increase in productivity is assumed to be caused by the reduction of production uncertainty caused by climate change (i.e. drought and unreliable rainfall) and other constraints as a result of the use of irrigation. Therefore, the difference in production and food security between irrigators and no-irrigator farming households are assumed to be observed even if there is no difference in other factors of production such as input use.

However, in a household decision on either to use irrigation or not to use might be affected by both observed or unobserved characteristics which might be correlated with the outcome variable in which for the case of this study the outcome variable is food variety score per adult equivalent unit (Kassie *et al.*, 2015). In order to separate the impact of usage and to effectively analyse the factors influencing the usage of irrigation practise and the impact, the study employed endogenous switching regression. This approach has the advantage of evaluating the impact of irrigation practise on food security by controlling both observed and unobserved characteristics and come up with unbiased and consistent estimates (Di Falco *et al.*, 2011).

6.3 Methodology of the Study

In the impacts evaluation studies, a methodological problem that is frequently observed is the tendency to assume observed household food security difference between irrigator and no-irrigator farming households (Gebrehiwot *et al.,* 2017). Comparing the impact of irrigation on food security or any other outcome variables by considering the same person before and after access to irrigation cannot explain the impacts due to the presence of other factors which might confound the irrigation impact (Gebrehiwot *et al.,* 2017). Several quantitative categorized into experimental and non-experimental are used as an evaluation method in which they differ in construction of counterfactual (Omotilewa and Ricker-Gilbert, 2019).

In experimental methods, the counterfactual is constructed through by randomly assigning the treatment group and control group randomly. It is assumed that the treatment and the control group before the treatment are identical, but after the treatment, differences in the treatment and control groups are because of the treatment (Gertler *et al.,* 2016). This is called a randomized control trial (RCT). The RCTs are considered as the best method among impact evaluation methods as it cannot use complex econometric methods, easy to manage but the method cannot be used to all projects; it is expensive as it needs a large sample and is time-consuming compared to quasi-experimental methods. (Omotilewa and Ricker-Gilbert, 2019).

Non-experimental methods such as propensity score methods, derive the counterfactual using complex econometric methods but they are not time-consuming in data collection, hence not expensive as RCTs (Gertler *et al.,* 2016). In the present analysis, the non-experiment method called endogenous switching regression method was employed. It has the advantage of controlling both observed and unobserved heterogeneity compared to propensity score matching, which controls only observed heterogeneity, hence biased and inconsistent impact estimates.

6.3.1 Methods of analysis of the study

The expected utility theory was used in this study. Through this theory, it is assumed that farm households in the study area use irrigation practise if the expected utility of using irrigation is greater than not using the irrigation practise. In case of this study farming household is expected to use irrigation practise if the food variet score per adult equivalent unity is higher compared to the non-user of irrigation. To control for the self-select bias between users and non-user of irrigation practises an endogenous switching regression model was employed in this study.. The endogenous switching model involves separate estimations for subgroups of irrigators and non-irrigator farm households. The irrigation usage function is defined as:

$$D_i = \delta Z_i + \mu_i \quad \ldots\ldots(5)$$

with $i=1$for irrigators and 0 for non-irrigator farm households, $Z_i$stands for vector of households, farm and institution characteristics influencing the decision to use irrigation.

Following Equation (5), the outcomes are observed for the two groups of farm households (Asfaw *et al*., 2012; Maddala, 1983):

$Regime\,1: Y_{1i} = \alpha_1 X_{1i} + v_{1i}$ for irrigator farm households ……………………..…(6)

$Regime\,2: Y_{2i} = \alpha_2 X_{2i} + v_{2i}$ for no-irrigator farm households……………………...(7)

$Y_i$stands for FVS/AEU while X_i are vectors exogenous variables affecting the FVS/AEU, and v_i is the residuals. There is a probability that some unobserved characteristics (motivation, managerial skills) that affect the probability of using irrigation could also affect the FVS/AEU. Therefore, the error term in Equation (5) and the error terms in the outcomes functions (6) and (7) may be correlated. This problem was solved by estimating equations 5 – 7 simultaneously where the Full Information Maximum Likelihood (FIML) was used. The "movestay" command in STATA was used as it provides consistent estimation of the endogenous switching model (Lokshin and Sajaia (2004).

The endogenous switching model was used to compare the expected FVS/AEU of the irrigators (a) with respect to the non-irrigator farm households (b), and to examine the expected FVS/AEU in the counterfactual cases (c) that the irrigators did not use irrigation, and (d) that the non-irrigator farm households did use (Asfaw *et al.*, 2012; Di Falco *et al.*, 2011). These explain differences in the FVS/AEU between the two groups and to provide possible responses to changes in irrigation policy. The conditional expectations for FVS/AEU in the cases (a), (b), (c), and (d) are reported in Table 6-1. Cases (a) and (b) indicate the actual expectations, while the counterfactual expected outcomes are shown in cases (c) and (*d* ¿. The effect of irrigation usage on irrigators is expressed by Equation (8).

It is the “treatment effect on the treated” (TT) which is the difference between cases (a) and (c) (Asfaw *et al.*, 2012).

$$TT = E(y_{1i}|D_i = 1) - E(y_{2i}|D_i = 1) \qquad (8)$$

Likewise, the difference between cases (d) and (b) is the treatment effect on the untreated (TU) for the non-irrigator farm houdeholds. This is expressed by equation (9) as:

$$TU = E(y_{1i}|D_i = 0) - E(y_{2i}|D_i = 0) \qquad (9)$$

In this study the treatment effects were different based on the heterogeneity effects. For example, the FVS/AEU for irrigators may be high or low compare to the non-irrigator farm households nevertheless they used irrigation but rather because of unobservable characteristics that affect the FVS/AEU. The base heterogeneity effect is expressed in Equation (10) as the difference between cases (a) and (d) for the group of irrigators (Asfaw *et al.*, 2012; Di Falco *et al.*, 2011):

$$BH_1 = E(y_{1i}|D_i = 1) - E(y_{1i}|D_i = 0) \qquad (10)$$

Equation 11 give the base heterogeneity effect of non-irrigator farm household as the difference between cases (c) and (b):

$$BH_2 = E(y_{2i}|D_i = 1) - E(y_{2i}|D_i = 0) \qquad (11)$$

In addition, the study examined whether the effect of the using irrigation practise is greater or smaller for irrigator or for non-irrigator farm households if they use. That is, the "transitional heterogeneity effect" calculated as:

$$TH = TT - TU \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Table 6 1: Average expected Food Variety Score per adult equivalent unit for irrigator and non-irrigator farm households

Sub-sample	Decision Stage		Treatments effect
	Use	Not to use	
Irrigation farming households	a) $E(y_{1i} \mid D_{1i}=1)$	(c) $E(y_{1i} \mid D_{1i}=1)$	TT
Rain fed farming households	d) $E(y_{1i} \mid D_{1i}=1)$	(b) $E(y_{1i} \mid D_{1i}=1)$	TU
Heterogeneity Effect	BH_1	BH_0	TH

Note: (a) and (b) are the observed expected score per adult equivalent unit. (c) and (d) are the counterfactual expected food variety score per adult equivalent unit.

$D_i=1$ if farming households used irrigation; $D_i=0$ if farm household did not use

y_{1i} : Food security if farming household use

y_{2i}: Food security if farming household did not use

TT: Effect of the treatment on the treated

TU: Effect of the treatment on the untreated

BH_i: Base heterogeneity effect for farming household that used $(i=1)$, and did not used ($i=1$)

$TH=(TT-TU)$: Transitional heterogeneity

6.3.2 Study areas, sampling, data and description of variables

The data used for this study are derived from a farm household survey in the Southern Highlands zone of Mbeya and Songwe Regions. The survey was conducted during the period of September –December 2017. The Sokoine University of Agriculture in collaboration with the Integrated Project to Improve Agriculture Productivity and Food Security in the Bread Basket area of Southern Highlands of Tanzania conducted this survey. The survey aimed to examine the key factors influencing the usage of irrigation practises, and evaluate its impact on household food security. The sample covers a total of 1443 farm households. A multistage sampling was employed to select farmer organisations (FOs) from each district, and households from each FO. First, selection was based on their food production potential crops (maize, paddy, common beans, and soya beans), whereby four districts were selected purposively from two regions of the Southern Highlands of Tanzania (Mbeya and Songwe Regions). Second, 51 wards were randomly selected out of 92 wards. Third, FOs in each ward were identified then a proportionate sampling was used to select farm households from all FOs to get a total of 1443 households. In the collection of data a structured male and female questionnaires were used where open data kit (ODK) was used. The information collected includes household demographics, socioeconomic characteristics, use of irrigation, crop production and marketing, input use, food consumption, and other farm- and farmer-specific characteristics.

6.4 Results and Discussion

6.4.1 Descriptive statistics

A comparison of irrigator and non-irrigators households and individual characteristics (Table 6-2) shows significant differences in the populations of irrigators and non-irrigators, arguably in ways that would be expected. On average, the age of the head of the household found to be 50.61 and 50.39 years for irrigators and non-irrigator respectively. The non-irrigators are 0.27 years older than irrigators but not significant. This age profile means that the majorities of the household heads were people predominantly below midlife and could be regarded as potentially productive farmers with capacity to use climate smart agriculture practises such as irrigation practises to combat climate change impacts. From the statistical analysis performed, it is found that there was statistically insignificant mean difference between irrigators and non-irrigators.

Table 6-2 shows that FVS/AEU of irrigators was 0.2131/AEU and the average for the non-irrigators were 0.1944/AEU. This indicates that irrigators have higher FVS/AEU compared to non-irrigators and statistically significant at 10 %. The average production diversity of irrigators was found to be 2.4732 crops cultivated and the average for the non-irrigators was 2.9042 crops cultivated. This implies that irrigators are less diverse in crops they cultivate compared to non-irrigators. The findings revealed that the mean production diversity of the two groups was statistically significant at less than 1 % significant level with a difference of 0.40 number of crops cultivated. This might be caused by the fact that most of the irrigators cultivate mainly paddy and maize in their plots, for example in Madibila irrigation scheme the main crop cultivated is paddy. The mean livestock holding for user households was 1.2850 TLU and 1.8576 TLU for non-users. This implies that irrigators owned more livestock and the mean difference was statistically significant at 1% probability level.

The average household size between irrigators and non-irrigators were more or less seem with an average of 5.1845 and 5.4417 members for irrigator and non-irrigator. Household sizes were fairly where irrigators found to have a slightly higher average size for about 0.2572 members. The education level of the head of the household for irrigators was less by 0.3767 years of schooling and significant at 1 % significant level compared to non-irrigators.

On the other hand, farming experience between irrigators and non-irrigating households was statistically significant ($p<0.05$), where irrigators are 1.8614 more years of farming experience compared to non-irrigators. The result showed that there is no statistical difference in spouse age total plot size between irrigating households and non-irrigating households. The result also revealed that irrigators had on average more sources of income

(2.2917) than non-irrigators (2.1951) measured by number of income sources. However, the mean difference between the two groups with regard to income diversity was statistically insignificant.

Table 6 2: Descriptive statistics of variables for irrigators and non-irrigators

	Irrigators	Non-irrigators	Difference	t-test	Full sample
Outcome variables					
Food Variety Score per adult equivalent	0.2131	0.1944	0.0187	0.0564	0.2088
Covariates					
Age of the head of the household	50.335	50.607	-0.2720	0.7409	50.398
Age of the spouse	38.836	39.615	-0.7789	0.3684	39.434
Gender of the head of the household	0.7917	0.8663	-0.0746	0.0008	0.8489
Marital status of the head of the household	0.7560	0.8401	-0.0842	0.0005	0.8205
Education of the household head	6.4345	6.0578	-0.3767	0.0286	6.1455
Household size	5.1845	5.4417	-0.2572	0.0641	5.3818
Farm experience	20.613	22.502	-1.8892	0.0252	22.062
Own a television	0.3244	0.2285	0.0959	0.0004	0.2509
Own a radio	0.7262	0.6278	0.0984	0.0009	0.6507
Own a mobile phone	0.8988	0.8446	0.0416	0.0129	0.8572
Livestock ownership (TLU)	1.2850	1.8576	-0.5725	0.0035	1.7242
Production diversity	2.4732	2.9042	-0.4310	0.0000	2.8039
Number of group membership	0.8869	0.8988	-0.0119	0.5309	0.8960
Income diversity	2.2917	2.1951	0.0965	0.0199	2.2176

6.4.2 Factors affecting usage of irrigation

The results from endogenous switching regression model are presented in Table 6-3. Some variables such as distance to the farm and distance to the tarmacked road in the choice equation were excluded in the outcomes equations to meet the condition of model identification (Nonvide, 2017). The hypothesis was that these variables affect the probability of using irrigation but does not affect FVS/AEU as a food security indicator. The study found that the correlation coefficient (Rho_1) between the choice equations and outcome equation was positive and 5 % level of significant. This implies that the usage of irrigation decision is affected by observable and unobservable characteristics.

The endogenous switching model presents the results of both the usage and the outcomes. The results regarding choice model are only discussed briefly as the main objective to evaluate the impacts on household food security (i.e. FVS/AEU). Nevertheless, significant variables that explaining the decision to use irrigation practises were the radio ownership, education of the household head, farm experience, production diversity and livestock ownership. The significant determinants of the FVS/AEU in both irrigator and non-irrigator farm households were television ownership, mobile ownership, age of the head of the household and age of the spouse.

Gender of the head of the household, production diversity and ownership of radio were the other variables that contributed to the increase in FVS/AEU in irrigated farm households. In non-irrigator farm households, household size and households with more than one membership of farmer organisations significantly increased FVS/AEU. Farm households with radio or television were found to have higher FVS/AEU, indicating that they might be well informed on the good agronomic practises through the media. Information on both input and output markets may be also found through the media. Furthermore, ownership of a radio or television is also an indication of wealth; therefore, wealthier farming households can invest more in irrigation to increase yield hence more food secure.

6.4.3 Impact of irrigation on household food security

The expected FVS/AEU under the counterfactual analysis for irrigators and non-irrigator farm households are presented in Table 6-4. Cases (a) and (b) are the observed expected FVS/AEU which were 0.1962 for the irrigators and 0.0215 for the non-irrigator farming households. The study found that users of irrigation had significantly higher FVS/AEU with the difference being 0.1747 FVS/AEU; but, this cannot be attributed to the usage of irrigation practise alone. Table 6-4 also reports the treatments effects of irrigation usage.

In the counterfactual case (c), the FVS/AEU for irrigated households would have been 0.0336 less if they did not use irrigation. If the non-irrigator farm households had used irrigation (case (d¿¿, they would have 0.1916 FVS/AEU extra. The transitional heterogeneity effect is shown in the last column of Table 6-4 was negative ($TH=-0.158$), indicating that the impact of using irrigation practise was significantly smaller for the irrigators than the non-irrigator farmers. The FVS/AEU for non-irrigator farmers would be 0.158 FVS/AEU higher than the irrigators if they did use irrigation. The heterogeneity effect reveals that the non-irrigator farmers would have FVS/AEU less than the irrigators in the counterfactual case (c), while have more in case (d).

Table 6 3: Estimates of the impact of irrigation on food security

Variable Dependent Variable: FVS/AEU	Usage Model		Outcome Model			
			Irrigation Households		Rain-fed households	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Own a television	0.0962	0.0898	0.0242*	0.0127	0.0258**	0.0126
Own a radio	0.3047***	0.0868	0.0284**	0.0128	0.0053	0.0109
Own a mobile phone	0.2444**	0.1203	0.0431**	0.0176	0.0425***	0.0145
Education of the head of the household head	0.0309**	0.0155	0.0025	0.0022	0.0004	0.002
Household size	-0.0129	0.0183	-0.0028	0.0026	-0.008***	0.0024
Farm experience	-0.0071*	0.0038	-0.0004	0.0005	0.0004	0.0005
Age of the head of the household	0.0066	0.0047	-0.0013*	0.0007	-0.0031***	0.0006
Livestock ownership (TLU)	-0.0292**	0.0129	-0.0024	0.0018	0.0015	0.0016
Age of the spouse	0.0013	0.0039	-0.001*	0.0005	-0.0014***	0.0006
Sex of the head of the household	-0.155	0.1754	-0.0633**	0.0253	-0.037	0.0236
Marital status of the head of the household	-0.2413	0.1664	-0.015	0.0242	-0.0259	0.0222
Production diversity	-0.1715***	0.0358	-0.0136**	0.0055	0.0069	0.0045
Number of group membership	-0.0608	0.1227	-0.0148	0.0174	0.0322**	0.0164
Income diversity	0.0642	0.0586	0.006	0.0082	0.0031	0.008
Constant	-0.3288	0.0802	0.181	0.0506	0.4124	0.0426
Rho_1	1.9684**					
Rho_2	0.0275					

The study found a positive relationship between usage of irrigation practise and FVS/AEU, as it contribute to the increase of FVS/AEU by 0.0336. Enhancing the usage of irrigation practise is important in improving household food security and fighting against climate change. This is supported by studies from India that show that using irrigation practise is important in employment creation, that transforms into improved quality of life of the farming households (Tesfaye *et al.,* 2008). Furthermore, earlier findings by Abro *et al.,* (2014); Dillon (2011); Huang *et al.* (2006), Kemah and Thiruchelvam (2008) reported that, irrigation practises has positive impact on agricultural production as it play an important role in improving crop yield through reduced losses, multiple cropping, and land expansion.

Table 6 4: Impact of Irrigation on food security (Food variety score per adult equivalent unit)

Subsamples/Effects	Decision		Treatment effect
	To use	Not to use	
Irrigation farm households	(a) 0.1962	(c) 0.1626	TT = 0.0336 ***
Rain-fed farm household	(d) 0.2131	(b)0.0215	TU = 0.1916 ***
Heterogeneity	$BH_1=$¿-0.0169	$BH_2=$¿0.1411	TH = -0.158

6.5 Conclusion and Recommendation

The study employed the endogenous switching regression model to determine factors influenced usage of irrigation practises and evaluate the impact of using irrigation practises on household food security. The results indicated the presence of selection bias between irrigator and non-irrigator farming households as the correlation coefficient between the error terms of the choice and outcome equations were statistically significant. The result indicated that variables such as radio ownership, education of the head of the household, farm experience, livestock ownership and production diversity shown a significant impact on farming household's decision to irrigate. In addition, information variables such as television ownership, mobile ownership have a positive effect on FVS/AEU.

Membership of more than one organisation was also found to have a positive effect on FVS/AEU. Furthermore, the average treatment effect of the treated (ATT) and the average treatment effect of untreated (ATU) are positive and highly significant for irrigation users and non-users. This implies that the use of irrigation as a CSA-practise has resulted has a positive impact on household food security.
Several implications can be driven can be driven from the results of this study. The findings indicate that promoting irrigation farming as a CSA-practise for the usage by farming households should consider radio ownership, level of education of the head of the household, farm experience, livestock ownership and production diversity. Therefore, without consider these socio-economic aspects may lead to inappropriate results when aiming for higher rates of usage of irrigation farming as a CSA-practise.

Furthermore, the findings showed that farming households that joined into more than one farmer organisations have shown positive impact on food security. Therefore, the government should strengthen farmer organisations, such as Agricultural Marketing Cooperative Society (AMCOs), Madibira-AMCOS, Idimi-AMCOS and others. This will be beneficial for food crop farmers if they could be organised in these AMCOS for collective marketing. Encouraging farming households to join these cooperatives can assist farmers to get better prices. This can increase household income to purchase diverse food products which are not produced by the households, hence improve household food security.

Finally, the usage of irrigation has shown an impact on household food security and may have contributed to poverty reduction. Therefore, rehabilitating the existing irrigation schemes and constructing new small-scale irrigation schemes should be considered to widen the impacts. However, despite the positive impact of irrigation, the study recommends the use of other irrigation practises such as drip irrigation, sprinkler irrigation in the areas where construction of small-scale irrigation is not possible. Moreover, rained agriculture can be improved with other CSA-practises such as reduced tillage, crop residual retention and intercropping.

This study was vital as it makes a good contribution to the usage and impact of irrigation practises on farming households' food security but there are some limitations. The study relied on cross-sectional information, collected from farming households in the Southern Highlands of Mbeya and Songwe in Tanzania, which is associated with limitations. It is therefore likely the usage and impact of irrigation on household food security might be somewhat biased because of the cross-sectional nature. Therefore, the use of longitudinal data in the forthcoming studies might give results that are more robust.

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References

Abro, Z. A., Alemu, B. A., & Hanjra, M. A. (2014). Policies for agricultural productivity growth and poverty reduction in rural Ethiopia. *World development*, *59*, 461-474.

Akrofi, N. A., Sarpong, D. B., Somuah, H. A. S., & Osei-Owusu, Y. (2019). Paying for privately installed irrigation services in Northern Ghana: The case of the smallholder Bhungroo Irrigation Technology. *Agricultural water management*, *216*, 284-293.

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural practises on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food policy*, *37*(3), 283-295.

Bacha, D, Regasa N, Ayalneh B and Abonesh T, (2011), Impact of Small-Scale Irrigation on Household Poverty: Empirical Evidence from the Ambo District in Ethiopia, Irrigation and Drainage, 60: 1– 10.

Brown, M. E., & Funk, C. C. (2008). Climate: Food security under climate change. *Science*, Available from https://digitalcommons.unl.edu/nasapub [Accessed 13/10/2018]

Capone, R., El Bilali, H., Debs, P., Cardone, G., &Driouech, N. (2014). Food system sustainability and food security: connecting the dots. *Journal of Food Security*, *2*(1), 13-22.

Chambura, M., & Macgregor, J. (2009). Cultivating success: the need to climate-proof Tanzanian agriculture.

Debertin, D.L., (1986). Agricultural Production Economics. Macmillan, NY

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829-846.

Dillon, A. (2011). Do differences in the scale of irrigation projects generate different impacts on poverty and production?. *Journal of Agricultural Economics*, *62*(2), 474-492.

Domènech, L. (2015). Improving irrigation access to combat food insecurity and undernutrition: A review. *Global Food Security*, *6*, 24-33.

Fan, S., Hazell, P., & Thorat, S. K. (2000). Impact of public expenditure on poverty in rural India. *Economic and Political Weekly*, 3581-3588.

Fanadzo, M. (2012). Revitalisation of smallholder irrigation schemes for poverty alleviation and household food security in South Africa: A review. *African journal of agricultural research*, *7*(13), 1956-1969.

Food and Agriculture Organization of the United Nations (FAO), (2010a). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2010 Key messages. Available from http://www.fao.org [Accessed 13/10/2017]

Food and Agriculture Organization of the United Nations (FAO), (2014a). The state of food insecurity in the world. Available from http://www.fao.org [Accessed 14/1/2018]

Food and Agriculture Organization of the United Nations (FAO), (2017). The state of food insecurity in the world. Available from http://www.fao.org [Accessed 10/2/2018]

Food and Agriculture Organization of the United Nations (FAO), (2010b). "*Climate-Smart" Agriculture*. *the Hague Conference on Agriculture, Food Security and Climate Change*. Rome Italy. Available from http://www.fao.org [Accessed 10/8/2018]

Food and Agriculture Organization of the United Nations (FAO), (2014b). FAO success stories on climate-smart agriculture. Rome Italy. Available from http://www.fao.org [Accessed 10/8/2018]

Food and Agriculture Organization of the United Nations (FAO). (2019). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2019 Key messages. Available from http://www.ifpri.org/ [Accessed 29/1/2019].

Gebregziabher, G., & Namara, R. E. (2008). *Investment in irrigation as a poverty reduction strategy: Analysis of small-scale irrigation impact on poverty in Tigray, Ethiopia* (No. 614-2016-40936).

Gebrehiwot, K. G., Makina, D., & Woldu, T. (2017). The impact of micro-irrigation on households' welfare in the northern part of Ethiopia: an endogenous switching regression approach. *Studies in Agricultural Economics*, *119*(3), 160-167.

Gertler, P. J., Martinez, S., Premand, P., Rawlings, L. B., & Vermeersch, C. M. (2016). *Impact evaluation in practise*. The World Bank.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., et al. (2010). Food security: the challenge of feeding 9 billion people. Science, 327(5967), 812–818.

Hagos, F., Makombe, G., Namara, R. E., & Awulachew, S. B. (2009). *Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation* (Vol. 128). IWMI.

Hagos, F., Mulugeta, A., Erkossa, T., Langan, S., Lefore, N., & Abebe, Y. (2017). Poverty profiles and nutritional outcomes of using spate irrigation in Ethiopia. *Irrigation and Drainage*, *66*(4), 577-588.

Haji, J., Aman, M., & Hailu, T. (2013). Impact Analysis of Mede Telila small scale irrigation scheme on House Poverty Alleviation: Case of Gorogutu District in Eastern Haratghe Oromia National Regional State Ethiopia. *International Journal of Development and Economic Sustainability*, *1*(1), 15-30.

Hoddinott, J. (1999). *Choosing outcome indicators of household food security*. Washington, DC: International Food Policy Research Institute.

Huang, Z., & Karimanzira, T. (2018). Investigating Key Factors Influencing Farming Decisions Based on Soil Testing and Fertilizer Recommendation Facilities (STFRF)—A Case Study on Rural Bangladesh. *Sustainability*, *10*(11), 4331.

Hussain, I., & Hanjra, M. A. (2004). Irrigation and poverty alleviation: review of the empirical evidence. *Irrigation and drainage*, *53*(1), 1-15.

IFAD. 2007. International Fund for Agricultural Development Strategic Plan 2007-2010.

International Food Policy Research Institute (IFPRI). (2017). *Global Food Policy*. Washington, D.C.

IPCC (2014). Part A: Global and Sectoral Aspects. (Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate

Change). *Climate Change 2014: Impacts, Adaptation, and Vulnerability.*, 1132.

Jin, S., Huang, J., Hu, R., & Rozelle, S. (2002). The creation and spread of technology and total factor productivity in China's agriculture. *American Journal of Agricultural Economics*, *84*(4), 916-930.

Kamwamba-Mtethiwa, J., Weatherhead, K., & Knox, J. (2016). Assessing performance of small-scale pumped irrigation systems in sub-Saharan Africa: evidence from a systematic review. *Irrigation and Drainage*, *65*(3), 308-318.

Kassie, M., Ndiritu, S. W., & Stage, J. (2014). What determines gender inequality in household food security in Kenya? Application of exogenous switching treatment regression. *World Development*, *56*, 153-171.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practises in eastern and southern Africa. *Land Use Policy*, *42*, 400-411.

Kemah, T., & Thiruchelvam, S. (2008). An analysis of the effects of the scale of irrigation on paddy production in Anuradhapura district.

Kole, E. S. (2002, May). Connecting women from developing countries to the internet: searching for an appropriate paradigm. In *41st Annual Convention of the International Studies Association (14-17 March), at http://www. antenna. nl/~ waterman/kole. html, accessed* (Vol. 20).

Kuwornu, J. K., & Owusu, E. S. (2012). Irrigation access and per capita consumption expenditure in farm households: Evidence from Ghana. *Journal of Development and Agricultural Economics*, *4*(3), 78-92.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., ... & Hottle, R. (2014). Climate-smart agriculture for food security. *Nature climate change*, *4*(12), 1068-1072.

Lipton, M., J. Litchfield and J-M. Faures (2003), 'The Effects of Irrigation on Poverty: A Framework for Analysis', Water Policy, Vol. 5, No. 5-6, pp. 413–27.

Lokshin, M., & Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *The Stata Journal*, *4*(3), 282-289.

Maddala, G. S. (1991). A perspective on the use of limited-dependent and qualitative variables models in accounting research. *The Accounting Review*, *66*(4), 788-807.

Maestre, M., Poole, N., & Henson, S. (2017). Assessing food value chain pathways, linkages and impacts for better nutrition of vulnerable groups. *Food Policy*, *68*, 31-39.

Magrini, E., & Vigani, M. (2016). Technology adoption and the multiple dimensions of food security: the case of maize in Tanzania. *Food security*, *8*(4), 707-726.

Mango, N., Makate, C., Tamene, L., Mponela, P., & Ndengu, G. (2018). Adoption of Small-Scale Irrigation Farming as a Climate-Smart Agriculture Practise and Its Influence on Household Income in the Chinyanja Triangle, Southern Africa. *Land*, *7*(2), 49.

Mdemu, M. V., Mziray, N., Bjornlund, H., & Kashaigili, J. J. (2017). Barriers to and opportunities for improving productivity and profitability of the Kiwere and Magozi irrigation schemes in Tanzania. *International Journal of Water Resources Development*, *33*(5), 725-739.

Miao, C., Ni, J., Borthwick, A. G., & Yang, L. (2011). A preliminary estimate of human and natural contributions to the changes in water discharge and sediment load in the Yellow River. *Global and Planetary Change*, *76*(3-4), 196-205.

Mnyenyelwa, M.A (2008). Traditional irrigation systems and livelihoods of smallholder farmers in Same Distrct, Kilimanjaro, Tanzania. Dissertation for Award of

Msc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 112pp.

Mudima, K. (2002) Socioeconomic Impact of Smallholder Irrigation Development in Zimbabwe: A Case Study of Five Successful Irrigation Schemes. In Private Irrigation in Sub Saharan Africa; Sally, H., Abernethy, C.L., Eds.; IWMI: Colombo, Sri Lanka,.

Mwongera, C., Shikuku, K. M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., & Winowiecki, L. A. (2017). Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture practises. *Agricultural Systems*, *151*, 192-203.

Nonvide, G. M. A. (2017). Effect of adoption of irrigation on rice yield in the municipality of Malanville, Benin. *African Development Review*, *29*(S2), 109-120.

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., &Mungai, C. (2017). Adoption and Dissemination Pathways for Climate-Smart Agriculture Practises and Practises for Climate-Resilient Livelihoods in Lushoto, Northeast Tanzania. *Climate*, *5*(3), 63.

Ochieng, J., Afari-Sefa, V., Karanja, D., Kessy, R., Rajendran, S., &Samali, S. (2018). How promoting consumption of traditional African vegetables affects household nutrition security in Tanzania. *Renewable Agriculture and Food Systems*, *33*(2), 105-115.

Ochieng, J., Afari-Sefa, V., Lukumay, P. J., & Dubois, T. (2017). Determinants of dietary diversity and the potential role of men in improving household nutrition in Tanzania. *PloS one*, *12*(12)

Oldeman, L. R., Engelen, V. W. P., & Pulles, J. H. M. (1990). The extent of the status of human-induced soil degradation. Annex 5: world map of the status of human-induced soil degradation, an explanaotry note. Wageningen: UNEP-ISRIC.

Omotilewa, O., & Ricker-Gilbert, J. (2019). Impact Evaluation of Large-Scale Extension Activities on Agricultural Technology Adoption: Experimental vs. Non-Experimental Estimates

Passarelli, S., Mekonnen, D., Bryan, E., & Ringler, C. (2018). Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania. *Food Security*, *10*(4), 981-997.

Passarelli, S., Mekonnen, D., Bryan, E., & Ringler, C. (2018). Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania. *Food Security*, *10*(4), 981-997.

Pender, J., Jaggera, P., & Gebremedhinb, B. (2000). Agricultural change and land management in the highlands of Tigray: Causes and implications. *Policies for sustainable land management in the highlands of Ethiopia*, *24*.

Robins, J., Sued, M., Lei-Gomez, Q., & Rotnitzky, A. (2007). Comment: Performance of double-robust estimators when" inverse probability" weights are highly variable. *Statistical Science*, *22*(4), 544-559.

Rosegrant, M. W., & Evenson, R. E. (1992). Agricultural productivity and sources of growth in South Asia. *American Journal of Agricultural Economics*, *74*(3), 757-761.

Saleth, R. M., Namara, R. E., & Samad, M. (2003). Dynamics of irrigation-poverty linkages in rural India: Analytical framework and empirical analysis. *Water Policy*, *5*(5-6), 459-473.

Shiferaw, M. B., & Mengistu, A. D. (2015). Helminthiasis: hookworm infection remains a public health problem in Dera district, South Gondar, Ethiopia. *PLoS One*, *10*(12).

Shively, G., & Hao, J. (2012). A review of agriculture, food security and human nutrition issues in Uganda (No. 12–3). Department of Agricultural Economics. West Lafayette.

Staatz, J. M., Boughton, D. H., & Donovan, C. (2009). Food security in developing countries. *Critical Food Issues: Problems and State-of-the-Art Solutions Worldwide*, *157*.

Tedros, T. (2014). *Contribution of Small Holders' Irrigation to Households Income and Food Security: A Case Study of Gum-selasa and Shilena Irrigation Schemes, Hintalowejerat, South-Estern Zone of Tigray, Ethiopia* (Doctoral dissertation).

Tesfaye, A., Bogale, A., Namara, R. E., & Bacha, D. (2008). The impact of small-scale irrigation on household food security: The case of Filtino and Godino irrigation schemes in Ethiopia. *Irrigation and Drainage Systems*, *22*(2), 145-158.

TFNC. (2014). *Ministry of Health and Social Welfare Tanzania National Nutrition Survey 2014*. Dar es slaaam.

United Republic of Tanzania (URT). (2010). The National Strategy for Growth and Reduction of Poverty. Dar es Salaam: Ministry of Finance and Planning.

United Republic of Tanzania (URT). (2013). Agriculture national key result area. President's delivery bureau. Dar es Salaam.

United Republic of Tanzania. (2002). *National Water Policy*. Dar es Salaam: Ministry of Water and Livestock Development.

Urama, K. C. and I. Hodge (2004), 'Irrigation Externalities and Agricultural Sustainability in South-eastern Nigeria', Journal of Agricultural Economics, Vol. 55, No. 3, pp. 479–501.

URT (2016). Rapid Agriculture Need Assessment in Response to the El-Nino Effect.

URT, (2010). *Economic Survey 2009.* Dar es Salaam, Ministry of Finance and Economic Affairs.

URT, (2012). "Tanzania National Sample Census of Agriculture 2007/2008 Small Holder Agriculture: Regional Report - Singida Region (Volume Vm)," United Republic of Tanzania, Ministry of Agriculture, Food Security and Cooperatives, Ministry of Livestock Development and Fisheries, Ministry of Water and Irrigation, Ministry of Agriculture, Livestock and Environment, Zanzibar.

URT. (2017). A*nnual agriculture sample survey*. Government of printer, Dodoma, Tanzania. 88pp

Waterman, A. S. (2004). Finding someone to be: Studies on the role of intrinsic motivation in identity formation. *Identity*, *4*(3), 209-228.

WFP, (2015). The State of Food Insecurity in the World: Meeting the 2015 international hunger targets: Taking stock of uneven progress. *FAO, IFAD and WFP*.

Woldeab, T. (2003). Irrigation practises, State intervention and farmers' life world in drought prone Tigray, Ethiopia. A PhD thesis presented to university of Wageningen, the Netherlands. 249p.

Woldegebrial Zeweld, Guido Van Huylenbroeck, Assefa Hidgot, M. G. Chandrakanth and Stijn Speelman, 2015. Adoption of Small-Scale Irrigation and Its Livelihood Impacts in Northern Ethiopia.

Zeleke, M. T., & Aberra, Y. (2014). Determinants of the adoption of land management strategies against climate change in Northwest Ethiopia. *Ethiopian Renaissance Journal of Social Sciences and the Humanities*, *1*, 93-118.

CHAPTER SEVEN

SYNTHESIS

7. 1 Introduction

Climate change is a threat to food security systems and one of the biggest challenges, particularly in countries which depend on agriculture as a source of their livelihood (FAO, 2019; FAO, 2017). Agriculture systems need to produce more food in order to improve food security under the challenge of climate change and rapid population growth by 2050 (Harvey *et al.*, 2018). This is vital as statistics show that in 2018 still, 821 million people in the world were estimated to be chronically undernourished; an increase up from 815 million (FAO, 2019). Although, still a reduction from about 900 million in 2000 (FAO, 2015).

Climate change poses fears to food production and farm households' welfare, resulting in malnutrition, hunger, and persistent poverty in Tanzania, where Mbeya and Songwe regions are inclusive (Maliondo *et al.*, 2012). Climate smart agriculture practises have been viewed as a capable approach to guarantee food and livelihood security in the face of climate change (FAO, 2010a). The approach is imperative because of its potential benefits of enhancing productivity, improve adaptation to climate change and reduction or removal of greenhouse gases and (FAO, 2010b).

Despite the triple benefits of CSA-practises and the efforts made by the government and non-governmental organizations to promote usage of CSA-practises to farming households, still there is lack of evidence on farming households' determinants of usage of the CSA-practises and their implication on household food security (Malondo *et al* ., 2012; Tenge *at al*.,2004). Thus, knowing the determinants of CSA-practises, usage and its implications on food security of the household is imparative in informing the policy makers and other development partners as it enhances farming household usage of CSA-practises.

The study contributes to the understanding of the impact of usage of CSA-practises, either in isolation or in combination for household food security. The study investigated on whether the usage of CSA-practises in combination could improve food security than using these practises in isolation. This knowledge is relevant to the debate on whether farmers should use practises in piecemeal or in the package so as to improve household food security. Also, the study can be used in designing operative extension policy by recognising combination of practises that deliver the highest payoff. The study encompasses the empirical and methodological approach in the literature through implementing both parametric and non-parametric approaches to evaluate the impact of CSA-practises on food security while controlling the selection bias, both from observed and unobserved heterogeneity.

7. 2 Methodology

7.2.1 Sampling and data collection

The study used data collected from a farm household survey in the Southern Highlands Zone of Mbeya and Songwe in Tanzania. The Sokoine University of Agriculture in collaboration with the Integrated Project to Improve Agriculture Productivity and Food Security in the Bread Basket area of Southern Highlands of Tanzania conducted the survey during the period of September –December 2017 where a total of 1443 farm households participated. A multistage sampling was employed to select Farmer Organisations (FOs) from each district and households from each FO. First, based on their food production potential crops (maize, paddy, common beans, and soya beans), four districts were selected purposively from two regions of the Southern Highlands of Tanzania (Mbeya and Songwe Regions). Second, 51 wards were randomly selected out of 92 wards. Third, FOs in each ward were identified and a proportionate sampling was used to choice farming households from all FOs to get 1443 households. Data collection involved a household survey where structured male and frmale questionnaires were used where open data kit (ODK) was used. The survey collected information on household characteristics, plot characteristics, institutional characteristcs, different CSA-technologies used, crop production and marketing, and food consumption.

7.2.2 Estimation strategies

Chapter two provides a comprehensive understanding of the determinants of using multiple CSA-practises, whereby an analysis framework which combine a multivariate and ordered probit models were employed to analyse the decisions to use six CSA-practises that are mostly used. The multivariate probit model was found to be relevant to this analysis compared to univariate models as it considers possible complementarities and substitutability between the CSA-practises (Greene, 2003).

In chapter three, the determinants to the usage of eight combinations of CSA-practises were examined using a multinomial probit model. The combinations of CSA-practises includes; non- user ($C_0R_0I_0$), crop rotation ($C_1R_0I_0$), crop residue retention ($C_0R_1I_0$), intercropping ($C_0R_0I_1$), crop rotation and intercropping ($C_1R_1I_0$), crop rotation and crop residue retention ($C_1R_0I_1$) crop residue retention and intercropping ($C_0R_1I_1$) and crop rotation, crop residue retention and intercropping ($C_1R_1I_1$). The model was tested for the validity of the independence of the irrelevant alternative (IIA) assumptions using the Hausman test for IIA.

In chapter four, the study estimated the impact of combination of CSA-practises (crop rotation, intercropping and residue retention) on household food security using a multinomial endogenous switching regression model (MESRM). The model allows the set of CSA-practises to intermingle with observable variables and unobserved characteristics. This implies that the impact of combination CSA-practise used is not limited to the intercept of the outcome equations (Zeng *et al.*, 2015), but can also have a slope effect. The model allows interaction by estimating separate regressions for users and non-users. A multinomial logit selection model was used to model the decisions to use combination of CSA-practises in the first stage while recognizing the inter-relationships among the choices and in the second stage. The ordinary Least Square was applied in the second stage with selectivity correction to estimate the impacts of CSA-practises on household food security.

In chapter Five, the impact of combinations of organic manure, drought-tolerant maize seeds and irrigation on household food security were estimated using a multinomial endogenous treatment effect model. The model is an appropriate framework for evaluating

CSA-practises used either in isolation or in combination as it captures the interactions among choices of alternative CSA-practises (Wu and Babcock, 1998). Two steps are used in the estimation. First, the farming household's choice of combination or individual CSA-practise was modelled using a mixed multinomial logit selection model. Second, the ordinary least square (OLS) with selectivity correction terms were used to estimate the impact of outcome variables. For the case of this study, the outcome variable is Household Dietary Diversity Score per Adult Equivalent Unit (HDDS/AEU) as an indicator of household food security.

In chapter six, the determinants and impact of using irrigation practises on household food security was estimated using the endogenous switching regression model. The model was used to compare the expected food variety score per adult equivalent unit (FVS/AEU) of the irrigators with respect to the non-irrigator farm households. Furthermore, the expected FVS/AEU in the counterfactual cases that the irrigators did not use irrigation and that the non-irrigator farm households did use (Asfaw *et al.*, 2012; Di Falco *et al.,* 2011). These explains the differences in the FVS/AEU between the two groups, and to provide possible responses to changes in irrigation policy.

7.3 Results and Policy Implications

Results from chapter two show farming households are using CSA-practises as complements which is important to designing combinations of CSA-practises. The econometric results confirm that gender of the head of the household, geographical location, extension services and plot ownership were important determinants on the use of the type and number of CSA-practises. It is recommended that agricultural experts should carefully design combinations of CSA-practises for the aim of increasing agricultural productivity, resilience to climate change, mitigation of greenhouse gases and improvement of food security. In addition, it is recommended that, inorder in order to enhance the usage of CSA-practise, policy makers and local government authorities should target equipping extension workers with adequate items of infrastructure that enable their easy movement to the farmers. In addition, more more extension agents should be trained and deployed in the country to reduce the workload of the limited number of extension officers available.

Chapter three found that the determinant of using different combination of CSA-practises are the education level of household head, gender of the household head, household size, production diversity, farm size, access to extension services, livestock ownership and occupation. The analysis of the determinants of using combination of CSA-practises revealed that production diversification, gender and livestock ownership were found to be positive and significant influence the usage of combination of crop residue and intercropping ($C_0R_1I_1$). In addition, education level and gender of the head of the household were positive and significant in the usage of combination of crop rotation, crop residue and intercropping ($C_1R_1I_1$). This study will be of significance for a finer understanding of the synergistic effect of interrelated CSA-practises. The study calls for policy makers on policies and plans that promote CSA-practises as a combination including other interrelated practises that can contribute to upscale CSA-practises usage while harnessing the synergies between them.

In chapter four, three primary results are found. First, CSA-practises significantly increase food variety score per adult equivalent unit when used either singly or jointly. Second, the use of intercropping in isolation show the highest food variety score per adult equivalent unit among all the possible combinations of CSA-practises. Third, the use of crop rotation in isolation also showed a high pay off after intercropping followed by a joint combination of crop rotation and residue retention. Therefore, a comprehensive approach that focuses on joint usage of a combination of crop rotation, intercropping and residue retention was found to be the best food security portfolio. Consequently, results point towards the need for promotion of the usage of CSA-practises, in isolation and in combination. CSA-practices should be encouraged because all possible combinations result in significant positive effects on food variety per adult equivalent unit as an indicator of food security.

In chapter five, the findings show that characteristics of the household, plot characteristics and institutional characteristics have significant effects on usage of different combinations of climate smart agriculture practises. The study also found that the highest payoff of food security is achieved when climate smart agriculture practises are used in combination rather than in isolation. The package that contains combination of drought-tolerant maize seeds and Irrigation ($Or_0Dt_1Ir_1$) gave higher payoff than the combination of all three CSA-practises. The study suggests that based on the practises considered in this study, usage of combinations of various practises result into better food security compared to usage of these practises individually. This suggests that policy makers and other agricultural practitioners should encourage usage of combination of CSA-practises to enhance household food security.

In chapter six, the study found that radio ownership, education of the household head, farm experience, production diversity and livestock ownership were the determinants of using irrigation in the study area. The average treatment effect of the treated (ATT) and the average treatment effect of untreated (ATU) were positive and highly significant for both irrigator and non-irrigator farming households. This suggests that the use of irrigation as CSA-practises has resulted into a positive impact on household food security. The study recommends to the policymakers to consider rehabilitating the existing irrigation schemes and constructing new schemes to widen the impacts of irrigation for household food security. However, despite the positive impacts of irrigation, the study recommended the use of other irrigation practises, such as drip irrigation, sprinkler irrigation in areas where construction of irrigation schemes is not possible.

7.4 Further Research

Previous studies in Tanzania have shown that there is a lot of heterogeneity within the farmer's population with a variability with regards to food production, income and household food security over time (Smale and Mason, 2014). Disentangling the dynamics relating to this heterogeneity requires studying the behaviour of the farming households over a period of time. It was possible to do this in this study, because of the nature of the data used (i.e cross-sectional data). Therefore, the use of panel data might help in mitigating some of these problems because panel data allows one to fully understand the dynamics with regard to the determinants of practise usage as individuals are followed up overtime. Even though methodologies that account for selection bias and endogeneity were used in this study, finding a suitable instrument that is correlated with treatment variable and uncorrelated with the outcome variable is always a challenge. Panel data models can help to get round this problem because lagged values can be used as valuable instruments.

Child malnutrition is a very complex issue which is influenced by many multidimensional factors (Jesmin *et al.*, 2011). Understanding how combination of CSA-practises affects the nutritional status of children using antrhopomentric measures such as stunting, underweight and wasting levels as indicators of nutritional security is important. It was possible to do this in this study, because of the nature of the data used. Therefore, future studies could look into these antrhopometric measures as the outcome variables in evaluating the impact of combination of CSA-practises on household nutrition status, especially for children below five years. This would build more confidence in the resulting estimates on malnutrition.

Research efforts need to be expanded to focus not only on increasing crop production and yield, but also maintaining crop nutritional value. This will require a large shift in focus from the shortlist of large acreage annual row crops like maize beans paddy to include relevant wild fruits and vegetable crops which are tolerate climate change and readly available to the community. This will ensure nutrition status of the farming households at low cost inder the climate change era.

References

Asfaw, S., Shiferaw, B., Simtowe, F., & Lipper, L. (2012). Impact of modern agricultural practises on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food policy*, *37*(3), 283-295.

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829-846.

Food and Agriculture Organization of the United Nations (FAO). (2019). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2019 Key messages. Available from http://www.ifpri.org/ [Accessed 29/1/2019].

Food and Agriculture Organization of the United Nations (FAO). (2017). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2017 Key messages. Available from http://www.ifpri.org/ [Accessed 10/6/2018].

Food and Agriculture Organization of the United Nations (FAO). (2015). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2015 Key messages. Available from http://www.ifpri.org/ [Accessed 10/6/2018].

Food and Agriculture Organization of the United Nations (FAO). (2010a). “Climate-Smart” Agriculture. the Hague Conference on Agriculture, Food Security and Climate Change. Available from http://www.fao.org [Accessed 3/8/2018].

Food and Agriculture Organization of the United Nations (FAO). (2010b). The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2010 Key messages. Available from http://www.ifpri.org/ [Accessed 20/5/2018].

Greene, W. H. (2003), Econometric Analysis, fifth edition, Upper Saddle River, NJ, PrenticeHall.

Harvey, C. A., Saborio-Rodríguez, M., Martinez-Rodríguez, M. R., Viguera, B., Chain-Guadarrama, A., Vignola, R., & Alpizar, F. (2018). Climate change impacts and adaptation among smallholder farmers in Central America. *Agriculture & Food Security, 7*(1), 1-20.

Harvey, L. D. (2018). *Climate and global environmental change*. Routledge.

Jesmin, A., Yamamoto, S. S., Malik, A. A., & Haque, M. A. (2011). Prevalence and determinants of chronic malnutrition among preschool children: a cross-sectional study in Dhaka City, Bangladesh. *Journal of health, population, and nutrition*, *29*(5), 494.

Maliondo, S. M. S., Mpeta, E. J., & Olson, J. (2012). Climate change and food security in Tanzania: an analysis of current knowledge and research gaps and recommendations for a research agenda. *Ohio State University and Sokoine University of Agriculture: Columbus, OH, USA*.

Smale, M., & Mason, N. (2014). Hybrid seed and the economic well-being of smallholder maize farmers in Zambia. *Journal of Development Studies*, *50*(5), 680-695.

Tenge, A. J., De Graaff, J., & Hella, J. P. (2004). Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands, Tanzania. *Land Degradation & Development, 15*(2), 99-114.

Wu, J., & Babcock, B. A. (1998). The choice of tillage, rotation, and soil testing practises: Economic and environmental implications. *American Journal of Agricultural Economics*, *80*(3), 494-511.

Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M. and Yirga, C, 2015. Ex post impacts of improved maize varieties on poverty in rural Ethiopia', *Agricultural Economics, Vol. 46*, pp. 515–526.