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Combining Climate Smart Agriculture Practises Pays Off: Evidence on Food Security From Southern Highland Zone of Tanzania

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Concerns of food insecurity and climate change are serious global challenges, Tanzania included. 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, increasing resilience to climate change, and reducing mitigation costs for greenhouse gas (GHG) emissions 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 CSA-practises (in particular organic manure, drought-tolerant maize seeds, and irrigation) and the impact of the usage of household food security was examined. The cross-sectional study design was used to collect information from farming households in the Southern Highlands of Tanzania (Mbeya and Songwe regions). To evaluate the impact of the 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 CSA-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 CSA-practises are used in combination rather than in isolation. The package that contains a combination of drought-tolerant maize seeds and Irrigation ($Or_0Dt_1Ir_1$) gave a 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 results in better food security compared to the usage of these practises individually. This indicates that promoting a combination of CSA-practises could enhance household food security.

Keywords: climate, smart, agriculture, practises, food

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 attaining zero hunger by 2030 (Food Agriculture Organization of the United Nations, 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 exposes them to a high risk of malnutrition and poor health (Food Agriculture Organization of the United Nations, 2019). Statistics show that 1.2 billion people are 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 not 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, 2017). 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 an active and healthy life* (Food Agriculture Organization of the United Nations, 2010b).

Because of the high demand for food as the consequence 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 shortened 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 (Food Agriculture Organization of the United Nations, 2010a). Subsequently, it is important to simultaneously improve agricultural productivity and reduce yield variability over time 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, 2012). Previous studies in Africa indicate the importance of investigating 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 (Baethgen, 2010; Thornton et al., 2010).

An anticipated means to achieve this is the increased usage of climate-smart agriculture (CSA) approach as proposed by Food Agriculture Organization of the United Nations (2010a). CSA is an approach to developing the technical, policy, and investment conditions to achieve sustainable agricultural development for food security under climate change (Food Agriculture Organization of the United Nations, 2013). The CSA approach is vital as it contains 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) emissions (Shirsath et al., 2017). However, efforts to promote CSA in Africa are proceeding at the policy level as African leaders endorsed the inclusion of CSA in the New Partnership for Africa's Development (NEPAD) program on agriculture and climate change to improve food security in the region (Zougmoré et al., 2016).

In Tanzania, the agricultural sector employs about two-thirds of the total employed persons, and almost 90% of those employed in the sector are smallholder farmers living in rural areas (Tanzania, NBS, 2014). Crop production is the dominant farming activity that engages 60% of households; followed by mixed crop-livestock production (39% of farm households) and livestock/pastoralism (1%). On average, farm households cultivate 5 acres of land (Tanzania, NBS, 2012). Farm productivity is generally low; it is estimated that production is 10% less than a decade ago (Irish Aid, 2011). The main types of crops grown in Tanzania are cereals (for example maize, rice, and sorghum) which occupy 67% of the land under annual crops, followed by pulses (11%), oil seeds and oil nuts (11%), root and tubers (3%), cash crops (tobacco, cotton, pyrethrum, jute, and seaweed) (7%), and vegetables and fruits (1%) (Tanzania, NBS, 2012). However, it should be noted that the land area proportions for every crop as presented here do not reflect intercropping practises. Smallholder farmers in rural areas produce most of Tanzania's food; yet they are poorer and more food insecure than their counterparts in urban areas (Tanzania, NBS, 2012).

Many initiatives related to CSA have been taken in Tanzania. For example, the establishment of the CSA program (2015 – 2025) is one of the initiatives aimed at enhancing the usage of CSA-practises and food security (United Republic of Tanzania, 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), and African Conservation Tillage Network (ACTN) implemented CSA-practises programs and projects in different regions (Mbeya and Songwe Regions inclusive) aimed at improving food crop productivity and food security (African Green Revolution Alliance, 2016; Lipper and Zilberman, 2018).

However, according to Mugabe (2020), the majority of the CSA-practises projects and programs are ongoing but CSA-practises are not broadly used 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, preventing of soil erosion, improving infiltration of water, and improving soil health (Bhatt, 2017). Crop rotation is another CSA-practise that improves the adaptation to climate change through improving soil health and structure, improving soil water holding capacity, helping to break the circle of pests and diseases, and playing a major role in increasing yield stability (Kuntashula et al., 2014). Residue retention enables climate change adaptation through soil erosion control, conserving soil moisture, reducing soil compaction, decreasing carbon dioxide (CO_2) emission, and improving 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 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 the Mbeya and Songwe regions (Tenge et al., 2004; Kassie et al., 2015). A Study by Tanzania Food Nutrition Centre (2014) found that the prevalence of food insecurity in the Mbeya and Songwe regions 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 (Kirkegaard et al., 2014; Giller et al., 2015; Pittelkow et al., 2015; Kimaro et al., 2016) that examined the link between the usage of CSA-practises and food security in Tanzania and elsewhere. However, there are scarce empirical studies that examined the determinants of the 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 the Mbeya and Songwe regions. 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 analysing the decision to use a combination of practises identified using a multinomial endogenous treatment effect model. This is relevant because knowledge of 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 identifying a good combination of CSA-practises with the highest payoff could be important in designing an effective agricultural extension policy.

LITERATURE REVIEW

Concept of Climate-Smart Agriculture

According to Food Agriculture Organization of the United Nations (2010a), CSA is defined as an approach that 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 national food security through its goals of improving agricultural productivity and income, improving adaptation to climate change, and reducing or removing greenhouse gases emission (Food Agriculture Organization of the United Nations, 2014). In addition, CSA aims 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 in agricultural productivity, improving adaptation to climate change, and mitigation of greenhouse gases. The trade-off and synergies of CSA (i.e., productivity, adaptation, and mitigation) lead to addressing economic, environmental, 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 involve access to agricultural loans and different sources of household income (Ekwere and Edem, 2014). Improvement of subsidy scheme together with access to input and output markets are CSA-practises under the option of institutional change as explained by Mendelsohn (2006). The last option is technological developments which include practises like drought-tolerant maize seeds, crop rotation, use of irrigation, residues retention, and reduced tillage (Deressa et al., 2009; Blanco-Canqui and Ruis, 2018; Li et al., 2019; Page and Connell, 2020). However, some of the CSA-practises are localised 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 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 households increase productivity and yield stability in 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 abiotic stress like drought. These seeds increase production per unit area, reduce costs of production, increase and/or maintains above- and below-ground biomass during drought periods (Masuka et al., 2017). The use of irrigation is the best CSA-practise because of enabling 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 maize seeds and organic manure that can use moisture more efficiently (Arslan, 2013).

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 that 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 utilisation is considered the proper way of food consumption through consideration of requirements of human nutrition (Capone et al., 2014).

Generally, development specialists face difficulty 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 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 the 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 (HDDS/AEU) as an indicator of food security.

Theoretical Framework

The theoretical framework by Singh et al. (1986) was used in this study. The model is referred to as the agriculture household model (AHM) which is applied in developing countries where markets are imperfect. Because of imperfect input and output markets, there is an interaction between household production and consumption which indicates that farming households are both producers and consumers of goods and services with the objective of maximising 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 an 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 their own consumption rather than for market production. 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 Weersink et al. (1998) and Fernandez-Cornejo et al. (2005), the utility (U), is a function of the consumption of purchased goods (G) and leisure (L), subject to human capital (H) , and other household characteristics Z_h as exogenous factors. Therefore:

$$Max\ U\ \left[G, L, H, Z_h\right] \tag{1}$$

The utility is maximised subject to time, production and income constraints as:
Time constraint:

$$T = L_f\left[CSA_j\right] + L_e + L\ \geq 0 \tag{2}$$

Production constraint:

$$Q = Q\left[X\left[CSA_j\right], L_f\left[CSA_j\right], H, CSA_j, R\right] CSA_j \geq 0 \tag{3}$$

Income constraint:

$$P_g G = P_q Q - W_x X + W_e L_e + A \tag{4}$$

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 the agricultural production process (L_a), human capital (H), the choice of CSA-practises used CSA_j and a vector of exogenous factors that shift the production function (R). X and L_f are functions of CSA_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 (Pl_x), institutional characteristics (I_x) and household assets (H_a) determine the choice of CSA- practise (CSA_j) in turn.

$$CSA_j = \left[H_x, Pl_x, I_x, H_a\right] \tag{5}$$

i = 1, ..., max I, j = 1, ..., max j

The final constraint is shown in Equation 4, 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 income from agriculture [the price of crops cultivated (P_q) times the quantity of crops cultivated (Q)], off-farm income wage rate (W_e) times (L_e) - total off-farm labour supplied by the household and other income sources (W_x) times (X) such as remittances and pension (A). Plugging in Equation 3 into Equation 4 yields a farm practise-constrained measure of household income:

$$P_g G = P_q Q\left[X\left(CSA_j\right), L_f\left(CSA_j\right), H, CSA_j, R\right] - W_x X + W_e L_e + A \tag{6}$$

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

$$\begin{aligned}\iota &= U(G.L : H, Z_x)\\ &+ \lambda\left\{P_q Q\left[X\left(CSA_j\right), L_f\left(CSA_j\right), H, CSA_j, R\right] - W_x X + W_e L_e\right.\\ &+ \left. A - P_g G\right\}\\ &+ \eta\left[T - L_f\left(CSA_j\right) - L_e - L\right] \end{aligned} \tag{7}$$

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

$$Y^* = Y\left(CSA_j\right), P_q, P_g, A, H, T, R, Z_h \tag{8}$$

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

$$G = G(CSA_j, P_g, Y^*, H, T, Z_h) \tag{9}$$

Therefore, the reduced forms of Y^* and G are affected by a set of explanatory variables, including CSA_j . The main objective of this paper is, therefore, to evaluate the impact of organic manure, drought-tolerant maize seeds, and irrigation on HDDS/AEU as a food security indicator.

Empirical Review

Earlier studies have focused on the relationship between the usage of CSA-practises and crop productivity but there is scarce information on the impact of the 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 that 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 seeds on household welfare in Malawi. The study found female-headed farming households which were the users of improved maize seeds had better household welfare compared to male-headed households. A propensity score matching method (PSM) was employed by Allotey (2019) to evaluate the effect of the fertiliser subsidy programme on the income of the household. The study found that the fertiliser 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 the same variations. For example, in Arusha, farming households used terraces, in Dodoma they used reduced tillage while in the Ruvuma they used *Matengo pits*, but all have shown a positive impact on the productivity of maize and coffee. Furthermore, in the Southern Agricultural Growth Corridor, planting basins have doubled maize yields compared to that conventional tillage. Mkonda and He (2017) found that farming households that used irrigation, reduced tillage, and crop rotation has improved food crop productivity from an average of 0.5-t ha−1 to 1.5-t ha−1 in the northern zone of Tanzania. Subsequently, maize yields have increased from 2,500 to 4,166 kg per hectare and 3.75 t per hectare 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 their 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 reduces household poverty. In their study, Ouma et al. (2006) analysed factors influencing the usage of maize practises and fertiliser. They found that education, access to credit, access to extension, and agro-ecological differences had a significant influence on fertiliser usage in maize.

A study by Ariga et al. (2008) examined the usage of chemical fertiliser s 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 fertiliser in maize production. Furthermore, the result found that the decision to buy chemical fertiliser was positively related to land ownership but not with household wealth. In addition, closeness to the agro-dealer influenced peasants' decision to use chemical fertiliser 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 tillage, its negative impacts on yield are minimised. Moreover, the 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 dry land regions. Even though the reduced tillage was found to reduce crop yield by 5.7%, 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 a 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 their impact on household food security.

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 that use a specific CSA-practises 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 correlates 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 HDDS/AEU as an indicator of household food security.

METHODOLOGY

Study Area

The study was conducted in the Mbeya and Songwe Region where four districts were involved, i.e., Mbozi, Mbarali, Momba, and Mbeya Districts. The study area is in the Southern Highlands, which is the breadbasket area of Tanzania where different food crops are cultivated. The farming system in the study area is as follows; Irrigation (Rice, maize, vegetables, rain-fed crops, cattle, poultry), highland perennial (Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work), Highland temperate mixed (potatoes, sheep, goats, livestock, poultry, and off-farm work), cereal-root crop mixed Maize (sorghum, millet, cassava, yams, legumes, and cattle) and agro-pastoral millet/sorghum (Sorghum, pearl millet, pulses. sesame, cattle, sheep, goats, poultry, and off-farm work; Dixon et al., 2001).

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 5 years are stunted (Tanzania Food Nutrition Centre, 2014), and there have been an 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 generalise the results. Furthermore, mixed agronomic practises also were the main driver for the selection of this study area.

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. 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 1,443 households. A structured male and female questionnaires were used to capture information using an 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.

Estimation Strategies

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

$$U_{ij}^{*} = Z_{i}^{'}\alpha_{ij} + \sum_{k=1}^{j} \delta_{jk} l_{ik} + \eta_{ij} \tag{10}$$

Zi was used to denote the vector of household characteristics, plot characteristics, institutional factors, and location with the associated parameters α_{ij}; η_{ij} are independently and identically distributed error terms. The U_{ij}^{*} includes a latent factor l_{ik} that incorporates unobserved characteristics common to i^{th} farming households' 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 unobserved characteristics that may have an impact on outcome variables (Khonje et al., 2015). The assumption is that the l_{ik} is independent of η_{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

TABLE 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						**1,443**	**100.00**

the choice of a different combination of CSA-practises and as a vector of:

$$CSA_i = (CSA_{i1}, CSA_{i2}, ..., CSA_{ij}) \quad (11)$$

let

$$l_i = (l_{i1}, l_{i2}, ..., l_{ij}) \quad (12)$$

The probability of treatment can be represented as:

$$pr(\left(CSA_i \middle| z_i l_i\right) = g(z_i^{'}\alpha_i + \delta_1 l_1, z_i^{'}\alpha_2 + \delta_2 l_{12} \ldots\ldots\ldots z_i^{'}\alpha_j + \delta_j l_{ij}) \quad (13)$$

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

$$\Pr(\left(CSA_i \middle| z_i l_i\right) = \frac{\exp(z_i^{'}\alpha_j + \delta_j l_{ij}}{1 + \sum_{k=1}^{j}\exp(z_i^{'}\alpha_k + \delta_k l_{ik}} \quad (14)$$

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

$$E(\left(y_i \middle| CSA_i x_i l_i\right) = x_i^{'}\beta + \sum_{j=1}^{j}\gamma_j CSA_{ij} + \sum_{j=1}^{j}\lambda_j l_{ij} \quad (15)$$

y_i stand for the HDDS/AEU as the outcome variable and an indicator of household food security for i^{th} farming household, a set of exogenous variables are presented by x_i with parameter vectors β, and γ_i represent the treatment effects relative to the control group i.e., non-users of CSA-practises. If $CSA_{\ ij}$ is treated to be exogenous but there is a possibility of endogeneity in usage decision of CSA-practises which resulted in inconsistent estimates γ. $E(\left(y_i \middle| CSA_i, x_i l_i\right)$, is a function of each of the latent factors l_{ij}. This means that the outcome variable is affected by the unobservable characteristics which also affect selection for treatment. When λ_j, is the factor-loading parameter and when it 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 an effect on the usage decisions of CSA-practises but are 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., Di Falco and Bulte, 2013; Khonje et al., 2018).

Measuring Food Security (Outcome Variables)

Household dietary diversity score per adult equivalent unit was used as an indicator of food security to evaluate the impact of CSA-practises on household food security. The HDDS/AEU is suggested to be a suitable measure for assessing diets quality and nutritional adequacy at the household level (Assenga and Kayunze, 2016; Kinabo et al., 2016). The HDDS/AEU was computed by aggregating food varieties that households reported consuming over the previous 24 h as suggested in other studies (Kinabo et al., 2016; Mbwana et al., 2016). The households indicated whether they consumed one of the food items within a particular food group in the previous 24 h. 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 (Food Agriculture Organization of the United Nations, 2011).

The scores ranging from 1 to 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 sizes and compositions 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. Because households of different sizes have different requirements in terms of resources, the sum of adult equivalent was adjusted based on the economies of scale constants.

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 their effect on household food security. The different combinations of the three CSA-practises were used as dependent variables as shown in **Table 1**. The organic manure, drought-tolerant maize seeds, and irrigation were denoted as O_r, D_r, and I_r, respectively. 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 better than the conventional grouping method which makes 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 a generalisation about a group (Chatterjee et al., 2015).

Several explanatory variables such as production diversity, sex of the household head, age of the household head, marital status of the household head, occupation, education of the household head, education of the spouse, household size, tropical livestock unit, total plot size, plot ownership, land title, household asset, soil fertility, soil erosion, access to loan, region dummy, age difference, farm experience, average farm distance, access to extension, distance to the extension office, and access to the tarmac road. The study hypothesised 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 has a positive association with the usage of CSA-practises (Deressa et al., 2011). In addition, farming households that use CSA-practises differ based on their locations such as those located (Taneja et al., 2014). Access to extension services measured as a dummy variable is an important source of technical information for farmers. It is, therefore, posited that access to extension services will increase usage of CSA- practises either in isolation or in combination. Access to agricultural extension services typically plays a crucial role in enhancing usage and innovation (Chowdhury et al., 2014).

RESULTS

Descriptive Statistics

Climate-smart agricultural (CSA)-practises might be used in a wide range of different combinations, and this has implications on a 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 organic manure ($Or_1Dt_0Ir_0$) while 26.8 and 12.06% used a 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.

The mean age of sampled farm households surveyed in the study area is 54 in Mbeya and 53 in the Songwe regions, respectively. These findings agree with the study of Chavanapoonphol et al. (2005) that found that Thailand rice farmers were quite old with an average age of 51 years, and also agrees with the study of Nwaru and Onuoha (2010) that the respondents were a bit old with an 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) who found out that small and medium-scale soybean farmers in Benue State, Nigeria had an average age of about 33 and 39 years respectively.

The findings show that (50%) of household heads in the Songwe region were male while 49% of household heads in the

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 seven members while in Momba four members, seven members in Mbozi, and five members in the Mbeya district. Otitoju and Arene (2010) in their study found similar results that the respondents used a modern variety of soya- beans have an average household size of seven people. It was found that the average number of different sources of income was 2.2. In the Mbeya region, the average source was 2 same as in the 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 for the farmer does not necessarily help farmers to use CSA- practises.

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 the base category. The model fits the data with the Wald test, Wald χ^2 (186) = 1,890.39; $p > \chi^2 = 0.000$ which implies that the null hypothesis that all the regression coefficients are jointly equal to zero should be rejected.

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 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 roads and access to agricultural extension services were included in the selection equation but not in the outcome equation. Similar to Beyene et al. (2017), the study used as selection instruments in the food security functions the variables related to past experiences 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 2** show that the gender of the household head has negatively related to the usage of irrigation in isolation ($Or_0Dt_0Ir_1$). This means that female-headed households were more likely to use irrigation in isolation ($Or_0Dt_0Ir_1$) by 1.7181 units at a 5% significant level relative to non-use of CSA-practises ($Or_0Dt_0Ir_0$) compared to the male household head. The 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 improving household dietary diversity. The result was contrary to the results of Wekesa et al. (2018), which found that male-headed households used CSA-practises compared to female-headed households in Kenya.

Farming households which owned land were less likely to use a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.2965 units at a 1% significant level. Furthermore, land owners land less likely to use a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.2289 units at a 1% significant level. Furthermore, land owners are less like to use drought-tolerant maize seeds ($Or_0Dt_1Ir_0$) by 1.7524 units at a 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 on the farm. A 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 on 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 a positive influence on the usage of CSA packages in Vietnam.

The study found a positive effect of marital status on the usage of a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) and a combination of organic manure and irrigation ($Or_0Dt_1Ir_1$). This implies that marriage farming households were more likely to use a combination drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.0051 units at a 10% significant level compared to single farming households. Furthermore, marriage farming households were more likely to use a combination of organic manure and irrigation ($Or_1Dt_0Ir_1$) by 2.2525 units at a 5% significant level. This is because marriage-headed households in the study area are likely to have more labour so they are likely to use practises which are labour-intensive compared to single households. Similar results were found by the study of Tambo and Abdoulaye (2012) in their study of the usage of drought-tolerant maize in northern Nigeria.

The study found a positive and significant relationship between 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 in the household size is likely to increase the usage of a combination of $Or_0Dt_1Ir_1$ by 0.1241 units at a 5% significant level. In addition, units increase in 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 a 10% significant level. This is due to the fact that application of organic manure, operation of irrigation activities on 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 sizes 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 decreases the probability of using the combination of organic manure and irrigation ($Or_1Dt_0Ir_1$) by 0.1937 units at a 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

TABLE 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)

*Standard errors where *P < 0.1, **P < 0.05, ***P < 0.01.*

farm. This makes the opportunity cost of working on a farm higher for educated household heads. Kassie et al. (2012) found the same result in their 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). In addition, the study found a positive and significant effect of the spouse's education on the usage of a combination of organic manure drought-tolerant maize seed and irrigation ($Or_1Dt_1Ir_1$). This is because female farmers in the study do not have access to big farms/plots, hence they are motivated to use CSA- practises in order to increase production under a small piece of land. In addition, spouse education is also important as it empowers women to make decisions on which practise to use which leads to increase agricultural productivity.

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 a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$). Farming households which owned land were less likely to use a combination of drought-tolerant maize seeds and irrigation ($Or_0Dt_1Ir_1$) by 1.2965 units at a 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 a 1% significant level. Finally, land owners are less like to use drought-tolerant maize seeds ($Or_0Dt_1Ir_0$) by 1.7524 units at a 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 on the farm. A 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 on 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 a positive influence on 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 a 10% significant level. The use of DTMS is mainly due to the farm input subsidy programme which has over the years disseminated Drought Tolerant Maize Seeds (DTMS). The DTMS has been an integral component of the government subsidy package and this has made it easy for farming households to access and use the seeds. In addition, farming households exposed to drought respond by using risk-reducing practises such as drought-tolerant maize seeds.

Furthermore, the agricultural extension services were found to be significant at a 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 services may get the courage to use and continuously apply CSA-practises. Similar results were found in studies conducted by Matata et al. (2010), Namwata et al. (2010), Odoemenem and Obinne (2010), and Solomon (2011) which found farming households that are frequently visited by extension officers use agricultural practises compared 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 practises compare to their counterparts.

The distance to an agricultural extension office is negative and significant to all combinations expect the usage of drought-tolerant maize seeds 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 the 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 a 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 a 1% significant level. Furthermore, the study found that households whose heads had access to credit had a 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 a 5% significant level. Finally, farming households whose heads had access to credit had a 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 a 10% significant level. A positive correlation between access to credit and usage of agricultural practises was also noted by Ogada et al. (2014).

As expected, the distance of the farm from the homestead has a negative and significant effect on the 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 that is 1 min closer to the farm/plot had a higher chance of using a combination of organic manure and drought-tolerant maize seed at 0.0166 units at a 5% significant level. In addition, the study found that 1 min close to the farm/plot increases the probability of using a combination of drought-tolerant maize seeds and irrigation by 0.0141 units at a 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 leading to not using the practises. A similar result was found by Gebremariam and Wünscher (2016) who concluded that the farm distance from the 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 the region dummy was found to be a 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 the Songwe region are less likely to use irrigation as a CSA-practise ($Or_0Dt_0Ir_1$) by 1.15 units at a 10% significant level. This is due to the availability of few irrigation schemes in the Songwe Region compared to number of irrigation schemes in the Mbeya Region such as Madibila, Kongolo Mswisi, Kapunga irrigation schemes 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 dummies 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% and positively influence the usage of irrigation (Or0Dt0Ir1) in isolation and significant at a 5% level positively associated with the usage of the combination of organic manure and drought-tolerant maize seeds (Or1Dt1Ir0). Furthermore, plot size was found to be significant 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 practised commercial farming and will usually adopt agricultural technologies such as CSA for profit maximisation. This result is different from the study conducted by Lunduka et al. (2012), which reported a farm size is negative and has significant effects on 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 a 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.

Estimation of the Treatment Effects

The estimates of the impact of CSA-practises used in isolation and in combination on HDDS/AEU as an indicator of food security were presented in **Table 3**. Remarkably, the study found that the 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 in 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.

TABLE 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
DTMS ($Or_0Dt_1Ir_0$)	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

*Standard errors where *P < 0.1, **P < 0.05, ***P < 0.01.*

The study found that farm households that used organic manure ($Or_1Dt_0Ir_0$) alone was negatively impacted HDDS/AEU at a 10% significant level. The usage of organic manure in isolation decreases the HDDS/AEU by 7.35% in comparison with non-users ($Or_0Dt_0Ir_0$). A similar result was found by Martey (2018) in Ghana, who found that usage of organic fertiliser 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 increases 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 a positive and insignificant impact on HDDS/AEU. Sileshi et al. (2019) 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 households 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 a positive and significant impact HDDS/AEU. The combination of drought-tolerant maize seeds with irrigation also had a positive and significant impact HDDS/AEU. The usage of drought-tolerant maize seed in combination with organic manure leads to an increase HDDS/AEU by 19.14%. It is somewhat lower compared to the impact of drought-tolerant maize seeds found elsewhere. For example, Khonje et al. (2015) and Mutenje et al. (2016) found 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) provides 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 a higher payoff than the combination of all three CSA-practises. This is similar to the study by Beyene et al. (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.

Though, 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 seeds and irrigation are used in isolation; leading to an increase in the 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%).

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), Khonje et al. (2015), and 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 the resident, extension visit, and the distance to the extension office to the farmers' residents were used. For example, extension service is considered 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).

TABLE 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	$\chi^2 = 7.844$, $p = 0.0975$

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 4**.

The result from Durbin and Wu–Hausman (DWH) tests for the exogeneity of the selection instrument were found to be highly insignificant while Wooldridge (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 the identification of the model. The test rejects the null hypothesis of the under-identification of the model at <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 <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.

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 was taken into account as well as unobserved characteristics of the farming household. Findings show that there are various variables that are important in influencing the 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. It is imperative for policymakers to ensure that a wider spectrum of smallholders farmers are able to have access to credit in order to improve their usage level of CSA-practises. Agricultural extension workers should try to understand the farmers' need as well as their ability to use CSA-practises in order to use practises that will suit them particularly in this era of climate change. Despite the fact that extension experts claim to spend most of their time in the field, usage of CSA practises is poor. This can be attributed to among other causes, low education levels of the farmers, negligence, poverty, poor monitoring by extension staff, and the methods of technology transfer applied. The technology transfer approach is mostly participatory but in most cases not practically implemented due to budget constraints. fertiliser use in the study area was influenced by the availability of subsidies from the government. Farmers still lack knowledge on-farm management aspects resulting in significant yield losses every season. As the agricultural policy stipulates, more extension workers should be deployed at the village level. However, they should be supported and facilitated by providing them with a conducive working environment. This can support extension officers in exploring CSA-practises that will fit farmers' needs and abilities based on their existing situation. They should focus on building farmers' capacity in terms of experimentation and help them realise through participatory methods that experimenting using locally available resources could reduce cost and bring more benefit.

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 characteristics 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 these results to influence the usage of different CSA-practises. Results from this study generally show that CSA-practises have a positive and significant effect on HDDS/AEU. The package that contains a combination of drought-tolerant maize seeds and Irrigation ($Or_0Dt_1Ir_1$) gave a higher payoff than the combination of all three CSA-practises. This implies that future interventions that aim to increase agricultural productivity and enhance HDDS/AEU as an indicator of food security should combine the use of drought-tolerant maize seeds and irrigation with other best CSA-practises that enhance agronomic practises.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Sokoine University of Agriculture. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

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

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