Climate Smart Agricultural Practices and Food Security: Evidence from Ugandan Maize Farmers

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Abstract

In the face of climate change and extreme weather events which continue to have significant impacts on agricultural production, climate-smart agriculture (CSA) has emerged as one important entry point to build resilience of agricultural households. We examine the relationship between CSA and food security of maize growing households in Uganda using the three waves of the Uganda National Panel Surveys data collected by the Uganda Bureau of Statistics. To understand the correlates of the adoption of CSA practices, we use a panel logistic regression. We further applied panel data analysis methods to evaluate the impact of CSA on food access and availability of maize farmers. We find a positive association between the adoption of all the four CSA practices and household dietary scores (HDDS). The number of months when a household has adequate food provision (MAHFP) was mainly affected by use of fertilizers and pesticides. While food consumption score (FCS) was primarily affected by legume intercropping and use of fertilizers on the maize plots. Although we show modest associations between the independent use of CSA practices such as adopting legume intercropping, improved seed, fertilizers and pesticides, we find that bundling CSA practices may lead to food security gains for maize growing households. The use of the different CSA combinations exhibited the strongest association between CSA and HDDS and FCS as less on MAHFP. The study findings have policy implications for targeting of maize farmers with suitable packages that can yield maximum gains for food security as well as maintaining environmental sustainability.

Key words: Climate change, Climate Smart Agriculture, Food security, Maize farmers, adoption, Uganda

1. Introduction

In the Sub Saharan Africa (SSA), food security[1] remains a serious challenge (Sekabira *et al.,* 2018). Due to over reliance on rain-fed agriculture as a source of livelihood, climate change is expected to compound this challenge especially for the poor in low and middle income countries across SSA (Black *et al.,* 2013; IFPRI, 2017). It is estimated that by 2050, the combined effect of increasing temperatures, declining rainfall, frequent floods and droughts could result into average reduction of maize yields by 5 percent, and food availability in SSA will average 500 calories less per person (Dawit *et al.,* 2017). For Uganda, understanding the impact of climate smart on food security, in the context of maize production is particularly vital because maize doubles as a major food and cash crop. Maize provides over 40 percent of the population's calorie requirements and has an annual consumption of about 23 kg per capita per year (Kagoda *et al.*, 2016; UBoS 2017). However, on-farm maize yields no longer exceed 2.5 MT per hectare, against a potential of 5.0 to 8.0 MT per hectare due to unpredictable weather patterns, scarcity of adapted varieties and emerging diseases such as the maize lethal necrosis (Kagoda *et al.,* 2016).

Given the anticipated threats of crop yield reduction and food scarcity from the impact of climate change, past studies (Makate *et al.,* 2016; Campbell *et al,* 2014; Nelson *et al.,* 2009) have recommended scaling up use of climate smart agricultural (CSA) practices to lessen the impact on the livelihoods of the most vulnerable segment of the population and improve on achievement of sustainable development goal 2 of zero hunger. In this respect, Sauer et al. (2018), Manda et al. (2015) and Anderson et al. *(*2014) suggested that maize–legume intercropping benefits both farmers and the environment, through nitrogen-fixation and increased soil-carbon content, which helps to mitigate the effects of climate change. In addition, the adoption of improved maize varieties has been reported to impact smallholder farmers' wellbeing through boosting crop yields, food security and household income (Mason and Smale, 2013; Smale and Mason, 2014).

Given the potential of CSA practices to address low crop yields and food insecurity issues, the main objective of the study is to examine the impact of CSA practices on food security. This question is important for Uganda where ensuring sustainable CSA practices and food security is of high policy relevance and where climate change instigated food insecurity is increasingly becoming a policy concern. Past studies (Manda *et al.*, 2015*;* Wekesa *et al.,*2018; Sibhatu and Qaim, 2017; Jaleta *et al.,* 2015; Maren *et al.,*2018; Teklewold *et al.,*2019; Nhat *et al.,*2019 Arslan *et al.,* 2014; Kim *et al.,*2019; Van Asten *et al.,* 2011) that attempted to examine the relationship between various CSA practices and food security, solely focused on estimating one dimension of food security[2] i.e. food access. Moreover, some did not use nationally representative data to examine the relationships. We fill these gaps by using three waves of nationally representative household dataset -the Uganda National Panel Surveys

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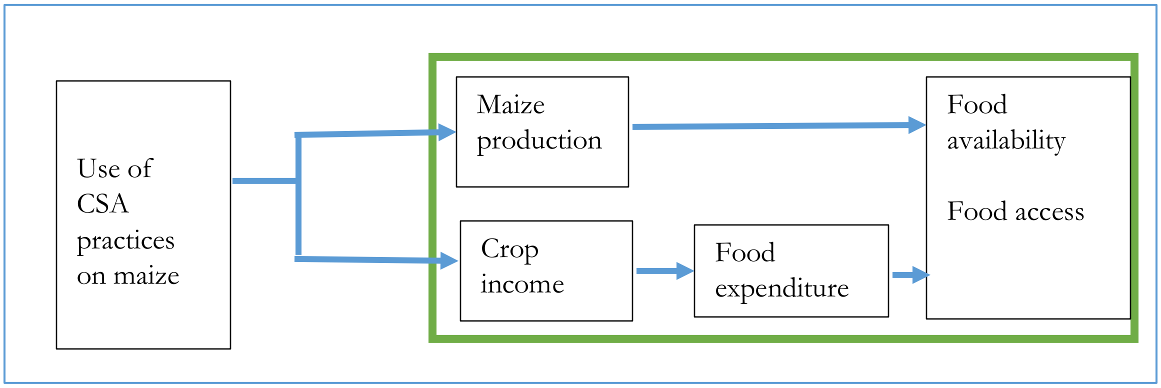
[1] Food security exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1996). Food security comprises four dimensions namely food availability, access, utilization, and stability.

[2] The four commonly recognized dimensions of food security are food availability, access, utilisation, and stability.

(UNPS) of 2015/16, 2018/19, 2019/20, collected by the Uganda Bureau of Statistics (UBoS) to estimate the effects of different combination of CSA practices on two dimensions of food security i.e. food access and availability. The four major CSA practices analysed in this study include: 1) maize–legume intercropping; 2) improved maize varieties; 3) pesticide application; and 4) use of inorganic fertilizers. We follow (Kipkoech *et al.,* 2015; Sauer *et al.,* 2018, Manda *et al.,* 2015; Wekesa *et al*., 2016; Holden, 2018 and Jayne *et al.,* 2019) to group the CSA practices used on a given maize plot into four categories: (i) "Non-adoption" (use of none of the practices); (ii) "Improved inputs" (use of improved seed, inorganic fertilizer and pesticide use only); (iii) "Legume-intercropping " (use of maize-legume intercropping); and (iv) "Improved inputs and Legume-intercropping" (use of improved seed, inorganic fertilizer and pesticide with legume intercropping).

We estimate the effects of use of practices in the various CSA categories on food access and availability. This is because CSA categories contribute to improved food production/productivity and crop income which are considered the two main potential impact pathways through which changes in cropping practices including CSA practices studied here are likely to affect household food access as well as food availability (Herforth and Harris, 2014; Kumar et al., 2015). For example, households' use of the practice(s) in each CSA category relative to "Non-adoption" could improve crop production or productivity in terms of the quality and/or quantity of crops produced on their maize plot, which household members could consume directly (Figure 1). In addition, it could increase a household's crop income through generating larger quantities of the crops that can be sold to the market which, in turn, allows farmers to purchase more and/or better-quality food. To measure food access, we consider several indicators including months of adequate food provisioning (MAFHP), a modified version of the standard household dietary diversity score (HDDS), and the household's food consumption score (FCS).

Figure 1: Conceptual pathways between CSA adoption on Maize and household food security



Source: Authors' conceptualization

Climate change instigated food insecurity in Uganda largely emanates from increasing incidence of climate related effects like long dry spells, floods and pests and diseases. As a result, the incidence of climate change effects has started manifesting and is deleterious to agriculture productivity and hence household food security. This study sought to answer two research questions: (i) What determines the choice of the CSA practice adopted by smallholder maize farmers? (ii) What is the impact of the adoption of the various CSA categories on food access and availability? We hypothesize that maize-growing households with better household socioeconomic characteristics, larger physical endowments, better access to institutional support and plot characteristics are more likely to adopt CSA practices compared to non-adopters, and *ceteris paribus*, maize-growing households that practice the CSA practices have: (1) significantly more amount of food available per member; and (2) greater ability to acquire sufficient quality food.

This study makes several contributions to the emerging body of literature on climate smart agriculture. First, we examine the impacts of households' use of combinations of CSA practices – improved inputs, improved inputs and legume-intercropping (as opposed to individual practices) on household food access and food availability, an area that has been rarely explored. Second, we go beyond previous studies on the impacts of combined use of agricultural practices by considering joint use of improved maize seeds, inorganic fertilizer and pesticides to rigorously examine the effects of such joint use on food access. There have been some attempts by Kassie et al., 2015 and Kassie et al., 2018 to analyze maize-legume intercropping, but grouped as maize-legume rotation. Finally, we use three waves of a nationally representative household panel survey data of the Uganda National Panel Survey, unlike previous studies (Manda *et al.*, 2015; Sibhatu and Qaim, 2017; Maren *et al.,*2018; Teklewold *et al.,*2019; Arslan *et al.,* 2014; Van Asten *et al.,* 2011) that either applied cross-sectional or panel data but not nationally representative panel data. We anticipate that our data set should be able to improve both the external validity of our findings (because the data are nationally representative) as well as the internal validity (due to use of panel data methods) – through a combination of panel random effects and fixed effects techniques.

The rest of the paper is organized as follows: the next section describes CSA in the context of Uganda, the policy relevance and objectives of the study; Section 3 delves into the data sources; Section 4 presents the methods of empirical analysis; results and discussions are presented in Section 5. Section 6, concludes with policy recommendations.

2. CSA and maize production in Uganda

Ugandan farmers, like farmers from other SSA countries, are disproportionately vulnerable to the impacts of climate change due to over reliance on rain fed agriculture (less than 1 percent practice irrigation). As the incidence of climatic change effects increases, it negatively affects crop yields and threaten food security. It is projected that between the year 2040-2069, suitable area for maize production in Uganda will decrease by 70 percent (UCSAP, 2015). Climate change instils greater urgency to find more sustainable, resilient, and efficient ways of producing and consuming diversified agricultural food products. CSA has been coined as one of the key approaches to enhance the adaptive capacity of farmers and to mitigate among others food security risks associated with climate variability.

To build a climate resilient economy, in 2015, Government of Uganda (GoU) launched the National Climate Change Policy and designed a National Adaptation Programme of Action (FANRPAN, 2017).

Additionally, GoU with support of development partners has implemented several projects aimed at scaling uptake of CSA practices by farmers. CSA practices that are being promoted and practiced by farmer range from; conservation agriculture (mulching, intercropping, crop rotation, nitrogen fixation), agro-forestry (tree based conservation), integrated soil fertility management (compost and manure application, fertilizer application), soil and water conservation (terracing), crop and livestock diversification (improved crop varieties, improved animal breeds), rhizobia innoculants, nitrogen-fixing crops like legumes among others (FAO, 2016; MAAIF, 2016; GoU and MWE, 2015).

To strengthen CSA adoption further, several polices, and strategies have been put in place. The National Agriculture Policy (2013), which aims at ensuring household and national food and nutrition security for all Ugandans, was operationalized through the Agricultural Sector Strategic Plan (2015-2020), which adopted 12 priority commodities targeting food security. In addition, MAAIF developed sub-sector policies including a comprehensive National Fertiliser Policy - NFP (2016) and the National Agricultural Extension Policy - NAEP (2016). NFP aims at improving soil nutrient levels through a reduction in annual nutrient loss by 30 kilogrammes per hectare and an increase in annual fertiliser application up to at least 50 kilogrammes per hectare. The aim of the NAEP is to promote access to appropriate agricultural information, knowledge and technologies. The aforesaid policies and strategies complement each other in increasing the availability and knowledge on critical production inputs and in promoting use of appropriate technologies to enhance yields, thus delivering food and nutrition security goals. However, it remains unclear as to whether the efforts have led to improvements in food security, especially for smallholder farming households.

We focused on four major CSA practices namely, maize–legume intercropping, improved maize varieties, pesticide application, and inorganic fertilizers. In Uganda, most smallholder maize farms are intercropped with legumes due to the small average farm sizes and the need to mitigate against crop failure (Goettsch, 2016). Therefore, intercropping has been widely encouraged as a sustainable risk mitigating strategy. In addition, to respond to declining maize yield, the National Agricultural Research Organisation (NARO) has continually released and encouraged uptake of several improved maize varieties specifically adapted to each of the agro-ecological zones of the country. As such, we consider improved maize varieties as being one of the CSA practices. However, to enhance the productivity of improved maize cultivars, complementarity is required with other CSA practices (Manda *et al.,* 2016 and Vanlauwe *et al.,* 2014). Considering the persistence of maize pests and diseases, adoption of improved maize varieties has increasingly required the use of pesticides. For this reason, we consider pesticide application to be one of the CSA practices. Moreover, there is empirical evidence that when improved seed is used in combination with fertilizer, productivity and production almost doubles compared to either single or non-application of the technologies (Odokonyero and Mbowa, 2019).

3. Empirical strategy

We analyse the relationship between CSA practices and food security within the theory of agricultural household models (Sadoulet and De Janvry 1995). We therefore utilise the random utility framework in modelling the impact of the CSA practices on food security. A maize growing household chooses the CSA practice or a combination that maximizes utility subject to available resources like land, labour, input costs and other constraints. A farmer will therefore choose any CSA combination over prevailing alternatives when the utility derived is greater than the other CSA category. However, farmers often self-select into the adopter/non-adopter categories which leads to endogeneity problems because unobservable factors may be correlated with the outcome variables. For example, if a maize farmer is highly motivated to adopt CSA practices, and has prior information not only on the benefits of various CSA practices but also on how to improve household food security. If omitted, the farmer's motivation could make it appear that the adoption of certain CSA categories is associated with food security even if there is no causal relationship.

We follow a two-step procedure to examine the effect of CSA on food security. In the first stage of the model, a farmer chooses one of the four CSA categories mentioned earlier. Given the binary nature of CSA practices, we adopt a panel logistic regression to model the dependence of the response and the current covariate vector. More formally, we assume that each CSA practices takes the value 0 or 1, corresponding to failure or success as specified below:

$$\log\left(\frac{\mu_{it}}{1-\mu_{it}}\right) = X'_{it}\beta_t \qquad \textbf{(i)}$$

Where $\mu_{it} = E(Y_{it}|X_{it}, \beta_t) = Pr\{Y_{it} = 1|X_{it,}\beta_t\}$

is the probability of success for the *i*th household and β_t *is a* J_tx1 vector or regression parameters.

In the second stage, we apply panel data analysis methods to evaluate the impact of CSA of food security of maize farmers. Following Wooldridge (2016), the error components model pooled across the three panel data periods was estimated as:

$$y_{it} = \alpha + \beta X_{it} + \mu_i + \varepsilon_{it} \qquad \textbf{(ii)}$$

Where, Y_{it}= outcome variable; X_{it}= vector of independent variables; α= is the intercept, β= vector of parameters to be estimated; $\mu_i + \varepsilon_{it}$= the composite error where μ_i= unobserved individual heterogeneity (which captures factors that are specific to each maize farmer but do not vary over time) such that $Var(\mu_i) = 0$ in the Ordinary Least Square (OLS) model and $Var(\mu_i) = \sigma_\mu^2$ in the random effects model; ε_{it}=idiosyncratic errors (assumed to vary among the maize farmers as well as over time) such that $Var(\varepsilon_{it}) = \sigma_\varepsilon^2$ for all the models; $i = 1,2,...,N$ (N =number of maize growing households); and $t = 1,2,...,T$ (T =number of time periods in this case three waves). From equation (ii), three different models based on the assumptions about individual heterogeneity were derived.

First is the OLS that assumes that $Cov(x_{it}, \mu_i) = 0$ and there are no unobserved individual heterogeneity (or all individual heterogeneity are the same) i.e. $\mu_1 = \mu_2 = ... = \mu_N = \mu$. This implies that equation (ii) can be written in the form;

$$y_{it} = \pi + \beta X_{it} + \varepsilon_{it} \qquad \textbf{(iii)}$$

Where; $\pi = \alpha + \mu_i$ is the common intercept for the OLS regression. Equation (ii) is estimated using the ordinary least squares method.

Second, we also estimated the Fixed Effects (FE) regression model. FE assumes that individual effects are fixed for each of the maize growing household and $Cov(x_{it}, \mu_i) \neq 0$. With individual effects correlated with the explanatory variables, OLS estimators are biased and inefficient. There is a need to transform equation (ii) to have efficient estimates. Equation (ii) can be transformed using time demeaning (within estimation) method to eliminate individual effects;

$$\widetilde{y_{it}} = \beta \widetilde{x_{it}} + \widetilde{\varepsilon_{it}} \qquad \textbf{(iv)}$$

Where; $\widetilde{y_{it}} = (y_{it} - \bar{y}_i)$, $\widetilde{x_{it}} = (x_{it} - \bar{x}_i)$ and $\widetilde{\varepsilon_{it}} = (\varepsilon_{it} - \bar{\varepsilon}_i)$

Third, we also estimated the Random effects (RE) model. RE model assumes that $Cov(x_{it}, \mu_i) = 0$ and μ_i is random, necessitating the need to keep it. With these two assumptions, equation one can be transformed using quasi demeaning method.

$$\ddot{y}_{it} = \ddot{\alpha} + \ddot{\beta} x_{it} + \ddot{\varepsilon}_{it} \qquad \textbf{(v)}$$

Where $\ddot{y}_{it} == (y_{it} - \theta \bar{y}_i)$, $\ddot{\alpha} = \alpha(1 - \theta)$, $\ddot{x}_{it} = (x_{it} - \theta \bar{x}_i)$, and $\varepsilon_{it} = (\varepsilon_{it} - \theta \bar{\varepsilon}_i)$.

The parameter θ normally lies between zero and one and is given by the formula $\theta = 1 - \sqrt{\frac{\delta^2{}_{\varepsilon}}{T\delta^2{}_{\mu} + \delta^2{}_{\varepsilon}}}$ With θ dependent on the number of time periods, the random effects estimates are closer to the fixed effects estimates as the number of time periods increase, and are closer to the OLS the lesser the time periods.

The empirical specification for the model on the effect of CSA on three indicators of food security was estimated as;

$$Y_{it} = \beta_0 + \beta_1 X_{jit} + u_{it} \qquad \textbf{(vi)}$$

Where y_{it} is the food security outcomes of household i at time t; x_{jit} is a vector of exogenous covariates including both household and plot level characteristics, associated parameter vector is β.

To choose the best possible model, the conventional F-test was undertaken to compare panel OLS and fixed effects. The null hypothesis for the F-test assumes individual effects do not matter and therefore, panel OLS is preferred. Second the study applied the Breush-Pagan test to compare between pooled OLS and random effects. The null hypothesis for the Breush-Pagan test assumes that no random effects and Panel OLS is preferred. Third, the Hausman test was undertaken to compare fixed effects and random effects respectively. The null hypothesis for the Hausman test assumes that $Cov(x_{it}, \mu_i) = 0$ i.e., random effects model is preferred to fixed effects model.

4. Data and key outcome and control variables

4.1 Data

This study primarily utilized the three waves (i.e. 2015/16, 2018/19, 2019/20)[3] of the nationally representative Uganda National Panel Surveys (UNPS) data collected by the Uganda Bureau of Statistics (UBoS). These surveys are part of the World Bank's Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA). The UNPS set out to track and re-interview 3,123 households that were distributed over 322 enumeration areas (EAs) across Uganda, selected out of the 783 EAs that had been visited during the Uganda National Household Survey in 2005/06, which provides an adequate sample for the study analysis. The panel survey data has the household, agriculture, and the community modules that capture information on farms, village characteristics (including access to input and output markets), household characteristics, current shocks/stresses experienced in crop production, participation and confidence in extension services, crop production, land tenure, perceptions of climate change, and climate change adaptation practices, and a range of maize plot-specific attributes (like soil fertility, slope, farm size in hectares, and walking distance to the plot). We shall control for some of these factors in the empirical estimations. Food and beverage consumption based on a seven-day recall period prior to the survey were elicited at the household level, covering more than 50 different food/beverage items. Quantities consumed include food from own production, market purchases, in-kind food transfers, out-of-home meals and consumption of fortified foods. The agricultural information from the survey waves was collected through two household visits—six months apart to account for the two agricultural seasons experienced in most parts of Uganda

4.2 Key outcome and control variables

To analyze the effects of various CSA categories on households' food security, we use three outcome variables: (i) A modified Household Dietary Diversity Score (HDDS), which was constructed from the 12 food groups[4] using the household food consumption data, basing on food consumed during the previous 7 days[5]; (ii) Months of Adequate Household Food Provisioning (MAHFP) (Bilinsky and Swindale 2010; Swindale and Bilinsky 2006; Jones et al. 2013), and (iii) Food Consumption Score (FCS).

For the modified HDDS and FCS outcome variables, we draw on the household food consumption data that were collected in the UNPS waves. Data are based on a seven-day recall period prior to the survey and cover over 50 food/beverage items. HDDS and FCS are both indicators of the food access component of household food security (Jones *et al.,* 2013). The modified HDDS is calculated as a count over 12 food groups (cereals, roots and tubers, vegetables, fruits, meat and poultry, eggs, fish and seafood, pulses/legumes/nuts, milk and milk products, oils and fats, sugar and honey, and miscellaneous) consumed during the seven-day reference period. A list of food groups was prepared based on the types of foods consumed by the maize growing households. The result was computed as the sum of food groups consumed at household level, and it is a count variable with a minimum

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[3] 2013/14 waves was dropped from the analysis due to limited number of observations. A sample refresh was carried during the UNPS 2013/14 (Wave 4) where, one third of the initial UNPS sample was refreshed with the intention to balance the advantages and shortcomings of panel surveys https://microdata.worldbank.org/index.php/catalog/3902

[4] The food groups are: Cereals, roots and tubers, vegetables, fruits, meat and poultry, eggs, fish and seafood, pulses/legumes/nuts, milk and milk products, oils and fats, sugar and honey, and miscellaneous.

[5] Data based on a 24-hour recall period are not available in the UNPS

value of one for a household that consumed only one food group during the reference period and a maximum of twelve food groups.[6]

MAHFP which measures the duration of an adequate quantity of food accessed by the household, was computed from the UNPS module that asked the respondent household in which months, if any, it did not have enough food to meet its needs during the most recent crop marketing year. The resultant MAHFP outcome variable is an integer between 0 and 12, with a lower value indicating more months with adequate household food provisions and thus better food access.

Food Consumption Score (FCS) as a measure of food security is used to measure both the types of food groups consumed and the frequency of consumption of these food groups (WFP, 2008). The FCS of the maize growing households was computed following the methodology as stated in WFP (2008). The FCS is composed of eight food categories: starches, pulses, vegetables, fruit, meat, dairy, fats and sugar, with frequency of consumption and weights attached to each food group. To be able to use this measure, a seven-day recall period as applied in the UNPS was applied which further reduces the risk of selection bias. The FCS takes on values ranging from zero to 112. To this effect, households with highest FCS were considered to be more food secure compared to those with lower values. Following WFP (2008), the FCS was computed as:

$$\begin{aligned}\mathrm{FCS} = (\mathrm{starches} * 2) + (\mathrm{pulses} * 3) + (\mathrm{Vegeatables} * 1) + (\mathrm{fruits} * 1) + (\mathrm{meat} * 4) \\ + (\mathrm{diary} * 4) + (\mathrm{fat} * 0.5) + (\mathrm{sugar} * 0.5)\end{aligned}$$

All sources of consumption were included (purchases, own production, gifts received, and goods bartered in) and the variables only included the actual consumption of the household over the previous seven days.[7] The descriptive statistics (Table 1) show the aforementioned welfare indicators of interest (HDDS, MAFHP). Results reveal that there has been a gradual reduction in HDDS from 7.95 in 2015/16 to only 2.2 in 2019/20. There has also been consistent trends in MAHFP at 11 months when maize households have adequate foods across the three time periods.

4.3 Socio-economic characteristics

The control variables were selected based on a careful review of the literature associated on technology adoption decisions and its impacts on household food security in African countries (Khonje *et al.*, 2018; Kassie *et al.*, 2015, b; Kassie *et al.*, 2018; Teklewold *et al.*, 2013; Manda et al., 2016). These variables include characteristics of the household head (gender, age, education, household size), farm characteristics (distance to plot measured in walking minutes, maize plot size measured in acres, number of maize plots, slope of the maize plot); resource constraints (farm size in acres, off-farm employment measured by participation in off-farm activities, livestock size measured in tropical livestock units (TLU), market access and extension, distance to output markets in kilometer, rating the quality of extension services) (Table 1). In terms of food availability, the results show that in total there are more households (63%) in the acceptable FCS category compared to other categories. This suggests that 63 percent of the households in three waves can be considered food secure.

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[6] The standard HDDS is calculated based on food consumption during the previous 24 hours (Swindale and Bilinsky, 2006). However, such data are not available in the UNPS so we calculate a modified HDDS based on food consumption during the previous 7 days.

[7] For all of these outcome variables except for the modified HDDS and the FCS, a one percent winsorization in each tail was used to prevent the results from being heavily influenced by outliers.

Table 1: Variable summary statistics

Variable	Description	2015/16	2018/19	2019/20	Overall
Outcome variables					
HDDS	Household Dietary diversity score	7.93	7.88	7.40	7.76
MAHFP	Months of adequate household food provisioning	11.46	11.41	11.41	11.43
FCS	Food consumption score	47.14	48.08	52.60	49.06
Poor food consumption	= 1 if household in poor food consumption category	11.24	10.76	5.08	9.34
Bordeline food consumption	=1 if household in bordeline food consumption category	31.73	28.23	21.77	27.42
Acceptable food consumption	=1 if household in acceptable food consumption category	57.03	61.01	73.15	63.23
CSA Technologies					
Legume intercropping	=1 if applied legume intercropping, 0 otherwise	0.64(0.48)	0.41(0.49)	0.61(0.49)	0.53 (0.50)
Improved maize	=1 if seeds are improved maize varieties, 0 otherwise	0.16(0.37)	0.09 (0.28)	0.13 (0.34)	0.12 (0.33)
Organic fertilizer	=1 if farmer applied organic fertilizers, 0 otherwise	0.03(0.18)	0.11 (0.31)	0.06 (0.24)	0.08 (0.26)
Inorganic fertilizer	=1 1 if farmer applied inorganic fertilizers, 0 otherwise	0.04 (0.19)	0.06	0.06	0.05
Any fertilizer	=1 1 if farmer applied either inorganic or organic fertilizers, 0 otherwise	0.07 (0.25)	0.15 (0.35)	0.11 (0.31)	0.12 (0.32)
Pesticides	=1 if farmer applied pesticides, 0 otherwise	0.09 (0.28)	0.16 (0.37)	0.13 (0.34)	0.13 (0.34)
Covariates					
Socio-economic characteristics					
Household size	Number of household members	6.37(2.69)	6.86 (2.94)	5.66 (2.48)	6.40(2.79)
Age	Age of the household head in years	46.30(14.96)	48.30 (15.56)	49.05(14.82)	47.96(15.23)
Urban	=1 if farmer is from urban location, 0 otherwise	0.11(0.32)	0.15(.36)	0.13(0.33)	0.13(0.34)
Male	=1 if the household head is male, 0 otherwise	0.72(0.45)	0.68(0.47)	0.67(0.47)	0.68(0.46)
Farm size	Total land owned by the household in acres	2.18(1.86)	1.91 (1.75)	2.59 2.07	2.33(1.96
Maize farm size cultivated_	Size of land that is allocated to maize	0.78(.75)	0.83 (0.80)	0.76 (0.74)	0.79(0.77)
TLU	Total livestock units	1.44(3.54)	1.45(3.21)	4.91(8.78)	2.46 (5.73)
Hired labor	=1 if household uses hired labor, 0 otherwise	0.34 (0.48)	0.39 (0.49)	0.34 (0.48)	0.37 (0.48)
Off-farm income	=1 if farmers earned from off income activities, 0 otherwise	0.41 (0.49)	0.39(0.49)	0.30(0.46)	0.37 (0.48)
Institutional variables					
Membershipship to groups	=1 if any of household members participates in any farmer group, 0 otherwise	0.08(0.27)	0.03(0.17)	0.02(0.16)	0.04(0.20)

Awareness of a training prograamme	=1 if any of household members is aware of any agricultural training programme, 0 otherwise	0.61 (0 .49)	0.45 (0.50)	0.42 (0.49)	0.49 (0.50)
Access to training services	=1 if any of household members was trained in agricultural related issues, 0 otherwise	0.12 (0.32)	0.05 (0.22)	0.05 (0.22)	0.07 (0.26)
Access to extension services any provider	=1 if any of household members had access to extension services from any service provider, 0 otherwise	0.14 (0.35)	0.09 (0.28)	0.09(0.29)	0.10(0.30)
Access to government extension services	=1 if any of household members had access to extension services from a government extension service provider, 0 otherwise	0.11(0.32)	0.05(0.21)	0.05(0.22)	0.07(0.25)
Information on agricultural production	=1 if household got extension information on agricultural production, 0 otherwise	0.13(0.34)	0.08 (0.27)	0.08 (0.28)	0.10 (0.30)
Information on agricultural prices	=1 if household got extension information on agricultural prices, 0 otherwise	0.07(0.25)	0.03 (0.16)	0.03 (.17)	0.04 (0.19)
Information on agro-processing	=1 if household got extension information on agro-processing, 0 otherwise	0.06 (0.23)	0.01 (0.12)	0.01 (0.11)	0.03(0.16)
Information on agricultural marketimg	=1 if household got extension information on agricultural marketing, 0 otherwise	0.06 0.24)	0.02 (.15)	0.03 (0.16)	0.03 (0.18)
Rating all extension services	Weighted average score of extension services	1.42 (.58)	1.23 (0.44)	1.38 (.62)	1.35 (0.55)
Climatic shocks					
Flood	=1 if household experienced floods, 0 otherwise	0.02 (0.16)	0.02 (0.15)	0.05 (0.23)	0.03(0.17)
Pests and diseases	=1 if household experienced pests and diseases, 0 otherwise	0.01 (0.12)	0.04 (0. .21)	0.03 (0.16)	0.03 (0.18)
Drought	=1 if farmer experienced drought, 0 otherwise	0.20 (0.40)	0.25 (0.43)	0.22 (0.42)	0.23 (0.42)
Farm characteristics					
Slope	Weighted average score of the slope	2.40 (0.61)	2.35 (0.68)	-	2.34(0.63)
Soil type	Weighted average score of the soil type	1.68(0.81)	1.79 (0.77)	-	1.72 (0.80)
Land quality	Weighted average score of the land quality	1.44 (0.52)	1.27 (0.46)	-	1.39 (0.51)
Observations	Number of households	*1459*	*2416*	*1456*	5331

Source: Authors owns construction based on the UNPs dataset

4.4 Incidence of CSA practices among maize growing households

Table 1 reveals that the legume intercropping was the most common practiced CSA practice (64%), followed by improved seed (16%), pesticides use (7%) and fertilizers (7%). Given the fact some households have multiple maize plots that might be managed in different ways, we disaggregate the CSA practices in terms of singular use, use of two, three and four combinations (Table 2). Findings emphasize that legume intercropping was the most used CSA practice which could be attributed to the fact that legumes are grown by households on a seasonal basis and do not have any cost attached as farmers recycle seed from previous seasons. These CSA combinations were applied in regression analysis to estimate the effects of the household's CSA combination strategies on household-level food access and food availability.

Table 2: Incidence of the use of CSA at household level

CSA technologies	N	Percentage use
Single CSA technology		
Improved maize	161	3.02
legume intercropping	1,929	36.18
Fertilizers	114	2.14
Pesticides	137	2.57
Use of two CSA technologies		
Improved maize+ legume intercropping	241	4.52
Improved maize+ Fertilizers	27	0.51
Improved maize+ Pesticides	40	0.75
legume intercropping + Fertilizers	165	3.1
Legume intercropping +Pesticides	0	0
Fertilizers+ Pesticides	0	0
Use of three CSA technologies		
Improved maize+ legume intercropping +Fertilizers	52	0.98
Improved maize+ legume intercropping +Pesticides	42	0.79
Legume intercropping +Fertilizers+ Pesticides	120	2.25
Improved maize +Fertilizers+ Pesticides	28	0.53
Use of four CSA technologies		
Improved maize+ legume intercropping +Fertilizers +Pesticides	42	0.79
None of CSA technologies	1,929	36

Source: Authors construction based on UNPS datasets

5. Results and discussion

Table 3 compares food security status of maize growing households by identified indicators between adopters and non-adopters of each of the studied four CSA technologies. Adopters of CSA technologies have significantly higher HDDS, MAHFP and FCS than non-adopters. This finding is in agreement with Lopez-Ridaura et al (2018), Wekesa et al. (2018) who found that adoption of CSA practices significantly and positively influences the food security status of adopters. In comparison, MAHFP between adopters and non-adopters of improved maize are less pronounced. However, these comparisons cannot be interpreted as impacts of technology adoption because of systematic differences between adopters and non-adopters. Such differences are controlled for in the impact statistical analysis.

Table 3: Food security status of maize growing households by CSA adoption status

CSA technology	HDDS		MAHFP		FCS	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Legume intercropping	7.92*** (0.04)	7.51 (0.04)	11.46* (0.03)	11.38 (0.03)	50.77*** (0.32)	47.13*** (0.34)

Improved maize	8.36*** (0.08)	7.68 (0.03)	11.51 (0.06)	11.41 (0.02)	52.71*** (0.73)	48.57 (0.25)
Organic fertilizer	8.40*** (0.09)	7.71 (0.03)	11.68*** (0.05)	11.41 (0.02)	56.27*** (0.91)	48.47 (0.24)
Inorganic fertilizer	8.59*** (0.12)	7.72 (0.03)	11.78*** (0.05)	11.41 (0.02)	55.04*** (1.09)	48.73 (0.24)
Any fertilizer	8.40*** (0.08)	7.68 (0.03)	11.73*** (0.04)	11.39 (0.02)	55.38*** (0.73)	48.24 (0.25)
Pesticides	8.51*** (0.07)	7.64 (0.03)	11.69*** (0.04)	11.38 (0.02)	52.90*** (0.67)	48.47 (0.25)

Notes: standard errors are shown in parentheses. ***, * indicate significant differences between adopters and non-adopters at the 1 per cent and 10 per cent level, respectively.

5.1. The determinants of the choice of CSA practices by smallholder maize farmers

Table 4 presents parameter estimates of the panel logistic model which estimates the factors that influence adoption of the various CSAs. Estimate results show that adoption of legume intercropping increases with age of household and increasing MAHFP. Age is associated with more the farming experience, and the higher the likelihood of accumulation of physical and social capital that would be used to adopt a particular CSA. This is agreement with Abegunde et al. (2016) who found age to have a significant and positive influence on the level of adoption of CSA practices in South Africa. Households with stable food supply throughout the year will make all efforts possible to ensure that they have adequate food for their members through adopting legume intercropping as a means to boost production. Male headed households, those that experienced drought, and floods were less likely to adopt legume intercropping. There is a tendency by farmers to recycle seeds for use in the forthcoming seasons. By the fact that such seeds would have been wiped away by floods and drought, chances are such households would not have much to save for food/seed, given the eventual losses. This constrains their ability even to buy such seeds. Hence the negative effect observed here. Similar results (MAHFP, floods, drought) influenced adoption of fertilizer use in maize.

As expected, increasing incidence of pests and diseases were associated with adoption of pesticides use among maize farmers. This implies once attacked by fall army worm as has been the case in Uganda since 2017, farmers have taken immediate efforts to curb the losses from these pests through use of pesticides. In addition, households with better HDDS and MAFHP have positive adoption levels of pesticide use compared to their counterparts. Contrary to the expected, occurrence of drought is associated with limited/non adoption to legume intercropping and fertilizer use. Drought as a risk to farmers exposes them to losses that many farmers once hit by this shock for any season, they may fail to bounce back to invest in fertilizer use. The study finding is a contradiction to Manda et al. (2016) who found that occurrence of droughts increased the use of maize–legume intercropping among maize farmers in Zambia.

We further observe that access to extension services is positively associated with the adoption of three of CSA technologies (improved maize, fertilizers and pesticides), a key signal to the importance of knowledge sharing about improved agronomic practices by extension agents. More importantly, it should be noted that the number of maize growing household accessing extension during the study period (2015/16-2018/19) has declined from 11 to 5 percent. This is not surprising given the past agricultural extension policy shifts in Uganda. Other factors that affected adoption of CSA practices include household size. Household size is critical form of labour, especially during the season when households have several agricultural activities.

Table 4. Panel logistic regression for factor affecting the use of CSA practices

Variables	Improved maize	Maize legume intercropping	Fertilizers	Pesticides
Household characteristics				
Sex (1=male)	0.740***	-0.132	-0.152	0.394***
	(0.154)	(0.094)	(0.131)	(0.141)
Household size	0.055**	-0.021	0.075***	0.0405*
	(0.023)	(0.015)	(0.022)	(0.022)
Age	-0.005	0.0019	0.0059	-0.0101**
	(0.0045)	(0.0029)	(0.0041)	(0.0043)
Hired labor	0.605***	-0.317***	0.626***	1.169***
	(0.117)	(0.0799)	(0.114)	(0.116)
Urban (1=Urban)	-0.311*	-0.227*	0.140	-0.325*
	(0.179)	(0.118)	(0.159)	(0.170)
Off farm income	0.003	0.0399	0.126	0.305**
	(0.126)	(0.0845)	(0.119)	(0.119)
TLU			0.0098	
			-0.01	
HDDS	0.136***	0.0745***	0.0969***	0.187***
	(0.0345)	(0.0218)	(0.0332)	(0.0333)
MAHFP	-0.0160	0.00298	0.158***	0.122**
	(0.0429)	(0.0264)	(0.0548)	(0.0497)
FCS	0.0037	0.0113***	0.0118***	0.0024
	-0.0037	-0.0025	-0.0035	-0.0036
Institutional variables				
Awareness of training programme	0.203*	0.0453	0.204*	-0.251**
	(0.117)	(0.0763)	(0.112)	(0.112)
Training in last 12 months	-0.174	0.0096	-0.323	-0.530*
	(0.264)	(0.193)	(0.272)	(0.292)
Extension access	0.808***	-0.0592	0.414**	0.585***
	(0.196)	(0.148)	(0.199)	(0.198)
Membership to farmer groups	0.292	0.318	0.319	-0.0133
	(0.291)	(0.228)	(0.295)	(0.325)
Climatic shocks				
Floods	-0.291	-0.0642	-0.671*	-0.561
	(0.318)	(0.209)	(0.373)	(0.353)
Pests and diseases	0.0855	-0.283	-0.124	0.851***
	(0.305)	(0.210)	(0.334)	(0.272)
Drought	-0.282*	-0.242***	-0.375**	-0.250*
	(0.146)	(0.0917)	(0.148)	(0.140)
lnsig2u	0.999***	0.642***	0.681***	0.907***
	(0.140)	(0.114)	(0.168)	(0.150)

Constant	-4.999*** (0.624)	-0.807** (0.377)	-6.999*** (0.736)	-6.234*** (0.686)
Year Dummies	Yes	yes	Yes	Yes
Observations	5,292	5,292	5,292	5,292
Number of households	2,510	2,510	2,510	2,510

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

5.2 The effect of adoption of various CSA categories on food access and availability

The treatment variables for the evaluation are CSA technology adoption, referring to the four technologies described above plus selected technology combinations. In principle, 11 different combinations are possible, but many of these combinations are not observed in reality. We focus on those that are more common (see Table 2) so that a sufficient number of adopters is available for the statistical analysis. It should be mentioned that data on technology adoption were collected at plot level, even though the impact evaluation is done at household level. We define a household as CSA technology adopter if it adopted the particular technology on at least one of the maize plots.

From the findings (Table 5), we observe varied effects of CSA practices on food security. For improved maize seed, legume intercropping and fertilizers, we do not observe any significant impact on months of MAHFP. In comparison, use of pesticides had a significant positive effect on MAHFP. Adoption of pesticides increases months of adequate food provision by 0.2 months. Improved maize seed had a significant positive effect on HDDS. Adoption of improved seed increased the HDDS by 0.3. On the other hand, legume intercropping had a significant positive effect on HDDS and FCS. Use of legume intercropping increases HDDS and FCS by 0.1 and 1.7 respectively. This implies that the use of maize-legume intercropping could improve soil quality and then enhance crop yield response of applied inorganic fertilizer use, which could lead to increases in crop income and productivity. In addition, legume crops produced using maize-legume intercropping could help maize farmers to increase their crop income. The emanates due to the improved ability to diversify the food types produced and hence market sales that provide more income and food for households. Thus, the improvement in HDDS emanates from the use of legume intercropping and pesticide use as compared to fertilizer use.

Use of fertilizers is associated with a positive effect on Household FCS. Maize growing households who use only fertilizers on their maize plots are associated with an increase of 3.5 percent in their FCS when compared to their counterparts. The insignificant effect of fertilizer adoption on HDDS and MAHAF could be attributed to the average fertilizer rates use in the Uganda smallholder, which is still lower than recommended levels (MAAIF,2020.). Apart from the usage levels, the proportion of all farming households that use any fertilizer is still low, estimated at only 28.5 percent. Majority of whom use organic fertilisers (22%) compared to inorganic fertilisers (9.6%) (UAAS, 2019).[8] The study findings concur with Wainaina et al (2017) who found similar results among Kenyan farmers.

Pesticide use has a significant positive effect on MAHFP, however, this was not the case regarding HDDS and FCS. The use of pesticides is associated with increasing months when households have

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[8] Uganda Annual agricultural survey report released by UBoS in 2020. Accessible at: https://www.ubos.org/wp-content/uploads/publications/05_2022Uganda_UBOS_StatRelease_AAS2019-Final.pdf

adequate food annually. For months when households have adequate food measured by MAHFP, findings show that adoption of legume intercropping, and pesticide use are associated with increasing months when households have adequate food annually.

For HDDS, we find that legume intercropping, and use of improved maize seed have a positive significant effect on food security. This implies that the use of maize-legume intercropping could improve soil quality and then enhance crop yield response of applied inorganic fertilizer use, which could lead to increases in crop income and productivity. In addition, legume crops produced using maize-legume intercropping could help maize farmers to increase their crop income. This could result from increased opportunities to diversity the food types produced and increase market sales. Thus, improvement in HDDS emanates from the use of legume intercropping and improved maize seed as compared to fertilizers and pesticides.

For months when households have adequate food measured by MAHFP, findings show that adoption of a single CSA technology, did not have any significant effect on the number of months, when households had adequate food annually. MAHFP was only affected by pesticide use. Other factors (appendix 2) that affected MAHFP include household family size, sex of household head, age of household head, use of hired labor, climatic shocks (floods, pests and diseases, drought), and having an alternative off farm source of income. MAHFP tends to reduce in households with big households' size. This is partly explained by the fact that big households consume increasingly large quantities food which constrains the households through the year. In addition, male headed households tend to be more food secure compared to female headed households. This is associated with their access to sources of production like land, which could be used as collateral to access credit for investment in CSA practices. Further households that are prone to floods and drought during the crop growing seasons are susceptible to having increasing months of not having food.

A further synthesis of the effects for CSA technology combinations in Table 5 on food security reveals that adoption of improved seed combined with legume intercropping does not lead to a significant impact on food security, despite being used by over 4.5 percent of the maize household in Table 2. The study finding is a contradiction to Tabe-Ojong et al (2023) who reported that the combination had a positive effect on FCS in West Africa.

However, combining improved seed with pesticides is associated with positive and significant effects on the three food security indicators (HDDS, MAHFP and FCS). In addition, combining legume intercropping with fertilizers increases HDDS by 0.6. In addition, combining improved maize with legume intercropping and fertilizers improves HDDS by 0.8. However, when applied in a combination of the four CSA practices (improved seed + fertilizers + pesticides+ legume intercropping), HDDS increases by 1. The findings from a combination of CSA practices on food security raises the importance of investing in a combination of CSA practices to reap the benefits of CSA practices on their maize farms. This finding is in agreement with other studies (Wekesa *et al.,* 2018; Kim *et al.,* 2019; Egeru *et al.*, 2022) who found that a combination of CSA practices had a positive effect on food security among farming households.

However, food security of maize growing is not only affected by CSA technologies, but also influenced by a number of other factors which range from climatic shocks, institutional and household factors (see appendices 1-3). In this regard, climatic shocks (drought, floods, pests and diseases) have significant negative effects on the three studied indicators of food security (HDDS, MAHFP, FCS) for maize growing households. However, access to extension has a significant effect on food security.

Table 5: Effect of CSA practices on food access and availability

CSA practices	N	Food security indicators	(1)	(2)	(3)
			Pooled OLS	**Fixed effects**	**Random effects**
Improved seed	161	HDDS	0.326** (0.156)	0.110 (0.179)	0.275* (0.150)
		MAHFP	-0.015 (0.116)	-0.158 (0.146)	-0.047 (0.115)
		FCS	-0.202 (1.344)	-0.104 (1.599)	-0.016 (1.305)
Legume intercropping	1929	HDDS	0.149** (0.060)	0.057 (0.075)	0.136** (0.059)
		MAHFP	0.032 (0.045)	0.004 (0.061)	0.028 (0.045)
		FCS	2.084*** (0.519)	0.363 (0.668)	1.672*** (0.513)
Fertilizers	114	HDDS	-0.057 (0.183)	-0.406* (0.233)	-0.123 (0.176)
		MAHFP	0.242* (0.136)	-0.107 (0.189)	0.182 (0.135)
		FCS	5.055*** (1.573)	-3.188 (2.074)	3.501** (1.528)
Pesticides	137	HDDS	0.190 (0.169)	-0.117 (0.205)	0.100 (0.162)
		MAHFP	0.297** (0.126)	0.251 (0.166)	0.291**(0.124)
		FCS	1.253 (1.452)	-0.682 (1.829)	0.579 (1.406)
Improved seed + legume intercropping	241	HDDS	0.256* (0.131)	-0.118 (0.160)	0.178 (0.129)
		MAHFP	0.034 (0.097)	0.157 (0.130)	0.095 (0.099)
		FCS	3.269(1.124)	-0.069 (1.440)	2.326 (1.119)
Improved seed +pesticides	164	HDDS	0.760** (0.305)	0.0855 (0.365)	0.518* (0.293)
		MAHFP	0.163 (0.226)	-0.341 (0.296)	0.0496 (0.225)
		FCS	3.269*** (1.124)	-0.691 (1.430)	2.326** (1.120)
Legume intercropping +Fertilizers	52	HDDS	0.766*** (0.154)	0.104 (0.178)	0.556*** (0.147)
		MAHFP	0.198** (0.114)	-0.033 (0.145)	0.149* (0.113)
		FCS	8.457*** (1.320)	-2.219 (1.590)	5.286*** (1.285)
Improved seed + legume intercropping +Fertilizers	42	HDDS	0.856*** (0.268)	0.449 (0.286)	0.762*** (0.251)
		MAHFP	0.056** (0.199)	0.019 (0.232)	0.059 (0.195)
		FCS	10.84*** (2.304)	1.272 (2.554)	7.664*** (2.206)
legume intercropping + Fertilizers + Pesticides	120	HDDS	0.750*** (0.181)	0.0192 (0.198)	0.456*** (0.170)
		MAHFP	0.272** (0.134)	-0.013 (0.161)	0.177 (0.132)
		FCS	3.189** (1.551)	-3.905** (1.764)	0.802 (1.493)
Improved seed + fertilizers + pesticides+ legume intercropping	42	HDDS	1.247*** (-0.298)	0.496 (0.328)	1.007*** (0.283)
		MAHFP	-0.042 (0.221)	-0.107 (0.266)	-0.044 (0.218)
		FCS	2.354 (2.555)	-3.023 (2.924)	0.767 (2.472)

Controls	yes	yes	yes
Year dummies	yes	yes	yes
Observations	5,292	5,292	5,292
Number of Households	2510	2,510	2,510

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

6. Conclusions and policy recommendations

This paper examined the factors that influence the choice of the CSA practices among maize farmers in Uganda. It further analysed the impact of the adoption of the various CSA categories on food access and availability. Using the three waves of the Uganda National panel survey data collected by UBoS, the study examined four major CSA practices namely; maize–legume intercropping, improved maize varieties, pesticide application, and inorganic fertilizers and their effect on food security. The findings show that legume intercropping was the most adopted CSA technology at 53 percent. Family labour, access to extension services, awareness of training programme had a positive effect on the adoption of CSA technologies. Owing to considerably large proportion of non-adopters, the Government of Uganda, development partners, civil society and other agricultural extension actors ought to increase the dissemination of CSA information to maize growing farmers.

The estimation results further show that when adopted alone – some CSA technologies produce positive food security effects, while other technologies do not. At the same time, some of the technology combinations lead to higher positive food security effects. The largest positive food security effects in terms of HDDS are observed when improved seeds are adopted together fertilizers, pesticides and legume intercropping. This clearly underlines the importance of farmers using a combination of CSA practices for better food security outcomes. Despite the observed effects of using a combination of four CSAs, the number of maize growing households adopting such promising technology combinations is relatively low (less than 1%), suggesting that such combinations are not yet fully exploited. This implies that application of CSA technologies as a package yields maximal food security outcomes. Moreover, application of CSA practices in isolation does not deliver desired food security outcomes. This calls for increased public investment in the implementation of a combination of CSA agricultural technologies in an integrated manner to increase maize crop productivity, as well as boost food security among farming households.

In addition, we observe low adoption rates in combination of CSA technologies. Majority of the maize farming households use improved seed with intercropping (5%) which is applied to nutrient deficient soils, which does not yield desired agricultural outcome. Results as well show that none of the maize growing households applied a combination of fertilizers and pesticides on their maize, which presents a challenge to majority of farmers since many believe that application of fertilizers in one way helps to control pests in maize. There is a need to strengthen the agricultural extension system to improve agronomic practices at the farm level.

Further research could assess the effect of combination of CSA practises on farm outcomes. This is needed for designing and promoting suitable technology combinations in particular settings. In addition, further research should focus on examining the content of agricultural extension packages to ascertain if it contains any climate related information to guide farmers.

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Appendix I: The effect of CSA on Household Dietary Diversity Score (HDDS)

Variables	**(1) Pooled OLS**	**(2) Fixed effects**	**(3) Random effects**
Improved seed	0.326**	0.110	0.275*
	(0.156)	(0.179)	(0.150)
Legume intercropping	0.149**	0.0568	0.136**
	(0.0604)	(0.0749)	(0.0592)
Fertilizers	-0.0568	-0.406*	-0.123
	(0.183)	(0.233)	(0.176)
Pesticides	0.190	-0.117	0.0995
	(0.169)	(0.205)	(0.162)
Improved seed + legume intercropping	0.256*	-0.118	0.178
	(0.131)	(0.160)	(0.129)
Improved seed +pesticides	0.760**	0.0855	0.518*
	(0.305)	(0.365)	(0.293)
Legume intercropping +Fertilizers	0.766***	0.104	0.556***
	(0.154)	(0.178)	(0.147)
Improved seed + legume intercropping +Fertilizers	0.856***	0.449	0.762***
	(0.268)	(0.286)	(0.251)
legume intercropping + Fertilizers + Pesticides	0.750***	0.0192	0.456***
	(0.181)	(0.198)	(0.170)
Improved seed + fertilizers + pesticides+ legume intercropping	1.247***	0.496	1.007***
	(0.298)	(0.328)	(0.283)
Sex (1=male)	0.0580	0.0616	0.110
	(0.0581)	(0.192)	(0.0681)
Household size	0.108***	0.0820***	0.109***
	(0.00975)	(0.0226)	(0.0111)
Age	-0.00786***	0.00932	-0.00737***
	(0.00177)	(0.0106)	(0.00212)
Hired labor	0.495***	0.143**	0.394***
	(0.0557)	(0.0716)	(0.0550)
Urban	0.338***	-0.197	0.251***
	(0.0780)	(0.128)	(0.0824)
Off farm income	0.637***	0.364***	0.588***
	(0.0553)	(0.0915)	(0.0590)
Awareness of an agricultural training programme	0.172***	-0.0465	0.0945*
	(0.0552)	(0.0639)	(0.0524)
Received training	-0.0160	0.0378	0.00269
	(0.140)	(0.156)	(0.132)

Extension access	0.167	-0.00438	0.119
	(0.106)	(0.122)	(0.101)
Membership to farmers groups	-0.00843	-0.0135	-0.00946
	(0.164)	(0.183)	(0.154)
Flood	0.382**	0.329*	0.324**
	(0.151)	(0.177)	(0.144)
Pests and diseases	0.356**	0.184	0.317**
	(0.150)	(0.179)	(0.143)
Drought	-0.219***	-0.0382	-0.150**
	(0.0632)	(0.0744)	(0.0603)
Panel dummies (2015/16 as baseline)			
2018/19	-0.0643	0.0403	-0.0125
	(0.0671)	(0.0709)	(0.0577)
2019/20	-0.354***	-0.495***	-0.373***
	(0.0725)	(0.0810)	(0.0627)
Constant	6.849***	6.696***	6.860***
	(0.130)	(0.473)	(0.145)
Observations	5,294	5,292	5,292
R-squared	0.118	0.064	
Number of households		2,510	2,510
Diagnostics p-Values			
F-test			0.000
Breusch Pagan			0.000
Hausman			0.000

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

Appendix 2: the effect of CSA on MAHFP

	(1)	(2)	(3)
Variables	**Pooled OLS**	**Fixed effects**	**Random effects**
Improved seed	-0.0149	-0.158	-0.0469
	(0.116)	(0.146)	(0.115)
Legume intercropping	0.0323	0.00356	0.0283
	(0.0449)	(0.0608)	(0.0452)
Fertilizers	0.242*	-0.107	0.182
	-0.136	-0.189	-0.135
Pesticides	0.297**	0.251	0.291**
	(0.126)	(0.166)	(0.124)
Improved seed + legume intercropping	0.0338	0.157	0.0950

	(0.0972)	(0.130)	(0.0985)
Improved seed +pesticides	0.163	-0.341	0.0496
	(0.226)	(0.296)	(0.225)
Legume intercropping +Fertilizers	0.198**	-0.0326	0.149*
	(0.114)	(0.145)	(0.113)
Improved seed + legume intercropping +Fertilizers	0.0559	0.0186	0.0590
	(0.199)	(0.232)	(0.195)
legume intercropping + Fertilizers + Pesticides	0.272**	-0.0130	0.177
	(0.134)	(0.161)	(0.132)
Improved seed + fertilizers + pesticides+ legume intercropping	-0.0416	-0.107	-0.0442
	(0.221)	(0.266)	(0.218)
sex (1=male)	0.172***	-0.174	0.166***
	(0.0431)	(0.156)	(0.0489)
Household size	-0.0271***	-0.0371**	-0.0276***
	(0.00724)	(0.0183)	(0.00806)
Age	0.000528	-0.00266	-3.49e-05
	(0.00131)	(0.00860)	(0.00151)
Hired labor	0.205***	0.0368	0.164***
	(0.0413)	(0.0581)	(0.0419)
Urban	0.0154	-0.227**	-0.00496
	(0.0579)	(0.104)	(0.0614)
Off farm income	0.0985**	0.141*	0.111**
	(0.0410)	(0.0743)	(0.0438)
Awareness of an agricultural training programme	0.0243	0.0160	0.0250
	(0.0410)	(0.0519)	(0.0403)
Received training	-0.0122	-0.0725	-0.0235
	(0.104)	(0.127)	(0.102)
Extension access	0.134*	0.132	0.136*
	(0.0790)	(0.0994)	(0.0779)
Membership to farmers groups	-0.0922	-0.130	-0.101
	(0.122)	(0.148)	(0.119)
Climatic shocks			
Flood	-0.613***	-0.458***	-0.586***
	(0.112)	(0.144)	(0.111)
Pests and diseases	-0.196*	-0.201	-0.191*
	(0.111)	(0.145)	(0.110)
Drought	-1.042***	-0.836***	-0.991***

	(0.0469)	(0.0604)	(0.0463)
Panel (2015/16 as baseline)			
2018/19	0.000926	0.0164	0.00689
	(0.0498)	(0.0575)	(0.0455)
2019/20	-0.0161	0.0227	-0.00210
	(0.0538)	(0.0658)	(0.0494)
Constant	11.55***	12.06***	11.58***
	(0.0966)	(0.384)	(0.105)
Observations	5,294	5,292	5,292
R-squared	0.108	0.077	
Number of Households		2,510	2,510
Diagnostics p-Values			
F-test			0.000
Breusch Pagan			0.000
Hausman			0.000

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

Appendix 3: The effect of CSA on Food Consumption Score (FCS)

	(1)	(2)	(3)
Variables	**Pooled OLS**	**Fixed effects**	**Random effects**
Improved seed	-0.202	-0.104	-0.0160
	-1.344	-1.599	-1.305
Legume intercropping	2.084***	0.363	1.672***
	-0.519	-0.668	-0.513
Fertilizers	5.055***	-3.188	3.501**
	-1.573	-2.074	-1.528
Pesticides	1.253	-0.682	0.579
	-1.452	-1.829	-1.406
Improved seed + legume intercropping	3.269***	-0.691	2.326**
	-1.124	-1.43	-1.12
Improved seed +pesticides	2.181	2.786	2.280
	(2.616)	-3.257	(2.551)
Legume intercropping +Fertilizers	8.457***	-2.219	5.286***
	(1.320)	-1.59	-1.285
Improved seed + legume intercropping +Fertilizers	10.84***	1.272	7.664***

	-2.304	-2.554	-2.206
legume intercropping + Fertilizers + Pesticides	3.189**	-3.905**	0.802
	-1.551	-1.764	-1.493
Improved seed + fertilizers + pesticides+ legume intercropping	2.354	-3.023	0.767
	-2.555	-2.924	(2.472)
sex (1=male)	1.381***	0.729	1.582***
	(0.499)	(1.716)	(0.564)
Household size	1.116***	0.708***	1.058***
	(0.0837)	(0.201)	(0.0927)
Age	0.0171	0.210**	0.0212
	(0.0152)	(0.0945)	(0.0174)
Hired labor	4.007***	0.938	3.256***
	(0.478)	(0.639)	(0.476)
Urban	3.055***	-1.856	2.387***
	(0.670)	(1.144)	(0.701)
Off farm income	2.908***	2.031**	3.003***
	(0.475)	(0.816)	(0.501)
Awareness of an agricultural training programme	0.0150	0.146	0.198
	(0.474)	(0.570)	(0.457)
Received training	1.397	0.868	1.248
	(1.206)	(1.394)	(1.153)
Extension access	-0.281	-0.714	-0.280
	(0.913)	(1.092)	(0.884)
Membership to farmers groups	2.963**	-1.220	1.665
	(1.406)	(1.631)	(1.348)
Climatic shocks			
Floods	-1.750	0.902	-1.062
	(1.296)	(1.583)	(1.255)
Pests and diseases	0.364	0.121	0.573
	(1.284)	(1.598)	(1.248)
Drought	-2.671***	-0.793	-2.258***
	(0.542)	(0.664)	(0.525)
Panel dummies (2015/16 as baseline)			
2018/19	0.807	0.879	0.928*
	(0.576)	(0.632)	(0.513)
2019/20	6.941***	5.708***	6.864***
	(0.623)	(0.723)	(0.557)

Constant	33.88***	31.42***	34.43***
	(1.118)	(4.217)	(1.210)
Observations	5,294	5,292	5,292
R-squared	0.108	0.054	
Number of Households		2,510	2,510
Diagnostics p-Values			
F-test			0.000
Breusch Pagan			0.000
Hausman			0.000

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