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RESEARCH ARTICLE

Nourishing the farms, nourishing the plates: Association of climate-smart agricultural practices with household dietary diversity and food security in smallholders

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Abstract

Climate-smart agricultural (CSA) practices are increasingly being promoted as nature-based solutions to improve the livelihoods of smallholder farm households amid a sharp increase in climate-change anomalies. However, the extent to which CSA practices contribute to smallholder food security and dietary diversity remains unclear. In this study, we use panel and nationally representative data from Tanzania to examine the association between two climate-smart agricultural practices, namely, improved maize varieties and maize-legume intercropping, and food security in smallholder farm households. We use maize yield per acre, adult-equivalent food expenditure, and household dietary diversity scores to measure household food security, representing three of the four food security pillars: availability, access, and utilization. We also examine the complementarity and potential advantages of combining improved maize seeds with fertilizers. Using standard panel data estimation approaches, we find a positive

Abbreviations: AEZ, Agroecological Zones; BP-LM test, Breusch–Pagan LM test; CIAT, International Center for Tropical Agriculture; CSA, climate-smart agricultural; FAO, Food and Agriculture Organization of the United Nations; FE, fixed effects; GHG, greenhouse gasses; HDDS, Household Dietary Diversity Scores; LSMS-ISA, Living Standard Measurement Surveys-Integrated Surveys on Agriculture; MAFC, Tanzanian Ministry of Agriculture, Food Security and Cooperatives; NAIVS, National Agricultural Input Voucher Scheme; NBS, Tanzania National Bureau of Statistics; NPS, Tanzania National Panel Survey; RE, random effects; SSA, Sub-Saharan Africa; TSh, Tanzanian Shilling; URT, United Republic of Tanzania; WFP, World Food Programme.

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association between the adoption of improved maize varieties and maize-legume intercropping and an increase in food production measured through higher crop productivity. However, we do not find a corresponding improvement in household dietary diversity or increased food expenditure, despite the higher crop production. Several factors might explain this outcome, including the challenges faced by farmers in accessing markets to sell surplus produce, the influence of established dietary habits, gender issues, and other local factors that promote the consumption of cereal-based foods such as maize. Our findings suggest that CSA practices may help improve food production and availability, but more effort is needed to translate increased food production into improved dietary diversity and better food security among smallholder farmers in sub-Saharan Africa. [EconLit Citations: C23, D12, D13, D24, Q12, Q16, Q18, Q54].

KEYWORDS

climate change, climate smart agriculture, crop production, food security, maize, sub-Saharan Africa, Tanzania

1 | INTRODUCTION

Despite significant progress in food production to eradicate poverty and malnutrition, nearly 10% of the world's population goes to bed on an empty stomach every day (FAO et al., 2020). Sadly, the number of hungry and malnourished people is predicted to increase due to the expected negative effects of climate anomalies on food production (Mbow et al., 2019). Sub-Saharan Africa (SSA) is home to most of the people affected by poverty and malnutrition, especially smallholder farmers who rely on semi-subsistence farming for food and employment (FAO et al., 2020). At the same time, smallholder farming systems in SSA are expected to be the most negatively affected by climate change. Hence, the adoption of climate-smart agriculture (CSA)—a framework for sustainable agricultural production practices and technologies aimed at increasing agricultural productivity, promoting water and soil conservation, preventing soil damage, enhancing resilience to specific climatic stressors, and lowering GHG emissions—is widely viewed as a major route to simultaneously mitigate climate change and improve food security in smallholder farming systems in SSA (FAO, 2013).

Because of the promising claims, the extent to which adoption of CSA practices can improve smallholder households' crop productivity, adaptation, and mitigation has been increasingly researched (Branca et al., 2011; Rosenstock et al., 2016). In particular, a growing body of literature has examined the impact of CSA practices on smallholder crop productivity in SSA, given the fact that the region is characterized by frequent occurrences of climate change anomalies and the importance of smallholder farming for poor households' food security and employment, as stated above. Substantial research suggests that adopting CSA practices improves farm-level crop yields and productivity in smallholders (Abro et al., 2018; Amare et al., 2012; Arslan et al. 2015, 2017; Kassie

et al., 2014; Kathage et al., 2012; Kimaro et al., 2016; Magrini & Vigani, 2016; Manda et al., 2016; Teklewold et al., 2013). However, does the increase in crop productivity translate into better food security and improved dietary diversity in smallholder farm households? What are the mechanisms through which CSA practices influence household food security and dietary diversity? These questions are yet to be answered in the extant literature.

This study contributes to the literature by addressing these two questions. In particular, we investigate the association between CSA practices and food security and dietary diversity in smallholder farm households. We also explore the potential pathways through which CSA practices influence food security and dietary diversity. Numerous CSA practices and technologies have been suggested for smallholder farm households, including improved seed varieties and plantain materials, biodiversity management, integrated pest management, improved water use and management, sustainable mechanization, and other technologies (FAO, 2013). We take smallholder farming systems in Tanzania as our study context, focusing on the adoption of two CSA practices: (1) maize-legume intercropping and (2) improved maize varieties complemented with fertilizers.

Tanzania is an interesting case study because of the widespread undernutrition and pervasiveness of rain-fed smallholder farming systems in the country, which is a typical characteristic of SSA countries. Approximately 25% of the country's population is chronically malnourished (FAO, 2021a). Additionally, 40% of households lack an adequate diet in terms of quantity (food energy) and quality (diet diversity) (WFP, 2013). The country's workforce and livelihoods, which rely on the semi-subsistence agricultural sector, are the most affected (World Bank, 2021). Thus, the country's strategies to reduce poverty and food insecurity depend on sustainably improving smallholder agricultural production. Moreover, the impact of climate change on agriculture in Tanzania has been occurring more frequently and intensively (URT, 2012). Climate anomalies in the country will worsen by 2050, with an estimated yearly loss of US \$ 200 million in the agricultural sector (CIAT, World Bank, 2017). Hence, over the last decade, the government of Tanzania and its stakeholders have been implementing CSA practices, particularly in maize-dominated smallholder agricultural systems (MAFC, 2014; URT, 2012).

Maize is the dominant crop in Tanzania, occupying most cultivated land and providing income generation and food security for smallholder households in the country and other SSA countries (Kimaro et al., 2016; Krishna et al., 2023). However, the yield growth of maize has stagnated since 2003, particularly in Tanzania, where it is even lower than the regional average because of climate change and rising input prices (FAO, 2021b). To address this issue, the Tanzanian government launched fertilizer and seed subsidy programs known as NAIVS (National Agricultural Input Voucher Scheme) in 2008 (World Bank, 2012), as well as promoted legume intercropping in maize-dominated cropping systems (Mugi-Ngenga et al., 2022). These interventions align with the most extensively promoted CSA practices to address food insecurity in many SSA countries, including improved seed varieties and cereal-legume intercropping (Arslan et al., 2017; FAO, 2013). Therefore, it is paramount to investigate whether adopting these two CSA practices can result in greater household food security and dietary diversity, given the critical role of maize in smallholder households' livelihoods in Tanzania and other SSA countries. Improved maize varieties and grain-legume intercropping are typical examples of CSA practices in the literature examining the role of CSA technologies in SSA (Arslan et al., 2017; FAO, 2013; Sibhatu et al., 2022). Moreover, as we examine the possibility of increasing maize productivity on existing agricultural land with positive environmental and dietary impacts using these two innovative CSA practices, our study is also an important addition to the growing body of literature on sustainable intensification (Vanlauwe et al., 2014).

In this study, we measure household food security and dietary diversity using three metrics: maize yield per acre, adult-equivalent (AE) food expenditure, and household dietary diversity scores. These metrics represent three of the four food security pillars, availability, access, and utilization, which are discussed in the Materials and Methods section. To explore the association between CSA technology adoption and food security outcomes, we use nationally representative panel data of smallholder maize farmers and employ standard panel data regression models. Using panel data analysis adds robustness to previous research examining how CSA practices influence crop productivity using cross-sectional data. This is also an important contribution of our study to the available literature. Unlike studies that provide evidence from case studies, experimental plots, or lab-in-the-field

experiments of particular regions, we offer real-world evidence from farmers' fields and nationally representative data in this study, which might have stronger external validity and application in a broader context (Wooldridge, 2010). We also consider the complementarity and potential advantages of combining improved maize seeds with fertilizers, which was not done in previous studies to the best of our knowledge. Our findings show that improved maize varieties and maize-legume intercropping are significantly and positively associated with greater food production by increasing crop yield and productivity, but the increase in yield and productivity does not translate into higher spending on food and greater dietary diversity in smallholder farm households. This implies that CSA practices may help address SSA's pervasive hunger and malnutrition by increasing food availability, particularly if complemented with appropriate fertilizers. However, more research is needed to translate this increase in crop yield and productivity into adequate diverse food consumption and better food security.

The remainder of this paper is organized as follows. Section 2 presents the conceptual framework on which our empirical analysis is based. After describing the data, Section 3 explains the methodology and outlines the empirical approach. The results are reported in Section 4, and Section 5 discusses the findings and limitations of the present study. Section 6 concludes the study and provides directions for future research.

2 | CONCEPTUAL FRAMEWORK ON CSA PRACTICES AND FOOD SECURITY

Several factors affect food security and diet in smallholder farm households, including climate shocks, baseline poverty rates, and market constraints (De Pinto et al., 2020; Sibhatu & Qaim, 2017; Steenwerth et al., 2014). However, in this study, we are interested in examining how the two CSA practices (improved seed variety coupled with fertilizer and legume intercropping) are associated with the three indicators of food security (maize yield, household food expenditure, and dietary diversity scores). Hence, in this section, we review the literature to illustrate that CSA innovations' effects on each food security indicator generally follow three interlinked pathways.

First, intercropping maize with legumes can be directly and positively associated with maize yield because of crop synergism, resource sharing, and improved soil fertility (Arslan et al., 2015; Nassary et al., 2020). Similarly, adopting and cultivating improved maize seeds, especially when coupled with the recommended quantity of fertilizer, can help narrow the yield gaps (Abdoulaye et al., 2018; Abera et al., 2017; Koppmair et al., 2017a). These productivity-enhancing CSA practices and technologies can increase the quantity of food produced on own farm, implying an increase in households' physical availability and access to food. As our sample households are subsistence farmers suffering from undernourishment, we anticipate that adopting CSA practices would increase food availability.

Second, the two CSA practices we use in our study can directly and indirectly affect household food expenditures. In particular, increased productivity can boost surplus crop sales, allowing households to spend more on food. Higher food expenditure is a reliable proxy for higher physical availability, better economic access to food and nutrition (Smith & Subandoro, 2007), and reduced food insecurity (Salazar et al., 2015). Moreover, maize-legume intercropping and improved maize seeds can also positively affect food expenditure by ensuring a more stable income and strengthening resilience despite climatic shocks, allowing households to spend more on food (Chegere & Stage, 2020; Wekesa et al., 2018). However, improved maize seeds and other farm inputs are likely more expensive than regular varieties or recycled seeds; thus, farmers adopting these seeds might also be exposed to more risks. Nonetheless, we hypothesize that the higher the adoption of CSA practices, the higher the household spending on food.

Third, legume-maize intercropping could be linked to household food consumption through diversification, namely, the diversity of foods from farmers' own production (Qaim, 2014). Dietary diversity is an essential proxy for dietary quality, and improving crop diversification by adding legumes (a more nutritious

food) to cereals (maize) improves household food diversity and quality. This practice may increase the number of crops cultivated and available for consumption, especially for households that rely on subsistence farming (Marenya et al., 2018). However, particularly in the case of Tanzania, in our study context, the direct effect of maize-legume intercropping on dietary diversity might be because dietary diversity would increase by one food group and only for households in the absence of intercropping, and no legumes would be consumed at all in the last 7 days (see the methodology section). Hence, the magnitude of the positive effect may be context-specific and depends on the level of diversification, consumption of legumes, subsistence, and market access (Koppmair et al., 2017b; Sibhatu & Qaim, 2018). Nonetheless, we expect a positive relationship between the two CSA practices and the three indicators of food security and dietary diversity we examine in this study.

Overall, smallholders' adoption of improved seed varieties and legume intercrops can positively affect food security and dietary diversity through interlinked pathways of increased maize yield, higher household food expenditure, and improved dietary diversity.

3 | MATERIALS AND METHODS

3.1 | Data

The data for this study come from two survey waves of the Tanzania National Panel Survey (NPS) conducted by the Tanzania National Bureau of Statistics (NBS) and the World Bank (NBS, 2013). The first wave was conducted from October 2010 to November 2011, and the second from October 2012 to November 2013. The NPS is a series of Living Standard Measurement Surveys-Integrated Surveys on Agriculture (LSMS-ISA) at the plot and household levels, which provides information on agricultural production, nonfarm income-generating activities, food consumption, and other socioeconomic characteristics (NBS, 2013).

The sample households were selected based on a stratified multistage cluster sample designed to ensure a nationally representative panel. Households interviewed in 2010/11 were tracked in 2012/13, even if the household moved to another location, to minimize sample attrition. Moreover, households that could not be located or interviewed for certain reasons were replaced with other randomly selected households to maintain the representativeness of the sample at the national level.

This study focuses on maize farming households and plots cultivated with maize in the main growing season, during which maize grows in all regions and represents most of the total volume of seasonal crops harvested (Magrini & Vigani, 2016; Stahley et al., 2012). We construct an unbalanced panel that includes 1381 maize households and 2073 maize plots from the 2010/11 wave, and 1759 households managing 2626 maize plots from the 2012/13 wave. The sample observation rose in the 2012/13 wave due to the addition of new observations or households split into two or more households (NBS, 2013). We decided to use an unbalanced panel rather than a balanced one because the latter would lead to dropping observations and losing valuable information and efficiency in the estimation (Baltagi & Song, 2006).

3.2 | Variables description

We aimed to assess the association between smallholders' adoption of CSA practices, and food security, and dietary diversity. To accomplish this, we construct several indicators for the two CSA practices that our sample households adopted and measure their food security and diversity. We begin by explaining the indicators of CSA practices.

3.2.1 | Indicators of climate-smart agricultural practices

In our study, we utilize various CSA variables to analyze the adoption of improved maize seeds and maize-legume intercropping, depending on the level of analysis and outcome of interest. For productivity analysis at the plot level, we use a binary variable to identify the adoption of CSA practices. However, this approach may not be suitable for household-level analysis, as it fails to distinguish various degrees of adoption, especially in cases where some households adopt only one of the two CSA practices or none at all (Kathage & Qaim, 2012). Therefore, we use different indicators for the plot- and household-level specifications and several variables to represent the adoption of the two CSA practices. Specifically, for the plot-level analysis, we construct two adoption variables based on whether one of the two CSA practices was adopted. The first variable indicates whether improved maize seeds complemented with organic or inorganic fertilizers were used in a given plot. The second CSA variable represents whether maize is intercropped with legumes in a given plot.

For the household-level analysis, we construct and use continuous CSA indicators, which are calculated by identifying the total area in acres devoted to improved maize seeds complemented with fertilizers and the total area in acres of maize intercropped with legumes. This allows us to interpret the coefficients of the two continuous CSA variables as the change in the outcome variables given an increase of one acre in areas devoted to CSA (Kathage & Qaim, 2012). Additionally, we derive a variable that measures each household's share of land area devoted to maize cultivation under CSA practices. This CSA variable can serve as a measure of adoption intensity (Feder et al., 1985; Rahman et al., 2022).

3.2.2 | Measures of food security and dietary diversity

We employ three metrics to measure food security and dietary diversity: maize yield (kg/acre), AE food expenditure, and household dietary diversity. Crop yield per land area is commonly used to measure the physical amount of food available for a given household, particularly when households are semi-subsistent or subsistent (Magrini & Vigani, 2016). The NPS questionnaire asked farmers to report the quantity of maize harvested and plot size, which allows us to calculate maize yields at both plot and farm levels.

Food expenditure is another important metric for the assessment of food security. A household's higher food expenditure may indicate greater physical availability and economic access to food. Therefore, it is a proxy for a better diet and nutrition (Feleke et al., 2019). We use annual food expenditure per AE as an indicator of food security, including food consumed by households from their own production, gifts, and purchases. By measuring consumption expenditure in terms of the AE scale, which accounts for the demographic structure of a given household (children, adult females, and males), we may avoid underestimating consumption and account for economies of scale within a household (NBS, 2013).

Finally, we employ household dietary diversity scores (HDDS) to measure dietary diversity at a household level, which is a standard indicator of a household's food access and dietary quality (Swindale & Bilinsky, 2006). HDDS is computed by counting the number of food groups consumed by a given household in the previous 24 h or 7 days. The standard HDDS includes 12 food groups ranging from 0 to 12: cereals, roots and tubers, vegetables, fruits, meat, eggs, fish and seafood, legumes and nuts, milk and milk products, oil and fats, sugar and honey, and miscellaneous (spices, condiments, and beverages) (Swindale & Bilinsky, 2006). Based on the survey data, we use the HDDS for a 7-day recall period.

3.2.3 | Covariates

Apart from CSA practices, many factors related to plots, farms, households, and agroecology can also influence maize yields, food expenditure, and dietary diversity. To account for these factors in our estimations, we construct a

set of independent variables based on the literature. For observable farm and plot characteristics, we consider production inputs used by respondent households, such as inorganic and organic fertilizers, which are found to improve soil fertility and increase yields (Akinnifesi et al., 2007; Mtambanengwe et al., 2007). We consider labor use-related factors to be particularly relevant in small-scale, labor-intensive farm households. We measure labor use in terms of days spent on land preparation, planting, and harvesting by household members and hired workers (Abdoulaye et al., 2018). We also control for land size, given the importance of production input and the assumption of an inverse relationship between farm size and productivity (Carletto et al., 2013). Other plot characteristics that affect crop yield are soil quality, plot slope, nutrient availability and constraints, use of pesticides, and adoption of soil and water conservation (SWC) strategies (Arslan et al., 2017). We also include these characteristics in our estimation models (see the next section).

Household-level farm characteristics might also be associated with the outcome variables we use in this study. Based on the literature, we control for total land area in acres, the total number of livestock (measured in tropical livestock units) (Njuki et al., 2011), and ox-based machinery owned per acre (Chegere & Stage, 2020; Kassie et al., 2014). We also account for households' access to extension services, price information, input vouchers, credit, and off-farm income (Anderson, 2004; Norton et al., 2010). Other household-level information that we consider includes the household head's education level, gender, age, and household size on an adult equivalent scale (Arslan et al., 2015; Slavchevska, 2015). In addition, we include a dummy variable that captures if a household was severely affected by a welfare shock in the past 5 years, which could diminish food access and diet diversity. Finally, production diversity can influence dietary diversity, especially within smallholder farm households that consume a significant portion of what they produce. Thus, we include a production diversity indicator measured by the number of crops cultivated (Sibhatu & Qaim, 2018; Sibhatu et al., 2015).

The NPS surveys also provide georeferenced data concerning household residence, agroecological zones (AEZ), mean temperature, and rainfall, which could also influence the linkage of CSA practices with food security and dietary diversity (Block et al., 2021; Hörner & Wollni, 2021; Rowhani et al., 2011). Hence, we control our estimation for total rainfall, mean temperature during the primary growing season, and location dummies and binary variables for AEZ to capture the wide heterogeneity in Tanzanian maize production areas and climate.

3.3 | Estimation approach

Our objective is to assess the association between household CSA practices (improved maize seeds and maize-legume intercropping) and three outcomes (maize yield, expenditure on food consumption, and household dietary diversity score). To this end, we employ three regression models. The first regression model, which uses the Cobb-Douglas functional form and requires logarithm transformation for continuous variables, examines the relationship between maize yield and the two CSA practices (Arslan et al., 2017; Kathage et al., 2012; Sauer & Tchale, 2009). It is specified as:

$$Y_{hit} = \alpha X_{hit} + \beta_0 Z_{it} + \beta_1 Z_{ht} + \gamma IMPR_{hit} + \delta INTER_{hit} + \theta Wave_t + u_{hit} \quad (1)$$

where Y_{hit} is the natural logarithm of maize yield (kg/acre) in plot i of household h at time t ; X_{hit} is a vector of production inputs; Z_{it} is a set of characteristics of plot i at time t , whereas Z_{ht} is a vector of variables controlling for household characteristics; $IMPR_{hit}$ is a binary variable equal to 1 if household h in plot i at time t used improved maize seeds with fertilizers and 0 otherwise; $INTER_{hit}$ is a binary variable that equals 1 if maize is intercropped with legumes on plot i at time t and 0 otherwise; $Wave_t$ is a dummy variable capturing time-fixed effects (FE) and equals 1 if the observation refers to the 2012/13 NPS wave; u_{hit} is the composite error term given by the idiosyncratic time-varying error term ε_{hit} , and a_h , the time-invariant, unobserved individual heterogeneity: $u_{hit} = \varepsilon_{hit} + a_h$ (Wooldridge, 2019).

The second-panel regression equation estimates the relationship between the two CSA practices and AE food expenditure and household dietary diversity. It is constructed as follows:

$$Y_{ht} = \alpha X_{ht} + \gamma IMPR_{ht} + \delta INTER_{ht} + \theta Wave_t + u_{ht}, \quad (2)$$

where Y_{ht} is either the AE food expenditure or the HDDS of household h at time t ; X_{ht} is a vector of explanatory variables at the household level; $IMPR_{ht}$ refers to either the total area devoted to improved maize seeds with fertilizers or the share of an area of improved maize seeds with fertilizers out of the total maize area; $INTER_{ht}$ stands for the total area devoted to maize intercropped with legumes or the share of maize-legume intercropping on the total area devoted to maize; $Wave_t$ is the time-FE such as in Equation (1); u_{ht} is the composite error which includes both ε_{ht} , and a_h the unobserved heterogeneity.

The Cobb–Douglas functional estimation is particularly suitable for variables with few zero values, which is the case for our outcome variables. Nonetheless, for the continuous variables (yield) not used by the farmers or undefined values after logarithmic transformation, we replaced them with zero, based on Battese's (1997) suggestion. FE and random effects (RE) are two commonly used methods for panel data estimation. However, FE estimation is often preferred over RE when analyzing household survey data, as in this study (Wooldridge, 2010). In particular, FE estimation is a better model than RE estimation for several reasons. First, household survey data often contain unobserved heterogeneity, which can affect the dependent variable. The FE estimation allows for the control of time-invariant unobserved factors at the individual level, which helps eliminate biases arising from unobserved heterogeneity. For example, fixed effects can capture individual-specific characteristics that are constant over time but may affect outcomes, such as cultural or social factors (Wooldridge, 2010). This issue is particularly important in our study, given that diet is strongly associated with cultural and social factors.

Second, endogeneity arises when a correlation exists between the error term and independent variables. In household survey data, endogeneity can be a concern because of factors such as measurement errors, omitted variables, or reverse causality. The FE estimation helps mitigate endogeneity by differentiating the time-invariant unobserved factors, thereby reducing the potential for bias (Wooldridge, 2010). Third, household survey data often have a small number of time periods (t), but a large number of sample observations. The RE models assume that individual-specific effects are uncorrelated with the independent variables, which can be problematic when t is small, which is clearly the case in our dataset. The FE models, on the other hand, do not rely on this assumption and can provide consistent estimates even with a small t . Finally, FE estimation is particularly useful for causal inference because it allows researchers to control for time-invariant confounders. By differencing out individual-specific effects, fixed effects models can provide more reliable estimates of the causal relationship between the independent and dependent variables. Given this background, we use the FE model specifications to estimate Equations (1) and (2).

4 | RESULTS

We now present our findings and begin with descriptive results before the results of our regression estimations.

4.1 | Descriptive statistics

Table 1 reports the summary statistics for the main variables employed in this study, organized by survey rounds. The descriptive results for all the variables used in the analyses are presented in Supporting Information S1: Table A1. The average maize yield during the 2010/11 growing season was 658 kg/acre. However, this value decreased slightly during the 2012/13 growing season. The average annual food expenditure per AE was 437,120 TSh and 398,590 TSh in the 2010/11 and 2012/13 survey waves, respectively. The HDDS remained around a score

TABLE 1 Descriptive characteristics of maize farming households in Tanzania by survey wave for.

Variables	Survey wave			
	2010/11		2012/13	
	Mean	SD	Mean	SD
<i>Outcome variables:</i>				
Maize yield (kg/acre)	657.59	1315.11	640.67	1296.24
Annual food expenditure per AE ('000 TSh)	437.12	270.41	398.59	253.81
HDDS	8.20	1.95	7.94	2.15
<i>Plot-level characteristics:</i>				
Improved seeds with fertilizer	0.06	0.23	0.10	0.29
M-L intercropping	0.34	0.47	0.37	0.48
Organic fertilizer	0.13	0.34	0.15	0.36
Inorganic fertilizer	0.19	0.39	0.16	0.37
Maize area	1.47	2.53	1.44	2.14
Plot size	2.85	4.41	2.99	4.74
<i>Household-level characteristics:</i>				
Improved seeds with fertilizer area (acres)	0.13	1.20	0.26	1.34
HH used improved seeds with fertilizer	0.07	0.25	0.12	0.32
Share of improved seeds with fertilizer	0.06	0.23	0.10	0.29
Intercropped maize area (acres)	0.58	1.47	0.58	1.26
HH intercropped maize with legumes	0.42	0.49	0.45	0.50
Share of intercropped maize area	0.35	0.45	0.37	0.46
Number of households		1381		1759
Number of plots		2073		2626

Note: Means and standard deviations refer to the total sample for each wave. Standard deviations are shown in parentheses. Both food and total expenditure are in real terms, and for the 2012/13 NPS round, are adjusted for inflation at the 2010/2011 food prices (NBS, 2013). Descriptive statistics for all variables used in this study are reported in Supporting Information S1: Table A1.

of eight in both waves, indicating that households engaged in maize farming consumed an average of eight out of 12 food groups in the week before the interview.

Table 1 also presents the descriptive findings of the CSA practices at the plot-level. A small percentage of maize plots were cultivated with improved maize seeds complemented with fertilizers in 2010/11 (6%) and 2012/13 (just 10%). However, maize-legume intercropping was found in over one-third of the plots (34% in 2010/11 and 37% in 2012/13). The proportion of adopters of both CSA practices and the average area devoted to improved maize seeds with fertilizers increased slightly from 2010/11 to 2012/13. Maize-legume intercropping is a relatively common traditional practice adopted by almost half of the maize households. The size of land allocated to maize is less than three acres, accounting for approximately half of all plots owned by a given household.

Furthermore, households in Tanzania tend to diversify crop production by cultivating more than five crop species on a given farm in both production seasons. Supporting Information S1: Table A2 further displays the differences in the outcomes and main explanatory variables based on the gender of the household head. This

finding indicates that maize yields are notably higher for male-headed households than for their female-headed counterparts. The productivity gap can be attributed to various observable and unobservable factors. The figures illustrate that female-headed households face difficulties in accessing vital inputs such as fertilizers and pesticides and are more vulnerable to drought. Additionally, male-headed households possess significantly more total land and land dedicated to maize cultivation. We speculate that this disparity is primarily due to women's limited access to essential technologies, inputs, and resources.

Table 2 compares the outcome variables by survey year and CSA practice adoption. The results indicate that in 2010/11, the maize yield in plots with improved seeds and fertilizers was almost twice as high as that in plots without improved seeds and fertilizers. The same trend was observed in 2012/13, but the difference between plots without improved seeds and fertilizers decreased substantially. Additionally, plots under maize-legume intercropping had, on average, higher yields than those in which maize and legumes did not grow together.

Table 2 reports additional information on the average food consumption expenditure in AE and HDDS, broken down by CSA practice. Adopter households using improved maize varieties with fertilizers reported higher food expenditure in both survey rounds. In contrast, the food expenditure of nonadopter households decreased by 10% from 2010/2011 to 2012/2013, while the expenditure of adopter households decreased by 3.5%. On average, there was no significant difference in food consumption expenditure between intercropping adopters and nonadopters.

HDDS is higher among adopters of improved maize seeds by one food group, indicating that adopting this CSA practice could lead to an increase in food consumption expenses and a more diverse diet. However, based on the HDDS, the maize-legume intercropping decision does not seem to significantly influence the diversity of food groups consumed or the money spent on food. This is not surprising because nearly 90% of the sample households consumed legumes, nuts, and seeds (Supporting Information S1: Table A3). However, Supporting Information S1: Table A3 shows that the percentage of households among adopters of improved maize who consumed meat products, eggs, or milk/milk products was significantly higher than the proportion of intercropping households and

TABLE 2 Maize yield, household food expenditure, and dietary diversity by survey wave and CSA practices adoption.

Variables	Improved maize seed with fertilizer			Maize-legume intercropping		
	Adopters	Nonadopters	Difference	Adopters	Nonadopters	Difference
<i>2010/11 Survey wave:</i>						
Maize yield (kg/acre)	1164.1	626.5	537.6***	824.0	573.3	250.7***
Annual food expenditure per AE ('000 TSh)	513.4	431.4	82.0***	439.1	435.8	3.3
Household dietary diversity scores (12 food groups)	9.3	8.1	1.2***	8.3	8.1	0.2**
<i>2012/13 Survey wave:</i>						
Maize yield (kg/acre)	840.8	619.6	221.2***	783.4	556.0	226.4***
Annual food expenditure per AE ('000 TSh)	495.3	385.5	109.8***	399.1	398.2	0.9
Household dietary diversity scores (12 food groups)	9.1	7.8	1.3***	7.9	7.9	0

Note: Differences are significant at the 1% level (*** $p < 0.01$) and 5% level (** $p < 0.05$) levels. Average food consumption expenditure in the AE scale adjusted for 2010/2011-year prices. Maize yield is at plot level. Food consumption expenditure and household dietary diversity scores are household-level variables.

Abbreviation: AE, adult-equivalent.

the total sample. As a result, improved maize adopters, on average, consume one additional food group, which is likely to be a protein-rich, animal-source food.

Overall, the above findings demonstrate that those who adopt CSA practices tend to perform better in harvesting higher maize yields, with negligible differences in terms of food consumption diversity and security. However, these findings are from descriptive analyses without accounting for other confounding factors. In the following subsection, we test and provide more insights in a regression setting, where we control for potential confounding variables that might provide further insights into the association between the two CSA practices and three food security indicators.

4.2 | Association of CSA practices with maize yield

We now present and discuss the results of our panel regression model estimation. We begin with regression findings on the association between CSA practices and yield. Table 3 reports the summary results, and the full model estimations are presented in Supporting Information S1: Table A4. Both improved maize seeds with fertilizers

TABLE 3 Regression results of maize productivity analysis.

Dependent variable: log (maize yield)	Pooled OLS	FE
Improved seeds with fertilizer (dummy)	0.42*** (0.06)	0.19** (0.10)
M-L intercropping (dummy)	0.13*** (0.03)	0.22*** (0.07)
Organic fertilizer (dummy)	0.11** (0.05)	0.10 (0.08)
Inorganic fertilizer (dummy)	0.43*** (0.05)	0.20** (0.08)
Other control variables	Yes	Yes
Wave 3 2012–2013 (dummy)	−0.10*** (0.03)	−0.16*** (0.04)
Constant	6.47*** (1.33)	53.24* (30.97)
Number of observations	4,699	4,699
Number of IDs		3,522
R ²	0.37	0.29
Breusch-Pagan LM test		96.85***

Note: OLS is ordinary least squares. FE is fixed effects. The dependent variable is the logarithm of maize yield in kg/acre. Log means natural logarithm.

Abbreviations: FE, fixed effects; SWC, soil and water conservation.

***significant at 1% level.

**significant at 5% level.

*significant at 10% level.

In parentheses are clustered standard errors. Full model estimations are presented in Supporting Information S1: Table A4.

and maize-legume intercropping have a statistically significant and positive association with maize yields, respectively, at 5% and 1% significance levels. On average, the use of improved maize seeds with organic or inorganic fertilizers is associated with a 19% increase in maize yield. Similarly, maize-legume intercropping is associated with a 22% average increase in maize yield during both main growing seasons in Tanzania. The potential gains in yields due to the use of inorganic fertilizers, such as nitrogen and urea, are also evident in the coefficients of organic and inorganic fertilizers.

Among the covariates included in our estimation models (Supporting Information S1: Table A4), good soil quality is associated with a 16% higher maize yield. In comparison, drought is associated with an average decrease of 20% in the maize yield. Among the household characteristics, receiving information about agricultural prices is associated with a 14% increase in maize productivity, and gender is the only household head characteristic with a significant coefficient, with female household heads associated with an approximately 28% increase on average yields. Finally, the different coefficients of the agroecological zone dummies indicate no statistically significant heterogeneity in maize production in Tanzania.

4.3 | Association of CSA practices with food expenditure

We continued with the regression findings on the association between CSA practices and food expenditure, as presented in Table 4. We find significant differences across households (individual effects), which leads us to conclude that the variance of the residuals is statistically significantly different from zero (BP-LM test). This finding indicates that FE is more appropriate for controlling for unobserved characteristics, as indicated by the Hausman test coefficient.

The coefficients of improved maize varieties with fertilizers and intercropping are both positive in the FE model estimates but statistically insignificant. There is also no evidence of a statistically significant relationship between the area devoted to intercropping maize with legumes and annual food expenditure. Among the covariates included, access to credit is strongly associated with higher food expenditure. The coefficient of female headship is negative but statistically insignificant, showing that it is different from the descriptive statistics. Hence, other factors may explain the differences in food expenditure between female-headed and male-headed households. Notably, the coefficient of the time fixed effects dummy is highly significant; common shocks, such as food price inflation in the 2012/13 production season, might have a significant impact on food expenditure, reducing it by 38,530 TSh (Table 1).

4.4 | Association of CSA practices with household dietary diversity

Our last regression analysis examines the relationship between CSA practices and household dietary diversity and quality, as measured by the HDDS (Table 5).

Similar to the model estimation for the household food expenditure, neither of the CSA practices shows a statistically significant or large association with the number of food groups consumed within a household. As a robustness check, even by using dummies as a measure of CSA adoption variables, the coefficients and significance levels do not change (Supporting Information S1: Table A5).

On the other hand, the logarithm of total annual expenditure has a highly significant and positive coefficient; a 1% increase in total annual expenditure results in an increase of 0.012 HDDS. In addition, household size, measured on the AE scale, is highly associated with HDDS. Agricultural production diversity, as measured by the total number of crops cultivated by a household, also exhibits a statistically significant positive coefficient, although the coefficient is small, implying that a household must introduce an economically and agronomically unrealistic number of new crops to improve their dietary diversity by one food group.

TABLE 4 Regression results of adult-equivalent food expenditure model.

Dependent variable: food expenditure in AE	Pooled OLS	FE
Improved seeds with fertilizer area (acres)	12,821*** (4334)	150 (7710)
Intercropped maize area (acres)	-3068 (3183)	4082 (5033)
Total maize area (acres)	971.9 (1921)	92 (5638)
Off-farm income (dummy)	38,909*** (8798)	6339 (13,630)
Female household head (dummy)	-10,038 (11,953)	-57,388 (53,460)
Age of household head (years)	1347*** (360.9)	1055 (2146)
Years of education (household head)	12,976*** (1681)	343 (7387)
HH's size in adult equivalent (AE)	-41,171*** (2910)	-54,841*** (8616)
Credit access (dummy)	88,220*** (13,768)	51,599** (21,041)
Distance to nearest major road (km)	-287.0 (229.7)	2723 (3550)
Total land area (acres)	1896** (755.9)	860 (2682)
Livestock size in tropical livestock units (TLU)	3838*** (650.1)	2405 (1661)
Rural household (dummy)	-60,256*** (14,927)	58,367 (62,374)
Welfare shock (dummy)	-2173 (10,445)	15,375 (13,729)
Wave 3 2012-2013 (dummy)	Yes -51,915***	-47,341*** (9729)
Constant	(7,758) 447,570***	591,993*** (129,587)
Number of observations	(32,257)	3140
Number of Ids	3140	2127

(Continues)

TABLE 4 (Continued)

Dependent variable: food expenditure in AE	Pooled OLS	FE
R-squared		0.016
Hausman test	0.226	29.17**
Regional dummies		Yes

Note: OLS is ordinary least squares. FE is fixed effects. The dependent variable is annual food consumption expenditure per adult equivalent.

Abbreviation: FE, fixed effects.

***significant at 1% level.

**significant at 5% level.

*significant at 10% level.

In parentheses are clustered standard errors. Regional dummies are not reported for brevity.

Finally, female-headed households have a higher dietary diversity score for almost one food group, *ceteris paribus*. The 2012/13 dummy, controlling for time-fixed effects, captures the difference between the two waves in terms of HDDS. The statically significant coefficient shows a general deterioration in food diversity consumption from 2010/2011 to 2012/2013. Rather than idiosyncratic shocks, such as the death of a household member, countrywide shocks appear to explain the decline in food access, similar to the findings in the food expenditure analysis.

5 | DISCUSSION

In this study, we have analyzed the relationship between CSA practices and household food security using nationally representative panel data from Tanzania. Our regression results show evidence of a significant positive association between improved maize varieties with fertilizers and maize yields, which aligns with previous studies reporting a positive impact of smallholder agricultural interventions on household food security and diet (Garbero & Jäckering, 2021; Sibhatu et al., 2022). However, we have revealed that the increase in maize yield associated with this CSA practice is smaller than that reported in previous studies (Arslan et al., 2015; Manda et al., 2016). This could be explained using a national sample rather than narrowing the analysis to specific areas where the existing traits of modern varieties are more suitable (Kathage et al., 2012). The lack of a positive association between improved maize seeds and yields in similar studies in Tanzania could also be due to the consideration of improved seeds alone, without accounting for the complementarity with fertilizers (Arslan et al., 2017). Moreover, our study covers the peak period of the input voucher distribution promoted by the NAIVS and at the national level. That is why we have used only the 2010/2011 and 2012/2013 survey waves of the Tanzania NPS.

We have found a positive association between maize and legume intercropping and maize yields. This positive outcome has been well documented in the literature (Arslan et al., 2017; Nassary et al., 2020; Rusinamhodzi et al., 2012). Intercropping of cereals with legumes helps fixing nitrogen in the soil, improving soil quality and fertility (Jensen et al., 2020), even in less fertile soils (Kermah et al., 2017). Hence, intercropping cereals with legumes is a promising CSA practice for both increasing food security and improving soil fertility.

With respect to the relationship between improved maize varieties and food security metrics, our findings do not seem to comply with previous literature, which finds a positive impact of improved varieties on crop productivity (Abro et al., 2018; Kassie et al., 2014; Magrini & Vigani, 2016; Teklewold et al., 2013). We do not find that the decision to use improved maize varieties and fertilizers influences household food expenditure or dietary diversity. We also find no evidence of a positive and statistically significant association between maize-legume intercropping and HDDS scores. However, this is not surprising given that legumes are consumed by almost all households, regardless of intercropping

TABLE 5 Regressions results of household dietary diversity model.

Dependent variable: HDDS	Pooled OLS	FE
Share of improved seeds with fertilizer	0.31** (0.12)	-0.11 (0.21)
Share of intercropped maize area	-0.11 (0.07)	0.02 (0.11)
Off-farm income (dummy)	0.10 (0.06)	-0.11 (0.10)
Log (total annual expenditure)	1.47*** (0.06)	1.25*** (0.12)
Female household head (dummy)	0.08 (0.08)	0.85*** (0.31)
Age of household head (years)	-0.02*** (0.00)	-0.04*** (0.01)
HH's size in adult equivalent (AE)	0.18*** (0.02)	0.28*** (0.06)
Years of education (household head)	0.05*** (0.01)	0.04 (0.04)
Credit access (dummy)	0.11 (0.09)	0.22 (0.15)
Distance to agricultural market (km)	0.00 (0.00)	-0.03*** (0.01)
Distance to nearest major road (km)	-0.00** (0.00)	0.00 (0.02)
Log (total land area in acres)	0.03 (0.04)	0.13 (0.10)
Livestock size in tropical livestock units (TLU)	-0.00 (0.00)	0.01 (0.01)
Total number of crops cultivated	0.09*** (0.01)	0.07*** (0.03)
Rural household (dummy)	-0.36*** (0.09)	-0.04 (0.52)
Welfare shock (dummy)	-0.08 (0.08)	-0.12 (0.10)
Wave 3 2012–2013 (dummy)	-0.67*** (0.06)	-0.60*** (0.07)

(Continues)

TABLE 5 (Continued)

Dependent variable: HDDS	Pooled OLS	FE
Constant	-11.86*** (0.83)	-5.49*** (1.86)
Regional dummies	Yes	Yes
Number of observations	3140	3140
Number of Ids		2127
R-squared	0.36	0.05
Hausman test		39.62***

Note: OLS is ordinary least squares. FE is fixed effects. The dependent variable is the HDDS. Log stands for natural logarithm. Regional dummies are not reported for brevity.

Abbreviations: FE, fixed effects; HDDS, household dietary diversity scores.

***significant at 1% level.

**significant at 5% level.

*significant at 10% level.

In parentheses are clustered standard errors.

maize with legumes. Almost all households in our sample consumed food groups such as cereals, legumes, and nuts independent of the adopted CSA practices. Therefore, an improvement in dietary diversity among intercropping adopters could only occur through the income path rather than by increasing crop production alone.

The limited impact on household dietary diversity could be attributed to various barriers that hinder the translation of increased food production into a wider range of food choices. These barriers may include limited market access to purchase diverse food sources (Sibhatu & Qaim, 2017), cultural preferences for maize-based diets (Azzarri et al., 2022), and inadequate knowledge or resources to diversify food consumption patterns. Additionally, the persistence of traditional dietary habits within the community, shaped by cultural and social factors, might contribute to the dominance of maize consumption, despite the increased availability of other food options.

Moreover, market-related challenges, such as inadequate infrastructure, transportation issues, and price fluctuations, may hamper smallholder farmers' ability to effectively sell their surplus produce (Azzarri et al., 2022; Koppmair et al., 2017a). Difficulties in accessing markets or unfavorable market conditions may prevent farmers from capitalizing on increased food production to generate higher incomes or improve household dietary diversity (Headey et al., 2019; Hirvonen et al., 2017). Consequently, the benefits of enhanced food production may not be fully realized, limiting the potential positive impacts on nutrition and overall food security.

Our findings underscore the potential of CSA practices, such as the adoption of improved crop varieties and intercropping techniques, to enhance food security and agricultural productivity in smallholder farming systems. However, to fully harness the benefits of these practices, it is crucial to address the challenges faced by smallholder farmers in the Global South. Efforts are required to develop and strengthen market linkages, improve transportation infrastructure, and provide support and training to farmers to diversify their production and consumption patterns.

6 | CONCLUSION

Promoting CSA practices in smallholder agricultural systems has the potential to improve crop productivity, adaptation, and mitigation, particularly in SSA, where frequent occurrences of climate change anomalies are already affecting poor and malnourished rural households. However, it remains unclear whether an increase in crop productivity, adaptation, and mitigation leads to improved food security and dietary diversity and, if so, through

which mechanisms. To address these questions, this study has examined two well-known CSA practices: improved maize seeds complemented with fertilizers and maize-legume intercropping. For the empirical analysis, we have used nationally representative panel data from Tanzania because of data availability and the country's recent efforts to address pervasive hunger and malnutrition in rural households using these CSA practices. We have used standard panel data estimation approaches and found that adopting improved maize seeds is statistically significantly associated with higher maize yields but not with food expenditure and HDDS. These findings imply that promoting a sustainable agricultural approach could enable smallholder agricultural systems to be environmentally friendly as well as increase availability and access to food by increasing crop productivity, adaptation, and mitigation. However, translating increased yield and crop productivity into improved food security and dietary diversity faces significant challenges. Hence, to maximize the potential of CSAs, it is important to address market-related constraints (such as market access, spending money on diverse foods, and access credit) and cultural preferences, and help farmers become resilient to shocks. By doing so, governments and policymakers can improve food security and enhance dietary quality for smallholder farmers in the Global South.

In conclusion, we would like to highlight an important limitation of our study that could guide future research. We employ standard panel data regression estimation strategies with appropriate statistical testing. However, our analyses only control for endogeneity from the observable characteristics of the two waves with a short time frame—2010/11–2012/13 production seasons. Hence, future research should explore the causal impact of CSA practices on food security under different conditions, crops, and technologies, using long-term panel data from more geographical areas.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets analyzed for this study are publicly available in the World Bank's Central Data Catalog [<https://microdata.worldbank.org/index.php/catalog/lsm/?page=1&ps=15&repo=lsm>]. The data that support the findings of this study are available in Living Standards Measurement Study at <https://www.worldbank.org/en/programs/lsm/initiatives/lsm-ISA#7>. These data were derived from the following resources available in the public domain: - World Bank, <https://www.worldbank.org/en/programs/lsm/initiatives/lsm-ISA#40>

ETHICS STATEMENT

Ethical approval was not required for the study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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