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Adoption of sustainable agricultural intensification practices and their welfare impacts: Comparative evidence from Malawi, Uganda and Ethiopia

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ABSTRACT

Sustainable intensification practices are popular interventions for enhancing soil fertility and crop yield, and eventually improving household income and food security. Using the Living Standards Measurement Study - Integrated Surveys on Agriculture panel data from Ethiopia, Malawi, and Uganda, we conduct a multi-country comparative analysis of the adoption of sustainable intensification practices and their impacts on food and nutritional security. While most studies use the sex of the household head to define gender, we base our gender variable on decision-making: male, female, and joint households' decision-making at a farm level. We use multinomial logit, multinomial endogenous switching regression and multinomial endogenous treatment effects models to account for selection bias and endogeneity originating from both observed and unobserved heterogeneity. Our analysis shows that adoption of sustainable intensification practices is impacted household size, wealth, livestock ownership, agroecological zones, and gender decision-making at a farm level. Our econometric analysis reveals that the relationship between the adoption of sustainable intensification practices and households' food and nutritional security varies by country, confirming the importance of considering country-specific contexts and practices when designing agricultural interventions. Policymakers should consider promoting the adoption of sustainable intensification practices as they have shown to have a positive impact on food and nutritional security. Sustainable intensification practices s, along with training programs for farmers, are crucial for enhancing knowledge and resource availability to implement sustainable intensification practices and improve food and nutrition security effectively. There is a need to increase investments in agricultural research, extension services, and climate-smart agriculture.

Keywords: Sustainable intensification practices, welfare, multinomial logit, multinomial endogenous switching regression and multinomial endogenous treatment effects

JEL Classifications: D6, Q16

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ACRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
ATE	Average Treatment Effect
ATT	Average Treatment Effect on the Treated
CA	Conservation Agriculture
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization
FCS	Food Consumption Score
HDDS	Household Dietary Diversity Score
IMR	Inverse Mills Ratio
IOF	Inorganic Fertilizer
LSMS	Living Standards Measurement Study
LSMS-ISA	Living Standards Measurement Study – Integrated Surveys on Agriculture
MESR	Multinomial Endogenous Switching Regression
METE	Multinomial Endogenous Treatment Effects
MMNL	Mixed Multinomial Logit
MNLS	Multinomial Logit Selection Model
NPK	Nitrogen, Phosphorus, and Potassium
OF	Organic Fertilizer
SD	Standard Deviation
SIP	Sustainable Intensification Practice
SWC	Soil and Water Conservation

I. Introduction

Agricultural productivity in Sub-Saharan Africa is constrained by low adoption of new technologies, adverse effects of climate change, land degradation, declining soil fertility, and declining land sizes due to population growth (Kassie et al., 2015; Fisher et al., 2015). Sustainable intensification practices (SIPs) present a viable option for enhancing farm productivity and improving household welfare or well-being (Jindo et al., 2020). Households adopting SIPs are expected to have an improved nutrition status, household farm incomes, and food security. However, there is limited empirical evidence to back this hypothesis. Furthermore, the adoption of SIPs is generally low in many developing countries (Abdulai, 2016; Arslan et al., 2013), including Ethiopia, Malawi, and Uganda. Bridging knowledge gaps in these areas is essential for understanding the impact of SIPs on welfare outcomes in developing countries.

SIPs involve using approaches that increase agricultural yields without adverse environmental impact and conversion of additional non-agricultural land (Jayne et al., 2019). SIPs encompass an umbrella term that includes different productivity-enhancing agricultural practices and technologies, including agroforestry, application of organic fertilizer, chemical or inorganic fertilizer, herbicide, crop residue retention, reduced tillage, and improved seeds. While many investments have been made in research to raise agricultural productivity and combat climate change and rapid population growth, farm families, especially those headed by females, remain vulnerable to chronic food insecurity (Theriault et al., 2017). Adopting SIPs can improve the food supply in agricultural households (Ngoma et al., 2023) while still sustaining natural resources (Pandey et al., 2022). Given that women play a vital role in agriculture production in Africa (Vemireddy & Pingali, 2021; Kawarazuka et al., 2022; FAO, 2023), analysis of the role played by gender in the adoption of SIPs is of paramount importance, especially in designing effective programs and policies to increase agriculture productivity sustainably (Quisumbing & Doss, 2021).

Understanding the' adoption of SIPs and their effects on welfare indicators is critical for developing programs to increase SIP adoption and improve the welfare of small-scale farmers (Njuki et al., 2022). Our study will contribute to evidence in three main ways. First, while analyzing the factors associated with the adoption of SIPs, we use decision making at the farm level as our gender indicator as opposed to the gender of the household head. Second, we analyze the welfare impacts of the adoption of SIPs on food and nutritional security which is crucial for evidence-based policy formulation in the context of developing countries which generally face the challenges of high levels of food insecurity and poverty. Third, by using multiple countries, we conduct a comparative analysis of the adoption and welfare impacts of SIPS to understand how the results compare under different settings.

The rest of this article is structured as follows. Section 2 provides a detailed description of the data and methods. In Section 3, we present the Empirical Strategy. Section 4 provides a discussion of the results. Section 5 provides the conclusions while policy recommendations are provided in Section 6.

II. Data and methods

The study utilizes panel data sourced from the Living Standards Measurement Study (LSMS) for three African countries: Ethiopia, Malawi, and Uganda. Methods include measurement and definitions of two food and nutritional security indicators, namely the Food Consumption Score and the Household Dietary Diversity Score. The Multinomial Endogenous Switching Regression and Multinomial Endogenous Treatment Effects are used to analyze the impact of the adoption of sustainable intensification practices on food and nutritional security.

Data sources

The study utilized publicly available panel data from the Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) collected between 2008 and 2019 from Ethiopia, Malawi, and Uganda. The LSMS-ISA surveys are nationally representative and conducted using structured questionnaires by the respective national statistical offices with support from the World Bank.

The data sets are generally comparable across the countries, with at least three survey rounds available for each. The Ethiopian data contains three waves of panel data conducted in the 2011/12, 2013/14, and 2015/16 farming seasons. Malawi has four rounds of panel data collected in 2010/11, 2013, 2016/17, and 2019/20 farming seasons. Finally, Uganda has seven waves, and these include 2009/10, 2010/11, 2011/12, 2013/14, 2015/16, 2018/19, and 2019/20. The panel surveys allow us to conduct temporal analysis. However, it is important to note that the panel data is not balanced due to splitting of households over time.

The study uses multiple countries to ensure the comparability of results under different settings. The three countries (Ethiopia, Malawi, and Uganda) were selected because they are all agro-based economies, employing over 70 percent of the workforce in agriculture. Additionally, agricultural land is affected by soil degradation, and there is limited use of improved agriculture technologies, including SIPs, in the three countries (Abera et al., 2020; Asfaw et al., 2020; Mugizi & Matsumoto, 2021). The countries under study are similar in that maize is a dominant crop, with a large percentage of smallholder farmers growing maize more than any other crop. For easy comparison, the study uses data with similar collection periods, namely 2010/11, 2013/14, and 2015/16 growing seasons.

Specifically, the study utilised data from the household and agriculture questionnaires, which collect household socioeconomic and demographic information, geo-variables, and farm-level information, including technology adoption.

Measuring gender

Several studies researched gender differences in adopting SIPs (Hirpa Tufa et al., 2022b; Kassie et al., 2015; Ndiritu et al., 2014). They found that gender differences exist in adopting SIPs, such as intercropping, minimum tillage, use of manure, crop rotation, and improved varieties. However, they did not analyze the effects of adoption on household food and nutritional security. Moreover, each study has a limited geographic scope and uses cross-sectional data, making it difficult to control for unobserved confounding factors. For the studies that have analyzed the adoption of SIPs and their impacts on household welfare, there is less attention on examining how gender constraints influence adoption (Khonje et al., 2022; Setsoafia et al., 2022).

Furthermore, several studies have used the sex of the household head as an indicator of gender (Gaya et al., 2017). However, scholars have argued that household head sex does not reflect the household's decision-maker (Quisumbing et al., 2014). Other empirical studies examine gender differences in agriculture technology adoption by using the sex of a farmer in plot-level management decisions to determine who makes farm decisions on a specific parcel of land. This approach does not consider cases where farming decisions are made jointly by both males and females in households, which may affect policy recommendations (Addison et al., 2018). Some studies have considered gender differences in technology adoption by disaggregating the farm households' datasets by gender into three categories based on decision-making: male, female, and joint households' decision-making in agriculture technology adoption (Gebre et al., 2019). Our study adopts this approach, whereby we base our gender analysis on household decision-makers (male, female, and joint management decision-makers) at the plot level.

Measuring sustainable intensification practices

Our study focuses on the adoption of SIPs categorized into (i) conservation agriculture (if the household adopted any of the following: zero or minimum tillage, residual crop incorporation, and maize-legume intercropping); (ii) soil and water conservation (if the household adopted any of the following: contour bunds, vetiver grass (*Chrysopogon zizanioides*), and terraces); (iii) organic fertilizer (derived from either animal manure or compost or both); and (iv) chemical or inorganic fertilizer such as nitrogen, phosphorus, and potassium (NPK) and urea. Inorganic fertilizers are particularly important in many developed countries such as Ethiopia, Malawi and Uganda, often forming a significant component of farm input subsidy programs.

Measuring household welfare

We adopted two measures of household food and nutrition security indicators: food consumption scores and household dietary diversity scores. Of the several nutrition security indicators used in the literature, this study uses the food consumption score (FCS) and household dietary diversity (HDDS), which are the two most commonly used indicators in nutrition and food security studies (Kennedy et al., 2010; Villa et al., 2011).

The FCS is a count of the food items consumed, with higher scores assigned to food items with higher nutrition values. The food items typically include nine food groups: cereals and grains; roots and tubers; legumes and pulses; fruits and vegetables; meat and fish; dairy products, fat and oils; sugar and sweets; and eggs. The food groups are scored based on their nutritional value or contribution to a household diet, and the scores are then aggregated to provide an overall FCS for the household (Kennedy et al., 2010).

The HDDS uses 7-day household dietary recall food consumption data and is calculated as a count of 12 food groups (Muthini et al., 2020; Sibhatu et al., 2015). A higher score of HDDS indicates great dietary diversity. This methodology does not account for the quantities consumed but instead focuses on food groups included in the household's diet. Thus, while HDDS only considers the variety of food items, FCS includes both the variety of the food groups and the relative nutrition value of the foods consumed by the household (Khonje et al., 2022).

III. Empirical strategy

Our analysis adopts multinomial switching endogenous models, namely the Multinomial Endogenous Switching Regression (MESR) and Multinomial Endogenous Treatment Effects (METE) models. These models are chosen to account for self-selection and endogeneity issues in our analysis (Liang et al., 2021; Setsoafia et al., 2022b). Both models are estimated in two stages. In the first stage or selection stage, the models address the selection process, where households endogenously choose a particular treatment option or category of a sustainable intensification practice. The first stage analyses the factors that determine the adoption of multiple sustainable intensification practices using a multinomial logit selection model (see Equation 3). The dependent variable is categorized into four categories: conservation agriculture, soil and water conservation, organic fertilizer, inorganic fertilizer, and non-adopters. In the second stage, or the outcome stage, the models estimate the effects of the treatment or sustainable intensification practice on the observed outcomes. Thus, the second stage focuses on understanding how the treatment or sustainable intensification practice, after accounting for self-selection, impacts food and nutritional security. While MESR is typically used for continuous outcome variables, METE is more flexible in terms of the types of outcome variables it can handle. Specifically, METE models can be used for outcomes that are discrete (multinomial), continuous, count, or binary (Khonje et al., 2018).

Multinomial Endogenous Switching Regression (MESR)

We use the multinomial endogenous switching regression (MESR) to analyze the relationship between SIP adoption and household food security. For this study, we consider various possibilities that farmers may choose between different mutually exclusive types of SIPs, namely conservation agriculture, soil and water conservation, organic fertilizer, inorganic fertilizer, or combinations of the SIP options or not adopting any of the SIP options at all.

The choice of SIPs depends on the utility a farmer obtains from the chosen SIP. We assume that a farmer adopts m SIPs to gain utility U_i. For a farmer i to adopt SIP j over m alternatives, the expected change of utility gain from adopting j alternatives must be more significant than the change in utility gain from m alternatives. The expected utility U_{ij}^{i} from adopting alternative j is a latent variable that can be explained by the household, farm characteristics, and geographical observable X_i and unobservable characteristics ε_{ij}. Therefore, the expected utility function becomes;

$$U_{it} = X_{it}\beta_j + \varepsilon_{ijt} \quad (1)$$

Where β_j denotes an array of unknown parameters we intend to estimate and ε_{ijt} is the random error term. Farmer's choice of SIP is therefore be represented by;

$$I = \begin{cases} 1\ if\ U_{ijt} > \max(U^*_{mit}) or\ n_{1it} < 0 \\ \quad\quad\quad\quad\quad\quad . \\ \quad\quad\quad\quad\quad\quad . \quad\quad\quad\quad\quad\quad \forall\ m \neq 1 \\ \quad\quad\quad\quad\quad\quad . \\ 1\ iff\ U_{ijt} > max(U^*_{mit}) or\ n_{1it} < 0 \end{cases} \quad (2)$$

Where $n_{i1} = max_{m \neq j}\left(U^*_{im} - U^*_{ij}\right) < 0$. Equation 2 shows that a farmer i adopts SIP j to maximize the utility from the chosen alternative if $n_{i1} = max_{m \neq j}\left(U^*_{im} - U^*_{ij}\right) > 0$. The data is organized in such a way that categories of SIP options or categories are mutually exclusive. The probability that farmer i with X characteristics can choose alternative j is given by the multinomial logistic model (Mc-Fadden, 1973) below;

$$P_{ij} = \Pr\left(n_{jit} < 0 \middle| X_{jit}\right) = \frac{\exp\left(X_{it}\beta_j\right)}{\sum_{m=1}^{J} \exp\left(X_{it}\beta_m\right)} \quad (3)$$

The estimation of the multinomial logistic model may face inconsistency issues arising from the correlation of unobserved factors with explanatory variables. As advocated by Mundlak (1978) and Wooldridge (2010), this problem of unobserved heterogeneity is mitigated by including the means of all time-varying explanatory variables as additional explanatory variables in the multinomial logistic model, thereby contributing to more reliable and robust parameter estimates (see also Khonje, et al, 2018).

After estimating the multinomial logistic model, we fit the endogenous switching regression (ESR) model. In the ESR, we use exogenous variables like plot, soil quality, and household characteristics to determine the outcome variables, i.e., household food security indicators. The base category is the non-adopters of SIPs and is donated by $j = 1$. In the remaining set $(j = 2,3,4)$, a farmer adopts at least one SIP in the farm. The number of regimes for all functions of exogenous variables are expressed as;

$$\begin{cases} Regime\ 1: Q_{1it} = \delta_1 Z_{1it} + \epsilon_{1it}\ if\ I = 1 \\ \quad\quad\quad\quad\quad\quad . \\ \quad\quad\quad\quad\quad\quad . \\ \quad\quad\quad\quad\quad\quad . \\ Regime\ J: Q_{1it} = \delta_1 Z_{jit} + \epsilon_{jit}\ if\ I = J \end{cases} \quad (4)$$

Where Q_{ij} denotes the outcome adoption variable. Because there could be unobserved correlated factors between first and second regression error terms, ϵ_{1it} and ϵ_{jit} are not independent. We further assume that the linear combination of error terms is equal to zero, then the multinomial endogenous switching regression model is specified as;

$$
\begin{cases}
Regime\ 1: Q_{1it} = \delta_1 Z_{1it} + \sigma_1 \lambda_{1it} + \omega_{1it}\ if\ I = 1 \\
\quad\quad\quad\quad\quad\quad\quad\quad . \\
\quad\quad\quad\quad\quad\quad\quad\quad . \\
\quad\quad\quad\quad\quad\quad\quad\quad . \\
Regime\ J: Q_{jit} = \delta_1 Z_{jit} + \sigma_J \lambda_{Jit} + \omega_{jit}\ if\ I = J
\end{cases} \quad (5)
$$

In equation (5), σ_J indicates the magnitude of change of error term ω_{jit}, while λ_J shows the Inverse Mills Ratio (IMR), which is the ratio of the probability density function to the cumulative distribution function of the selection variable. The error terms in Equation (5) are bootstrapped to account for heteroskedasticity[1].

Instrumental variables were incorporated into the initial stage, namely the multinomial logit model, but deliberately omitted from the subsequent outcome equation or the second stage. The selected instruments included variables such as the distance to the main road, distance to the primary agricultural market, distance to the administrative capital, and the number of contacts with extension agents. Notably, in Uganda, where geographical data is available only in the first panel wave, the number of contacts with extension agents serves as the only instrument. Additionally, the absence of data on the number of contacts with extension agents in Malawi and Ethiopia necessitates the exclusion of this instrument from the analysis in these two countries.

The rationale behind the instrument choice is motivated by the understanding that farming households typically source essential inputs (e.g., seeds, fertilizers, and herbicides) from main agricultural markets or urban centers. Moreover, agricultural extension officers play an important role in disseminating information on sustainable intensification practices. The instruments adhere to the exclusion restriction principle, as they influence the adoption of sustainable intensification practices without directly affecting welfare. Specifically, variables such as distance to public services (e.g., roads, or access to extension services) impact SIP adoption, subsequently influencing welfare. This selection aligns with other empirical studies such as Khonje et al. (2018) where similar instrument variables were employed.

In order to verify the credibility of the instrumental variables, we conducted falsification tests (Di Falco et al., 2011) and examined correlations. The results affirm the validity of the instruments, demonstrating their collective influence on the adoption decision while exhibiting no direct impact on welfare outcome variables, namely FCS and HDDS.

Multinomial Endogenous Treatment Effects (METE)

We also estimate METE to assess the effects of participating in multiple sustainable agriculture intensification programs on household nutrition security. Just like MESR, METE consists of two stages. The first stage phase focuses on factors influencing the adoption of SIPs, and this adoption is

[1] MESR is estimated by the Selection Bias Corrections Based on the Multinomial Logit Model, selmlog Stata command.

modeled using a mixed multinomial logit (MMNL) approach, as outlined by Deb and Trivedi (2006)[2].

The second stage estimates the effect of the SIPs adopted by a household on the dependent variable. The outcome equation is presented as follows:

$$E(y_{it}|d_{it}, X_{it}, l_{it}) = X_{it}'\alpha + \sum_{i=1}^{i} \gamma_j d_{ijt} + \sum_{i=1}^{i} \lambda_j l_{ijt} \qquad (6)$$

Where y_{it} is the outcome variable; x_{it} is a set of explanatory variables for household i at time t; $E\ (y_i|d_i, x_i, l_i)$ is a function of each of the latent factors l_{ij}, namely the outcome is affected by latent variables that also affect selection into treatment. The same set of instruments is used as discussed in section 2.5.1. METE was estimated by the $mtreatreg$ Stata command.

IV. Empirical results and discussion

Section 3 presents empirical results. This includes descriptive analysis of data on key variables of interest, analysis of the factors that determine the adoption of sustainable intensification practices; and analysis of the relationship between the adoption of sustainable intensification practices and food and nutritional security in Ethiopia, Malawi, and Uganda.

Descriptive statistics

Table 1 describes the samples used in our analysis for all three countries by survey year and gender of the decision maker. On average, over the years (last column), data shows that Uganda has the highest proportion of male decision-makers (63%), followed by Malawi (60%) and Ethiopia (4%). Ethiopia has the highest percentage of joint decision makers (86%), while Malawi and Uganda have lower proportions (5% and 3%, respectively). These variations emphasize distinct gender dynamics in agricultural decision-making across these countries.

Table 2 below indicates the share of households in Ethiopia, Malawi, and Uganda by SIP adoption status and survey year (see Tables 2A, 2B and 2C for results by gender of decision maker for Ethiopia, Malawi, and Uganda). In Ethiopia, inorganic fertilizer is the most adopted SIP, followed by conservation agriculture (an average of 12.44 percent between 2010 and 2016) and soil and water conservation (averaging 9.68 percent). On average, adoption of SIPs increases year by year in Malawi, where inorganic fertilizer (IOF) is the most adopted SIP, although its adoption decreased from 77 percent in 2010 to 65 percent in 2016. In Uganda, conservation agriculture (CA) is the SIP that is more highly adopted than other SIPs. Notably, non-adoption (NA) of SIPs increased by each survey year in Uganda, from 16 percent in 2010 to about 36 percent in 2016, indicating that more farmers are adopting the SIPs. Unlike in other countries, in Malawi there were some farming

[2] The mixed multinomial logit (MMNL) approach is similar to multinomial logit selection model (MNLS) and therefore excluded because it is a conventional estimation technique.

Table 1: Sample sizes by gender of decision maker and year

Country		2010/11	2013/14	2015/16	All years
Ethiopia	Male	172	277	171	620
	Female	359	519	411	1,289
	Joint	3,359	4,433	4,351	12,143
	Total	**3,890**	**5,229**	**4,933**	**14,052**
Malawi	Male	769	981	1,036	2,786
	Female	346	508	726	1,580
	Joint	36	36	172	244
	Total	**1,151**	**1,525**	**1,934**	**4,610**
Uganda	Male	1,714	1,780	2,251	5,745
	Female	966	1,225	926	3,117
	Joint	41	114	128	283
	Total	**2,721**	**3,119**	**3,305**	**9,145**

Note: Authors' analysis

Table 2: Percentage adoption of combinations of SIPs by year

Country	Year	NA	CA	SWC	OF	IOF	All SIPs	Total
	2010	25.31	21.86	0.81	4.47	47.55	n/a	3,890
Ethiopia	2013	31.46	10.08	13.52	0.59	44.35	n/a	5,229
	2016	34.99	5.39	14.71	0.94	43.96	n/a	4,933
	All years	30.59	12.44	9.68	2.00	45.29	n/a	14,052
	2010	8.92	0.00	4.95	2.62	76.74	6.77	1,151
Malawi	2013	1.48	10.16	5.00	5.24	66.83	11.13	1,525
	2016	7.33	5.28	6.03	5.45	65.09	10.83	1,934
	All years	5.81	5.56	5.47	4.67	68.58	9.91	4,610
	2010	23.46	53.79	6.80	12.67	3.28	n/a	2,060
Uganda	2013	33.57	50.42	2.40	8.45	5.16	n/a	1,200
	2016	36.2	48.33	2.87	8.2	4.41	n/a	1,283
	All years	31.55	50.67	3.84	9.59	4.35	n/a	4,543

Source: Authors' analysis. Note: NA denotes non-adopters (households which did not adopt any of SIPs); CA denotes conservation agriculture; SWC denotes soil and water conservation; OF denotes organic fertilizer; IOF denotes inorganic fertilizer; and SIPs denotes sustainable intensification practices.

households who adopted all the SIPs jointly — about 6.77% in 2010 and in 2013 there was a notable increase to 11.13%, indicating a significant rise in SIPs adoption followed by a slight decrease in 2016 to 10.83%.

Descriptive statistics for the key variables used in this study are indicated in Table 3 (Ethiopia), Table 4 (Malawi), and Table 5 (Uganda). Detailed statistics providing in-depth data analysis for each country across different survey years are provided in the appendices: for Ethiopia, Tables A1 (year: 2011), A2 (year: 2013), and A3 (year: 2015); for Malawi, Tables A4 (year: 2010), A5 (year: 2013), and A6 (year: 2016); and for Uganda, Tables A7 (year: 2010), A8 (year: 2013), and A9 (year: 2016).

Overall, Ethiopia experienced a consistent upward trend in FCS, reflecting improved food access and consumption over the study period. Specifically, in 2011, the FCS was 44.754, indicating acceptable food consumption. By 2013, there was a notable increase in FCS to 47.245, suggesting improved food consumption. In 2016, the FCS continued to rise, reaching 48.154, indicating a further improvement in food consumption. Similar improvements are noted based on HDDS, whose scores have increased over time from 2011 to 2016, indicating an improvement in household dietary diversity (see Table 3).

The observed increases in food and nutritional security may reflect changing economic conditions, food security initiatives, or other factors affecting food access and consumption over the years. However, further analysis is carried out in the subsequent sections to identify the specific drivers behind these trends.

Table 3: Descriptive statistics by survey year in Ethiopia

	2011		2013		2016	
Variables	Mean	SD	Mean	SD	Mean	SD
Food Consumption Score	44.75	11.11	48.15	10.61	44.05	11.02
Household Dietary Diversity Score	6.13	1.69	6.96	1.78	6.17	1.89
Age of household head	3.73	0.35	3.78	0.34	3.70	0.38
Square of household head age	14.04	2.62	14.39	2.53	13.87	2.82
Household size	1.50	0.54	1.65	0.55	1.29	0.65
Female decision maker	0.07	0.56	0.06	0.55	0.13	0.35
Male decision maker	0.02	0.16	0.03	0.16	0.07	0.25
Joint decision maker	0.91	0.28	0.91	0.29	0.80	0.40
Access to credit	0.27	0.45	0.23	0.42	0.25	0.43
Access to extension	0.29	0.45	0.34	0.47	0.01	0.10
Durable asset index	0.05	0.94	0.15	0.88	-0.02	0.97
Agricultural asset index	-0.19	0.93	0.16	0.97	0.33	0.93
Had livestock	0.81	0.39	0.70	0.46	0.54	0.50
Self-employment	0.21	0.41	0.25	0.43	0.29	0.45
Literate household head	0.43	0.50	0.53	0.50	0.46	0.50
Had chronic illness	0.51	0.50	0.30	0.46	0.47	0.50
Instrumental variables						
Distance to the main road	2.22	1.13	1.87	1.29	2.07	1.27
Distance to the primary market	3.93	0.80	3.66	1.08	3.98	0.77
Distance to agricultural market	4.89	0.81	4.67	1.15	4.88	0.88
Number of households	3890		4933		1492	

Source: Authors' analysis

Note: NA denotes non-adopters; CA denotes conservation agriculture; SWC denotes soil and water conservation; OF denotes organic fertilizer; IOF denotes inorganic fertilizer; and SIPs denotes sustainable intensification practices.

Similar to Ethiopia, Malawi has shown a consistent upward trend in FCS, indicating substantial progress in food consumption over the years. Specifically, Malawi transitioned from borderline to acceptable food consumption between 2010 and 2016. In 2010, Malawi had an FCS of 33.334, which falls within the borderline food consumption category. However, by 2013, there was a significant increase in FCS to 35.909, moving into the acceptable food consumption range. In 2016, the FCS continued to rise substantially, reaching 43.358, which also remained in the acceptable range. With respect to the household dietary diversity scores (HDDS) in Malawi, our analysis reveals that there was a notable increase from 6.65 in 2010 to 7.09 in 2013, followed by a slight decline to 6.83 in 2016. The observed changes in FCS and HDDS may be due to a number of factors, and further analysis is carried out to understand the specific factors contributing to these changes.

Table 4: Descriptive statistics by survey year in Malawi

	2010		2013		2016	
Variables	Mean	SD	Mean	SD	Mean	SD
Food Consumption Score	33.34	17.45	35.91	16.20	43.36	17.66
Household Dietary Diversity Score	6.65	1.73	7.09	1.42	6.83	1.50
Male decision maker	0.67	0.47	0.63	0.48	0.51	0.50
Female decision maker	0.30	0.46	0.35	0.48	0.40	0.49
Joint decision maker	0.03	0.16	0.02	0.14	0.10	0.29
Age of household head	3.70	0.38	3.76	0.35	3.78	0.34
Marital status	1.82	1.43	1.87	1.49	1.90	1.50
Household size	1.49	0.50	1.51	0.51	1.50	0.51
Male household head	0.70	0.46	0.65	0.48	0.60	0.49
Access to credit	0.13	0.33	0.22	0.41	0.27	0.44
Access to extension	0.41	0.49	0.69	0.46	0.77	0.42
Durable asset index	-0.28	0.55	-0.24	0.66	-0.27	0.66
Agricultural asset index	0.03	0.80	0.13	0.91	0.15	1.04
Self-employment	0.19	0.39	0.29	0.45	0.30	0.46
Access to coupon	0.58	0.49	0.47	0.50	0.37	0.48
Literate household head	0.62	0.49	0.67	0.47	0.66	0.47
Had chronic illness	0.07	0.18	0.08	0.17	0.09	0.17
Had illness in the year	0.24	0.26	0.23	0.27	0.36	0.32
Instrumental variables						
Distance to agricultural market	1.98	0.57	1.96	0.59	1.96	0.60
Distance to the main road	1.84	1.03	1.80	1.04	1.77	1.04
Distance to district center	3.77	0.61	3.00	0.73	2.98	0.75
Number of households	1151		1525		1934	

Source: Authors' analysis

Table 5 shows descriptive statistics of Uganda. Uganda experienced an initial substantial increase in FCS from 2011 to 2013, suggesting improved food access and consumption. Although there was a slight decrease in 2016, it remained within the acceptable food consumption category. Specifically, in 2011, Uganda had a relatively high FCS of 48.74, indicating acceptable food consumption. By 2013, there was a substantial increase in FCS to 60.46, which remained well within the acceptable range. However, in 2016, there was a decrease in FCS to 47.33, which, while lower than in 2013, still stayed above the acceptable threshold (namely FCS > 35). Just like FCS, the HDDS for Uganda depicts a similar trend of increasing from 2010 to 2013 but declining in the final panel year, 2016.

Table 5: Descriptive statistics by survey year in Uganda

	2011		2013		2015	
	Mean	SD	Mean	SD	Mean	SD
Food Consumption Score	48.74	22.60	60.46	20.55	47.33	18.71
Household Dietary Diversity Score	5.28	2.08	6.05	1.60	5.56	1.58
Age of household head	3.72	0.35	3.83	0.31	3.80	0.25
Square age of household head	13.99	2.65	14.73	2.34	14.51	1.89
Household size	1.65	0.67	1.50	0.74	1.75	0.49
Female decision maker	0.35	0.41	0.42	0.27	0.3	0.28
Male decision maker	0.64	0.48	0.52	0.50	0.64	0.48
Joint decision maker	0.01	0.11	0.06	0.23	0.06	0.24
Access to credit	0.18	0.39	0.07	0.25	0.05	0.22
Access to extension	0.16	0.37	0.15	0.36	0.09	0.29
Durable asset index	-0.02	0.96	-0.01	0.98	-0.03	0.96
Agricultural asset index	0.01	0.92	-0.03	0.84	-0.04	0.80
Livestock ownership	0.25	0.43	0.21	0.41	0.22	0.42
Self-employment	0.83	0.38	0.85	0.36	0.84	0.36
Literate household head	0.71	0.45	0.73	0.45	0.97	0.17
Irregular rainfall (shocks)	0.00	0.00	0.07	0.26	0.00	0.00
Low off-farm earnings (shocks)	0.00	0.00	0.00	0.05	0.00	0.00
Had illness in the year(shocks)	0.00	0.01	0.03	0.16	0.00	0.00
Involved in an accident (shocks)	0.00	0.01	0.02	0.14	0.00	0.00
Had a death in the year (shocks)	0.00	0.00	0.01	0.09	0.00	0.00
Had conflict in the year (shocks)	0.00	0.01	0.00	0.06	0.00	0.00
Total land size (acres)	4.16	27.33	2.20	4.01	2.06	4.52
Number of extension contacts	0.54	2.34	0.46	3.10	0.23	1.16
Number of households	2713		1562		1756	

Source: Authors' analysis

Figures A1, A2, and A3 in the appendix present a comparative analysis of FCS and HDDS by adoption status of sustainable intensification practices in Uganda in Ethiopia, Malawi, and Uganda, respectively. Data shows that adopters of SIPs depicted higher average values of FCS and HDDS for Malawi and Uganda.

Empirical results and discussion

This section discusses the results from two sets of analyses. First, we analyze the determinants of the adoption of sustainable intensification practices (SIPs) based on a multinomial logit estimation strategy. Second, we analyze how the adoption of SIPs impacts food and nutritional outcomes using two related statistical methodologies: Multinomial Endogenous Switching Regression and

Multinomial Endogenous Treatment Effects. The main results are based on FCS, while the robustness checks are carried out based on HDDS with the results provided in the appendix.

Multinomial logit estimation results

Based on a set of household characteristics and socioeconomic factors, we analyzed the probabilities of households choosing different mutually exclusive alternative sustainable intensification practices: conservation agriculture (CA), soil and water conservation (SWC), organic fertilizer (OF), and inorganic fertilizer (IOF) as previously defined. The "non-adopters" category is used as a reference category.

In our analysis, we calculated coefficients and marginal effects using multinomial logit models for each country. However, we only discuss average marginal effects in Tables 6, 7, and 8 for Ethiopia, Malawi, and Uganda, respectively. It is more convenient to interpret the marginal effects on individual probabilities, as suggested by (Nguyen-Van et al., 2017). Our findings reveal that these marginal effects exhibit significant variations across both the choices of Sustainable Intensification Practices (SIPs) and the countries under consideration.

With respect to the gender of decision-making, the common similarity across these three countries is that joint decision-making often appears to be more favorable for the adoption of specific agricultural practices compared to male decision-making, especially in the case of inorganic fertilizer. In all three countries, male decision-making is less likely to adopt conservation agriculture compared to female decision-making. However, each country exhibits unique distinctions. In Ethiopia, male decision-making is also less likely to adopt soil and water conservation, while in Malawi, joint decision-making is less likely to adopt conservation agriculture and inorganic fertilizer. In Uganda, the differences are more balanced, with male decision-making being less likely to adopt conservation agriculture but more likely to adopt inorganic fertilizer.

Table 6 shows multinomial logit results for Ethiopia. The Wald test that all coefficients for explanatory variables are simultaneously equal to zero is rejected ($\chi^2 = 5814.78; p = 0.000$). Similarly, the falsification test yields significant results ($\chi^2 = 382.46; p = 0.000$). These results indicate that the estimated coefficients significantly differ across the choice of SIPs and validity of the instruments.

The results show that the there is a negative relationship between the adopting conservation agriculture and the following factors: household size, male decision maker, tropic-cool/semiarid AEZ, Tropic-cool/subhumid AEZ, literacy rate, and agricultural asset index.

With respect to gender, the analysis shows that male decision-makers are less likely to adopt conservation agriculture and soil and water conservation compared to female decision-makers. On the other hand, joint decision-making is more likely to adopt inorganic fertilizers compared to female decision-making. Furthermore, our analysis reveals that literacy is linked to a lower likelihood of adopting organic fertilizer. Conversely, access to extension increases the average probability of adopting conservation agriculture (CA), organic fertilizer (OF), and inorganic fertilizer (IOF). In contrast, there is a negative relationship between access to extension services and the adoption of soil and water conservation (SWC).

Table 6: Marginal effects for adoption of multiple SIPs in Ethiopia (Margins)

	CA	SWC	OF	IOF
Household size	-0.05**	0.03	0.01	-0.01
	(0.02)	(0.03)	(0.01)	(0.02)
Age of household head (Years)	-0.38	0.13	-0.04	0.31
	(0.31)	(0.43)	(0.06)	(0.44)
Square of household head age (Years)	0.05	-0.02	0.01	-0.04
	(0.04)	(0.06)	(0.01)	(0.06)
Male decision maker	-0.08***	0.00	0.01	0.04
	(0.03)	(0.02)	(0.01)	(0.03)
Joint decision maker	0.02	-0.03**	0.00	0.06***
	(0.01)	(0.01)	(0.01)	(0.01)
Literate household head	0.01	0.02	-0.01**	0.00
	(0.02)	(0.01)	(0.01)	(0.01)
Access to credit (1 =Yes, 0 =No)	-0.01	0.01	0.00	0.01
	(0.01)	(0.01)	(0.00)	(0.01)
Access to extension (1 =Yes, 0 =No)	0.04**	-0.06***	0.01**	0.19***
	(0.02)	(0.02)	(0.00)	(0.01)
Durable asset index	-0.01	0.01	-0.01**	0.01
	(0.02)	(0.03)	(0.01)	(0.02)
Agricultural asset index	0.00	0.01	0.00	-0.01**
	(0.00)	(0.00)	(0.00)	(0.00)
Livestock ownership	0.00	0.05***	0.00	0.02
	(0.02)	(0.02)	(0.01)	(0.02)
Self-employment (1 =Yes, 0 =No)	-0.01	0.00	0.01	0.00
	(0.02)	(0.02)	(0.01)	(0.01)
Illness (1 =Yes, 0 =No)	0.03***	0.00	0.00	-0.01*
	(0.01)	(0.01)	(0.00)	(0.01)
Tropic-cool/semiarid AEZ	-0.03***	0.08***	0.02***	0.11***
	(0.01)	(0.01)	(0.00)	(0.01)
Tropic-cool/subhumid AEZ	-0.02**	-0.02*	0.01**	0.18***
	(0.01)	(0.01)	(0.00)	(0.01)
Tropic-cool/humid AEZ	-0.01	-0.03***	0.01**	0.19***
	(0.01)	(0.01)	(0.00)	(0.01)
Distance to main road (km)	0.02***	0.00	0.00	-0.01***
	(0.00)	(0.00)	(0.00)	(0.00)
Distance to the primary market (km)	0.00	0.01**	0.00**	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Distance to agricultural market (km)	0.01***	0.00	0.00***	-0.02***
	(0.00)	(0.00)	(0.00)	(0.00)
Distance to nearest populated center (km)	0.02***	0.00	0.00*	-0.02***

	CA	SWC	OF	IOF
	(0.00)	(0.00)	(0.00)	(0.00)
Household size (Mean)	0.04*	0.01	-0.01	0.01
	(0.02)	(0.03)	(0.01)	(0.02)
Age of household head (Mean)	0.44	-0.19	0.04	0.15
	(0.37)	(0.45)	(0.10)	(0.43)
Square of household head age (Mean)	-0.06	0.03	-0.01	-0.02
	(0.05)	(0.06)	(0.01)	(0.06)
Literate (Mean)	-0.04**	-0.02	0.01**	0.01
	(0.02)	(0.02)	(0.01)	(0.02)
Access to credit (Mean)	-0.02	0.01	-0.01	0.02
	(0.01)	(0.01)	(0.01)	(0.01)
Access to extension (Mean)	-0.08***	0.05***	-0.01*	0.21***
	(0.02)	(0.02)	(0.01)	(0.01)
Durable asset index (Mean)	-0.02	0.17***	0.00	-0.03
	(0.02)	(0.04)	(0.01)	(0.02)
Agricultural Asset Index (Mean)	-0.03***	0.00	0.00	-0.03***
	(0.01)	(0.01)	(0.00)	(0.01)
Livestock ownership (Mean)	0.06***	-0.01	0.01	0.08***
	(0.02)	(0.02)	(0.01)	(0.02)
Self-employment (Mean)	0.02	0.00	-0.02**	-0.04**
	(0.02)	(0.02)	(0.01)	(0.02)
Illness (Mean)	-0.01	0.00	0.00	0.01
	(0.01)	(0.01)	(0.00)	(0.01)
Joint significance of instruments (chi-sq)			382.46***	
Wald test (chi-sq)			5814.78***	
Observations (n)	**14033**	**14033**	**14033**	**14033**

Source: Authors' analysis

Note: Coefficient estimates of marginal effects from multinomial regressions. * p < 0·10, ** p<0.05 and *** p < 0·01. CA denotes conservation agriculture, SWC denotes soil and water conservation, OF denotes organic fertilizer, IOF denotes inorganic fertilizer, and SIPs denote sustainable intensification practices.

Table 7 presents the multinomial logit results for Malawi. The Wald test that all coefficients for explanatory variables are simultaneously equal to zero is rejected ($\chi^2 = 752.56; p = 0.000$). Similarly, the falsification test yields significant results ($\chi^2 = 61; p = 0.000$). These results indicate that the estimated coefficients significantly differ across the choice of SIPs and validity of the instruments.

The results show that an increase in household sizes increases the average probability of adopting all SIPs by 3.0 percent for Malawi. With respect to gender, our results show that there is a notable contrast between male and joint decision-making compared to female decision-making. Joint decision-making is more likely to adopt SIPs, while it is less likely to adopt conservation agriculture and inorganic fertilizer compared to female decision-making.

Data analysis reveals that wealthier households are more likely to adopt inorganic fertilizers but less likely to adopt soil and water conservations. On the other hand, families with livestock are more likely to adopt all SIPs, while those households that experience sickness in the household are less likely to adopt conservation agriculture.

We also find that the adoption of SIPs differs across agro-ecological zones (AEZs). For instance, households living in the Tropical-warm/subhumid agrological zone are less likely to adopt conservation agriculture but are more likely to adopt inorganic fertilizer and a combination of all SIPs. On the other hand, residents of the Tropical-cool/semiarid agroecological zone are less likely to adopt organic fertilizer but are more likely to adopt inorganic fertilizer. Likewise, households in the Tropic-cool/subhumid agroecological zone are less likely to adopt conservation agriculture but more likely to adopt inorganic fertilizer and a combination of all SIPs.

Like agroecological zones, regions also play a significant role in influencing farmers' adoption decisions. Unlike households in the northern region, those in the south are less likely to adopt soil and water conservation but more likely to adopt a combination of all the SIPs. On the other hand, residents of the southern region are less likely to adopt soil and water conservation but more likely to adopt a combination of the SIPs.

Our results also show that distance to infrastructure plays a significant role in influencing the adoption of SIPs. We find that households close to the main road are more likely to adopt inorganic fertilizers but less likely to adopt inorganic fertilizers but less likely to adopt soil and water conservation practices. Similarly, households near an agricultural market depot are more likely to adopt organic fertilizer but less likely to adopt inorganic fertilizer. We also find that households near the district center are more likely to adopt soil and water conservation technologies.

Table 7: Marginal effects for adoption of multiple SIPs in Malawi (Margins)

	CA	SWC	OF	IOF	All
Household size	0.01	-0.01	-0.01	0.00	0.03**
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
Age of household head (Years)	0.23	-0.07	-0.18	0.55	-0.37
	(0.29)	(0.25)	(0.25)	(0.55)	(0.37)
Square of household head age (Years)	-0.03	0.01	0.02	-0.08	0.05
	(0.04)	(0.03)	(0.03)	(0.07)	(0.05)
Male decision maker	0.01	0.01	0.00	0.00	-0.01
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Joint decision maker	-0.05**	-0.01	-0.01	-0.07*	0.03*
	(0.03)	(0.02)	(0.02)	(0.04)	(0.02)
Access to credit (1 =Yes, 0 =No)	-0.02	-0.01	-0.01	0.02	0.00
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Access to extension (1 =Yes, 0 =No)	0.00	-0.01	0.00	0.01	0.00
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Durable asset index	0.00	-0.02*	-0.02	0.07***	-0.01

	CA	SWC	OF	IOF	All
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Agricultural asset index	-0.01	-0.01	-0.01	0.03***	0.01**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Livestock ownership	-0.01	-0.01	-0.01	0.03	0.05***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Self-employment (1 =Yes, 0 =No)	-0.01	-0.01	0.00	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Literate household head	0.00	0.01	-0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Illness in the year	-0.03*	0.01	-0.01	0.00	0.02
	(0.02)	(0.01)	(0.01)	(0.03)	(0.02)
Tropic-warm/subhumid AEZ	-0.03***	-0.01	0.00	0.04**	0.05***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Tropic-cool/semiarid AEZ	-0.02	0.01	-0.03***	0.06**	0.02
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Tropic-cool/subhumid AEZ	-0.06**	-0.04*	-0.02	0.14***	0.06*
	(0.03)	(0.02)	(0.02)	(0.05)	(0.03)
Central region	-0.03	-0.05***	0.01	0.04	0.12***
	(0.02)	(0.02)	(0.02)	(0.04)	(0.03)
Southern region	-0.02	-0.02*	0.00	-0.02	0.12***
	(0.02)	(0.01)	(0.02)	(0.03)	(0.03)
Distance to the main road (km)	-0.01	-0.01***	0.00	0.03***	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Distance to agricultural market (km)	0.00	-0.01	0.02***	-0.02*	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Distance to district center (km)	0.00	0.01**	-0.01	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Household size (Mean)	0.00	0.03*	0.00	-0.03	-0.03
	(0.02)	(0.02)	(0.01)	(0.03)	(0.02)
Age of household head (Mean)	0.54	-0.41	0.5	-1.82**	1.06*
	(0.41)	(0.38)	(0.37)	(0.81)	(0.55)
Household size (Mean)	-0.07	0.06	-0.07	0.24**	-0.14*
	(0.05)	(0.05)	(0.05)	(0.11)	(0.07)
Access to credit (Mean)	0.01	0.04**	-0.01	-0.09***	0.07***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)
Access to extension (Mean)	0.03**	0.01	0.02	-0.02	-0.02
	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)
Durable asset index (Mean)	-0.04**	-0.02	0.01	0.04*	-0.01
	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)
Agricultural Asset Index (Mean)	-0.01	0.00	0.00	-0.01	0.03***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Livestock ownership (Mean)	-0.03*	-0.03*	-0.01	0.04	0.00
	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)

	CA	SWC	OF	IOF	All
Self-employment (Mean)	0.01	0.02	-0.01	-0.02	-0.05**
	(0.02)	(0.02)	(0.01)	(0.03)	(0.02)
Literate head (Mean)	-0.02	-0.02	0.01	0.02	0.03
	(0.01)	(0.02)	(0.01)	(0.03)	(0.02)
Illness (Mean)	0.09***	0.02	0.03	-0.15***	-0.01
	(0.02)	(0.02)	(0.02)	(0.05)	(0.03)
Joint sig of instruments (χ^2)			61***		
Wald test (χ^2)			752.56***		
Observations	4610	4610	4610	4610	4610

Source: Authors' analysis

Note: Coefficient estimates from Multinomial regressions are shown with standard errors in parentheses. * p < 0·10, ** p <0.05 and*** p < 0·01. CA denotes conservation agriculture, SWC denotes soil and water conservation, OF denotes organic fertilizer, IOF denotes inorganic fertilizer, and SIPs denote sustainable intensification practices.

In Uganda, we find a positive relationship between household size and the adoption of SIPs (see Table 8). We find that large households are more likely to adopt of conservation agriculture (2.5 percent), soil and water conservation (0.08 percent), and organic fertilizer use (1.4 percent). Our gender analysis reveals distinct patterns in decision-making. Male decision-makers are less likely to adopt conservation agriculture but are more likely to adopt inorganic fertilizers. On the other hand, joint decision-making is more likely to adopt both conservation agriculture and inorganic fertilizer compared to female decision-making. Households with access to credit are more likely to adopt inorganic fertilizers (1.4 percent).

On the other hand, households with access to extension services are less likely to adopt conservation agriculture (2.7 percent) but more likely to adopt organic fertilizer and inorganic fertilizer by 2.8 percent each. Wealthier households are more likely to adopt organic and inorganic fertilizers by 2.7 percent and 1 percent, respectively, but less likely to adopt conservation agriculture by 3.8 percent. Households who own livestock are more likely to adopt organic fertilizers (9.4 percent) but less likely to practice conservation agriculture (8.9 percent). Self-employed households are less likely to practice soil and water conservation by 1.8 percent. On the other hand, households with literate heads are more likely to adopt organic farming (3.9 percent) than conservation agriculture (3.5 percent). Households that faced a death in the household are more likely to adopt conservation agriculture by 24.9 percent than inorganic fertilizer by 10.8 percent. Like in Malawi, the adoption of SIPs varies across agroecological zones in Uganda. Compared to households in the Tropical-warm/subhumid agroecological zone, residents of the Tropical-warm/humid agroecological zone are less likely to adopt soil and water conservation by 4.0 percent.

Table 8: Marginal effects for adoption of multiple SIPs in Uganda (Margins)

	CA	SWC	OF	IOF
Household size	0.02*	0.01*	0.02**	0
	(0.01)	(0.00)	(0.01)	(0.00)
Age of household head (Years)	-0.5	-0.03	-0.1	0.1
	(0.37)	(0.12)	(0.22)	(0.15)
Square of household age (Years)	0.06	0.00	0.01	-0.02
	(0.05)	(0.02)	(0.03)	(0.02)
Male decision maker	-0.03**	-0.01	0.00	0.02***
	(0.01)	(0.00)	(0.01)	(0.01)
Joint decision maker	0.09***	-0.02	0.00	0.04***
	(0.04)	(0.02)	(0.02)	(0.01)
Access to credit (1 =Yes, 0 =No)	0.01	0.01	-0.02	0.01**
	(0.02)	(0.01)	(0.01)	(0.01)
Access to extension (1 =Yes, 0 =No)	-0.03*	0.01	0.03***	0.03***
	(0.02)	(0.01)	(0.01)	(0.01)
Durable asset index	-0.04***	-0.01	0.02***	0.01***
	(0.01)	(0.00)	(0.00)	(0.00)
Agricultural asset index	0.00	0.00	0.01	0.01**
	(0.01)	(0.00)	(0.00)	(0.00)
Livestock ownership (1 =Yes, 0 =No)	-0.09***	-0.01	0.10***	0.01
	(0.01)	(0.01)	(0.01)	(0.01)
Self-employment (1 =Yes, 0 =No)	0.01	-0.02**	0.03	0.01
	(0.02)	(0.01)	(0.02)	(0.01)
Literacy of the household head (1 = if able	-0.04**	0.00	0.03**	0.00
to read and write, 0 = otherwise)	(0.02)	(0.01)	(0.01)	(0.01)
	0.21	-0.23	-0.01	0.01
Illness in the year (1 =Yes, 0 =No)	(0.18)	(0.29)	(0.06)	(0.03)
Accident in the year (1 =Yes, 0 =No)	0.02	0.01	-0.01	0.00
	(0.08)	(0.03)	(0.04)	(0.03)
Death in the year (1 =Yes, 0 =No)	0.26**	-0.10*	-0.03	-0.10**
	(0.11)	(0.06)	(0.07)	(0.05)
Total landholding size (Ha)	0.00	0.00	0.00*	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Tropic-warm/humid AEZ	0.00	-0.04**	-0.01	0.00
	(0.07)	(0.02)	(0.04)	(0.04)
Tropic-cool/sub-humid AEZ	0.01	-0.01	0.02	0.00
	(0.07)	(0.02)	(0.04)	(0.04)
Tropic-cool/humid AEZ	0.06	0.02	0.01	-0.01
	(0.07)	(0.02)	(0.04)	(0.04)
Central Region	0.07**	-0.01	0.02	0.07***
	(0.04)	(0.01)	(0.02)	(0.02)
Eastern Region	0.06	0.03***	-0.10***	0.05***
	(0.04)	(0.01)	(0.02)	(0.02)

	CA	SWC	OF	IOF
Northern region	0.08**	-0.01	-0.27***	0.02
	(0.04)	(0.01)	(0.03)	(0.02)
Wald test (chi-sq)			1264.73***	
Observations	6589	6589	6589	6589

Source: Authors' analysis

Note: Coefficient estimates from Multinomial regressions are shown with standard errors in parentheses. * p < 0·10, **p<0.05 and *** p < 0·01. CA denotes conservation agriculture, SWC denotes soil and water conservation, OF denotes organic fertilizer, IOF denotes inorganic fertilizer, and SIPs denote sustainable intensification practices.

The relationship between the adoption of SIPs and food nutritional security

In this section, we provide results from the analysis of the relationship between SIPs and food nutritional security. We examine the average treatment effects of adopting SIPs on household welfare outcomes under both actual and counterfactual scenarios. This involves predicting the anticipated values for both the actual and counterfactual welfare outcomes and subsequently calculating the differences between them. Our main results for MESR and METE are based on FCS, while robustness checks are based on HDDS and presented in the appendix.

For both MESR and METE, the following key variables are in the selection model: age of household head; square of household head age; household size; gender (male, female and joint decision making); access to credit; access to extension; durable asset index; agricultural asset index; ownership of livestock; self-employment; literacy of household head; chronic illness; instrumental variables (distance to the main road, distance to the primary market, distance to agricultural market; the number of contacts with extension agents) and means of all time-varying explanatory variables. The instrumental variables are included in the first stage model but they are excluded from the outcome equation.

Due to space constraints, a detailed discussion of the second-stage regression estimates is omitted. However, the relevant analysis based on FCS for Ethiopia, Malawi, and Uganda can be found in the Appendix, specifically in Tables B1, B2, and B3. In Ethiopia, we find evidence of positive relationship between food consumption scores and household size, access to credit, and access to extension. Within the context of Malawi; our analysis shows that the following variables exhibit a positive relationship with food consumption scores: ownership of durable assets; access to extension services; and self-employment. In Uganda, household size, access to credit, access to extension and ownership of livestock have a positive relationship with food consumption scores. Notable similarities exist in our cross-country comparisons The common factors include household size, access to credit, and access to extension services.

MESR analysis results based on FCS

Tables 9, 10 and 11 below show the average treatment effects (ATE) of adopting SIPs in Ethiopia, Malawi and Uganda, respectively. The results compare food consumption scores of households that adopted SIPs to those who did not adopt the SIPs. The results vary by country of study, and this emphasizes the importance of considering local contexts and practices when designing agricultural interventions. The adoption of SIPs in Ethiopia positively influences food consumption scores except for conservation agriculture which shows a negative significant relationship, whereas in Uganda, all SIPs positively influence food consumption scores, and in Malawi, only the adoption of inorganic fertilizer shows a positive relationship with FCS. With respect to the individual SIPs, the results indicate that adopting soil and water conservation and inorganic fertilizer has a positive impact on FCS in Ethiopia and Uganda, as shown by the positive and significant differences between adopters of individual SIPs and non-adopters. On the contrary, adopting conservation agriculture and soil and water conservation has a negative impact on FCS in Malawi. Adopting inorganic fertilizer positively and significantly increases FCS across all countries of this study. Negative and significant results of adopting conservation agriculture are noted only in Ethiopia and Malawi, but positive adoption effects of conservation agriculture are indicated only in Uganda. These negative findings on the adoption of conservation agriculture on food security are opposite to what Oduniyi et al. (2022) found, which is that the adoption of conservation agriculture in South Africa leads to increased income, which also means an improvement in food security.

Table 9: MESR-based average effect (ATT) of adoption of SIPs on FCS for Ethiopia

	Adopter	Non-adopter	Difference	Observations
Conservation Agriculture	42.32	42.66	-0.34***	1805
	(3.06)	(2.88)	3.18	
Soil and Water Conservation	42.93	41.65	1.28***	1611
	(2.99)	(2.59)	2.97	
Organic Fertilizer	45.53	43.03	2.50***	213
	(4.27)	(3.19)	5.00	
Inorganic Fertilizer	44.59	41.85	2.74***	4337
	(2.73)	(3.01)	3.99	

Source: Authors' analysis

Note: * $p < 0 \cdot 10$, ***$p<0.05$ and *** $p < 0 \cdot 01$. CA denotes conservation agriculture, SWC denotes soil and water conservation, OF denotes organic fertilizer, IOF denotes inorganic fertilizer, and SIPs denote sustainable intensification practices.

Table 10: MESR-based average effect (ATT) of adoption of SIPs on FCS for Malawi

	Adopter	Non-adopter	Difference	Observations
Conservation Agriculture	4.43	4.48	-0.05***	258
	(0.27)	(0.27)	0.26	
Soil and Water Conservation	4.41	4.46	-0.05***	253
	(0.29)	(0.29)	0.26	
Organic Fertilizer	4.46	4.49	-0.03	215
	(0.34)	(0.28)	0.33	
Inorganic Fertilizer	4.60	4.56	0.04***	3126
	(0.25	0.33)	0.19	
All SIPs	4.64	4.54	0.10***	457

Source: Authors' analysis

Note: * p < 0·10, ***p<0.05 and *** p < 0·01. CA denotes conservation agriculture, SWC denotes soil and water conservation, OF denotes organic fertilizer, IOF denotes inorganic fertilizer, and SIPs denote sustainable intensification practices.

Table 11: MESR-based average effect (ATT) of adoption of SIPs on FCS for Uganda

	Adopter	Non-adopter	Difference	Observations
Conservation Agriculture	50.18	48.76	1.42***	3,324
	6.52	7.40	4.09	
Soil and Water Conservation	51.69	48.04	3.65***	234
	11.87	6.91	10.66	
Organic Fertilizer	57.76	54.48	3.28***	631
	9.02	8.29	7.30	
Inorganic Fertilizer	58.49	51.62	6.87***	263
	8.38	8.33	10.37	
All SIPs	50.18	48.76	1.42***	3,324

Source: Authors' analysis

Note: * p < 0·10, ***p<0.05 and *** p < 0·01. CA denotes conservation agriculture, SWC denotes soil and water conservation, OF denotes organic fertilizer, IOF denotes inorganic fertilizer, and SIPs denote sustainable intensification practices.

METE analysis results based on FCS

The multinomial endogenous treatment effects (METE) results are shown in Table 12 below and in Table A11 in the appendix based on HDDS as part of the robustness checks. In general, the results from the robustness checks confirm the reliability and stability of our analysis of the impacts of SIPs on household welfare based on MESR and METE. Detailed information can be found in Table A10 (MESR) and Table A11 (METE).

The exogenous model of Malawi shows that the adoption of conservation agriculture, soil and water conservation, and adoption is negatively correlated with the welfare of farmers, while in Uganda, the adoption of SIPs has a positive impact. Our study's endogenous model shows that inorganic fertilizer adoption positively impacts FCS in Ethiopia by 5 percent, and the adoption of conservation agriculture, soil and water conservation, organic fertilizer, and inorganic fertilizer increases FCS in Uganda by 8-12 percent. Similarly, adopting IOF positively impacts FCS in Malawi. However, the adoption of conservation agriculture and soil and water conservation in Ethiopia and Malawi has a negative impact on FCS. While adopting inorganic fertilizer is related to a probability increase in FCS in Malawi and Uganda, it decreases the probability of reducing FCS in Ethiopia. The positive and significant effects of SIP adoption on FCS are in line with other studies in Bangladesh and Ethiopia that the adoption of climate-smart agriculture enhances food security (Hasan et al., 2018; Teklewold et al., 2013; Zegeye et al., 2022).

Table 12: METE estimates of adoption impacts of SIPs on FCS

	Ethiopia	Malawi	Uganda	Ethiopia	Malawi	Uganda
FCS	Exogenous Models			Endogenous Models		
Conservation Agriculture	-0.04***	-0.01	0.03***	-0.04***	-0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
Soil and Water Conservation	-0.02***	-0.01	0.04	-0.07***	-0.01	0.07*
	(0.01)	(0.01)	(0.03)	(0.01)	(0.01)	(0.04)
Organic Fertilizer	0.03	-0.01	0.07***	0.05**	0.01	-0.01
	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)	(0.03)
Inorganic Fertilizer	-0.02***	0.01*	0.12***	-0.08***	0.03***	0.08**
	(0.01)	(0.01)	(0.03)	(0.01)	(0.01)	(0.04)
All SIPs		0.02**			0.04***	
		(0.01)			(0.01)	
Selection terms						
λ Conservation Agriculture				-0.00	0.00	0.03
				(0.01)	(0.05)	(0.02)
λ Soil and Water Conservation				0.06***	-0.00	-0.03
				(0.01)	(0.01)	(0.02)
λ Organic Fertilizer				-0.02	-0.02***	0.09***
				(0.02)	(0.01)	(0.02)
λ Inorganic Fertilizer				0.07***	-0.02***	-0.04*
				(0.01)	(0.01)	(0.02)
					-0.02	
					(0.01)	
Wald Chi-Square	924***	1275***	700***	7147***	1984***	1861***
Observations	13,956	4,610	6,439	13,956	4,610	6,439

Source: Authors' analysis; Note: * p < 0·10, ***p<0.05 and *** p < 0·01.

Robustness checks based on HDDS

Robustness check results based on MESR and METE are presented in the appendix in Tables A10 and A11, respectively. Our results reveal similarities and variations across countries. For MESR, our analysis results shown in Table A10 reveal that while the adoption of conservation agriculture, organic fertilizer and inorganic fertilizer positively impacts HDDS in both Malawi and Uganda, the impact was negative in Ethiopia. Furthermore, soil and water conservation had a positive impact on HDDS in Uganda. With respect to METE (see Table A11), the results show that the adoption of conservation organic fertilizer has a positive impact on HDDS in all three countries: Ethiopia, Malawi and Uganda. In Ethiopia, the adoption of soil and water conservation had a positive impact on HDDS. In Uganda, the adoption of organic fertilizer and inorganic fertilizers had a positive impact on HDDS. Finally, while the adoption of conservation agriculture had a negative impact on HDDS in Malawi and Uganda, there was no significant impact in Ethiopia.

V. Conclusions

The study relies on publicly available data from the Living Standards Measurement Study (LSMS) datasets collected during the 2010/11 to 2015/16 growing seasons, enabling cross-country comparisons. The analysis employs multinomial switch endogenous models, considering the correlations between SIP choices and household food nutrition security.

Our study shows that the adoption of SIPs is influenced by factors such as the gender of the farm decision-maker, literacy levels, access to extension services, asset ownership, agroecological zones, proximity to infrastructure and services, and engagement in self-employment activities.

Our findings underscore the role of gender and decision-making dynamics in shaping the adoption of SIPs in the three countries under study. In Ethiopia, male decision-making is less likely to adopt conservation agriculture and soil and water conservation, while joint decision-making is more likely to adopt inorganic fertilizer. Malawi exhibits a pattern where joint decision-making is less likely to adopt conservation agriculture and inorganic fertilizer but more likely to adopt all SIPs. Uganda shows that male decision-makers are less likely to adopt conservation agriculture but are more likely to use inorganic fertilizers. In contrast, joint decision-makers are more likely to adopt both conservation agriculture and inorganic fertilizer compared to female decision-makers.

The relationship between SIP adoption and FCS varies across countries. In Ethiopia and Malawi, adopting conservation agriculture is negatively correlated with FCS, while in Uganda, it is positively correlated with FCS. FCS positively correlates with the adoption of soil and water conservation (SWC), organic fertilizer (OF), and inorganic fertilizer (IOF) in Ethiopia and Uganda but exhibits a negative relationship in Malawi. In Malawi, adopting IOF and combining all SIPs is positively impacts FCS.

These findings highlight the complex dynamics influencing the adoption of SIPs and their impacts on household food security. The study underscores the importance of considering context-specific factors when designing agricultural interventions. Additionally, promoting SIPs like conservation agriculture, soil and water conservation, organic fertilizer, and inorganic fertilizer could have positive implications for food security in these countries, but tailored strategies are necessary to account for varying conditions across the three countries.

VI. Policy recommendations

A number of policy recommendations emerge based on the study findings. Firstly, the adoption of SIPs, such as organic fertilizers and soil and water conservation practices, should be promoted. These practices have demonstrated positive impacts on food and nutritional security across various contexts. However, recognizing the country-specific results, interventions must be tailored to local conditions, accounting for gender differences, the unique needs and circumstances of each country. This entails fostering collaboration among researchers, policymakers, and agricultural practitioners to generate context-specific knowledge and solutions. These collaborations are essential in providing holistic problem solutions, effective policy solutions, and fostering technology adoption. Additionally, it is essential to encourage diversified production systems that incorporate a combination of SIPs — as shown in Malawi, where combinations are positively impact food and nutritional security. This multifaceted approach is likely to have a more significant impact on food security than relying solely on a single method.

Secondly, given the positive relationship between extension services and the adoption of SIPs, there is a need to scale up investments in agricultural research and extension services. This will equip farmers with the knowledge and resources necessary to adopt and implement SIPs effectively. Specific considerations should include the promotion of climate-smart agriculture practices within SIPs, highlighting their potential benefits in mitigating climate change while enhancing food security. Furthermore, providing training and capacity-building programs for farmers will improve their skills in sustainable agricultural practices, enabling them to implement SIPs effectively. In particular, considerations must be made for women's differential access to information and cultural barriers to engaging with extension and access to productive resources.

Thirdly, the study recommends the promotion of practices like integrated crop-livestock farming, given that livestock ownership has been found to have a positive relationship with SIP adoption. Under the crop-livestock farming systems, livestock provide a source of organic matter in the form of manure, which can be used as a natural fertilizer for crops, improving soil fertility and nutrient cycling. As a result, farmers can reduce their reliance on inorganic fertilizers and adopt organic fertilization as an SIP. Furthermore, combining crops and livestock diversifies income sources for farmers, which can be used as a buffer against income fluctuations, thereby providing financial stability and encouraging farmers to invest in SIPs over time.

Finally, there is a need to promote and implement agricultural policies that explicitly promote gender inclusivity, including encouraging and supporting female participation in decision-making processes related to agriculture; training and awareness programs for both male and female farmers on the benefits of SIPs such as conservation agriculture and soil and water conservation; and ensuring that these programs are accessible and tailored to the specific needs of different gender groups.

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