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Research Article

Keywords: Climate-smart agriculture, Adoption regimes, Food and nutrition security, Household dietary diversity, Food Consumption Score, Smallholder farmers

Posted Date: September 18th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11073051/v1>

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Additional Declarations: The authors declare no competing interests.

Climate-Smart Agriculture Package Combinations and Household Food and Nutrition Security among Smallholder Farmers in Southwestern Ethiopia

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Abstract

Climate-Smart Agriculture (CSA) may contribute to household food and nutrition security, but the outcomes associated with combinations of CSA practices can vary across households. This study examined the relationship between alternative CSA practice packages and household food and nutrition security among smallholder farmers in southwestern Ethiopia. Data were collected from 384 farm households and analyzed using a Multinomial Logit model and a Multinomial Endogenous Switching Regression framework. CSA adoption was classified into six mutually exclusive regimes based on crop management (CRM), soil nutrient management (SNM), and agroforestry (AF). Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS) were used as complementary indicators of household food and nutrition security. The results show substantial heterogeneity in adoption patterns and household characteristics across CSA regimes. The full CRM+SNM+AF package was the most common adoption regime (39.84%), while 14.06% of households did not adopt any of the three CSA domains. Access to CSA information, training, extension services, credit, education, and farm resources was associated with the selection of several CSA packages. The MESR results indicate positive and statistically significant ATT estimates for both FCS and HDDS across all observed adoption regimes, while ATU estimates varied across packages for FCS but were positive for HDDS. These findings highlight heterogeneous model-based counterfactual differences across CSA packages and household groups. Strengthening CSA training, extension, information, credit access, and locally appropriate integrated CSA interventions may help address adoption constraints and support household food and nutrition security.

Keywords: Climate-smart agriculture; Adoption regimes; Food and nutrition security; Household dietary diversity; Food Consumption Score; Smallholder farmers

1. Introduction

Agriculture remains central to Ethiopia's economy and rural livelihoods, providing employment, income, food, and raw materials for a large share of the population. However, Ethiopian agriculture is predominantly rain-fed and highly exposed to climate variability and climate change. Rising temperatures, irregular rainfall, droughts, floods, land degradation, and increasing pest and disease pressures pose substantial challenges to agricultural production and rural livelihoods (IPCC, 2014; FAO, 2022; World Bank, 2021). These climate-related stresses can affect agricultural productivity and household livelihoods and may also influence household food availability, access to food, and dietary quality, thereby increasing the vulnerability of smallholder households to food and nutrition insecurity.

These challenges are particularly relevant in southwestern Ethiopia, including the Kaffa, Sheka, and Bench Sheko areas, where smallholder agriculture is closely linked to natural resources and local ecosystems. The region has considerable potential for crop, livestock, and agroforestry production, but farmers face rainfall variability, excessive rainfall, soil degradation, pests, diseases, and other production constraints (FSRP, 2024). These conditions underscore the importance of agricultural strategies that can improve productivity and resilience while supporting sustainable management of natural resources and household livelihoods.

Climate-Smart Agriculture (CSA) has emerged as an approach for addressing the interconnected challenges of agricultural productivity, climate change adaptation, and food security. CSA aims to sustainably increase agricultural productivity and incomes, strengthen resilience and adaptive capacity to climate change, and, where possible, reduce or remove greenhouse gas emissions (FAO, 2013; Lal et al., 2023). In Ethiopia, a range of CSA practices—including improved crop management, soil and nutrient management, agroforestry, improved crop varieties, and sustainable land-management practices have been promoted to improve agricultural productivity and resilience. Previous studies have reported associations between CSA adoption and agricultural productivity, household income, food consumption, and food-security outcomes (Wekesa et al., 2018; Hasan et al., 2018).

Among the range of CSA practices relevant to smallholder farming systems in southwestern Ethiopia, Crop Management (CRM), Soil Nutrient Management (SNM), and Agroforestry (AF) represent important practice domains. CRM practices, such as improved varieties, crop rotation, intercropping, crop diversification, and row planting, can contribute to productivity improvement and production-risk management. SNM practices, including manure and compost use, crop-residue management, terracing, bunds, contour plowing, and legume integration, can contribute to soil fertility, nutrient availability, moisture conservation, and long-term land productivity. AF practices, including tree crop integration, fruit-tree planting, multipurpose trees, and windbreaks, can provide multiple benefits through soil conservation, nutrient cycling, microclimate regulation, biomass production, and diversification of household resources and income.

Importantly, smallholder farmers do not necessarily adopt these practices independently. Households may adopt several CSA practices simultaneously because practices can be complementary, mutually reinforcing, or jointly beneficial (Teklewold et al., 2013; Abyiot et al., 2023; Tamirat, 2022). For example, crop-management practices may contribute to crop productivity, soil nutrient-management practices may improve soil fertility and nutrient-use efficiency, while agroforestry may contribute to soil conservation, resource diversification, and additional sources of food and income. Consequently, analyzing individual CSA practices separately may overlook the potential complementarities, synergies, and trade-offs associated with their joint adoption. Examining CSA adoption as combinations or packages can therefore provide a more comprehensive representation of farmers' adoption choices and the potentially heterogeneous outcomes associated with different practice combinations.

Previous studies in Ethiopia and other developing countries have increasingly examined the simultaneous adoption of multiple agricultural and CSA practices and their implications for household welfare and food security. Some studies have used multivariate probit models to account for interdependence among individual adoption decisions, whereas others have employed endogenous switching approaches to examine outcomes associated with CSA adoption while accounting for potential selection bias (Mebratu et al., 2022; Samuel et al., 2022; Abyiot et al., 2023). Existing evidence generally suggests that CSA adoption can be associated with improved food consumption, dietary diversity, and other household welfare outcomes. However, the magnitude and direction of these associations may vary across practices and combinations of

practices. Treating all CSA adopters as a homogeneous group may therefore obscure important heterogeneity across alternative adoption packages.

Despite the growing literature on multiple CSA adoption, several empirical gaps remain. First, the composition of CSA practice packages and their associated outcomes are context-specific and may vary with agro-ecological conditions, farming systems, household resource endowments, and institutional environments. Evidence from other parts of Ethiopia may therefore not fully reflect the circumstances of smallholder farmers in southwestern Ethiopia. Second, relatively limited empirical evidence has examined mutually exclusive combinations of Crop Management, Soil Nutrient Management, and Agroforestry and their association with household food and nutrition security in this region. Third, household food and nutrition security is multidimensional, and a single indicator may not adequately capture differences in food consumption and dietary diversity. Examining both the Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS) can therefore provide complementary evidence on these dimensions of household food and nutrition security.

A further empirical challenge arises from the non-random nature of farmers' CSA package choices. Households adopting different combinations of practices may differ systematically in demographic characteristics, farm resources, access to extension and agricultural information, credit, training, and other institutional factors. Consequently, direct comparisons of food and nutrition security outcomes across adoption groups may be affected by observable and unobservable differences between households. Moreover, when households are classified into distinct and mutually exclusive CSA adoption regimes, methods designed to examine individual adoption decisions separately may not adequately represent the joint regime-selection process. A multinomial framework is therefore appropriate for examining farmers' choices among mutually exclusive CSA practice packages. An endogenous switching framework can subsequently be used to account for potential non-random selection into these regimes and to generate regime-specific and counterfactual outcome estimates.

Against this background, this study employs a Multinomial Logit (MNL) model to examine the household, farm-level, and institutional factors associated with farmers' selection among alternative CSA practice packages. A Multinomial Endogenous Switching Regression (MESR) framework is then employed to estimate regime-specific and counterfactual outcomes for

household food and nutrition security while accounting for potential endogenous selection into CSA regimes. The analysis focuses on three CSA domains Crop Management, Soil Nutrient Management, and Agroforestry and the mutually exclusive combinations of these domains observed in the sample. Household food and nutrition security is assessed using two complementary indicators: the Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS).

Therefore, this study examines the selection and outcomes of CSA practice packages among smallholder farmers in southwestern Ethiopia. Specifically, it aims to: (i) identify the household, farm-level, and institutional factors associated with farmers' selection among alternative CSA practice packages; (ii) estimate regime-specific and counterfactual outcomes associated with alternative CSA packages using FCS and HDDS; and (iii) identify the major constraints reported by farmers in adopting CSA practices. By jointly examining CSA package selection and heterogeneous food and nutrition security outcomes, the study contributes context-specific evidence on how alternative combinations of CSA practices are associated with household food consumption and dietary diversity. The findings may inform agricultural research institutions, extension services, development practitioners, and other stakeholders seeking to design context-specific approaches to CSA promotion in southwestern Ethiopia.

2. Conceptual Framework

The conceptual framework links the factors influencing farmers' choices among Climate-Smart Agriculture (CSA) practice packages with household food and nutrition security outcomes (Figure 1). It assumes that farmers' CSA adoption decisions are shaped by their socioeconomic and demographic characteristics, household and farm resources, institutional support, and access to CSA-related information and training. These factors include the sex, age, and education of the household head; farm size, household size, livestock ownership, and household income; access to extension and credit and cooperative membership; and access to CSA information and training.

CSA adoption is represented by three practice domains: Crop Management (CRM), Soil Nutrient Management (SNM), and Agroforestry (AF). Farmers may combine these domains in different ways, resulting in mutually exclusive adoption regimes. The study identifies six observed CSA adoption regimes, which constitute the choice alternatives analyzed using the Multinomial Logit (MNL) model.

The framework further assumes that alternative CSA adoption regimes may lead to differences in household food and nutrition security through improved agricultural productivity, resource management, resilience, food availability, and income diversification. Food and nutrition security is assessed using two complementary indicators: the Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS). Because farmers self-select into different CSA adoption regimes and may differ in both observable and unobservable characteristics, simple comparisons of outcomes may be biased. Therefore, the Multinomial Endogenous Switching Regression (MESR) framework is used to account for potential endogenous selection and estimate regime-specific and counterfactual outcomes.

Overall, the framework proposes a pathway from household, farm, institutional, and information-related factors → CSA adoption regimes → household food and nutrition security, providing the basis for jointly analyzing CSA package selection and its associated food and nutrition security outcomes.

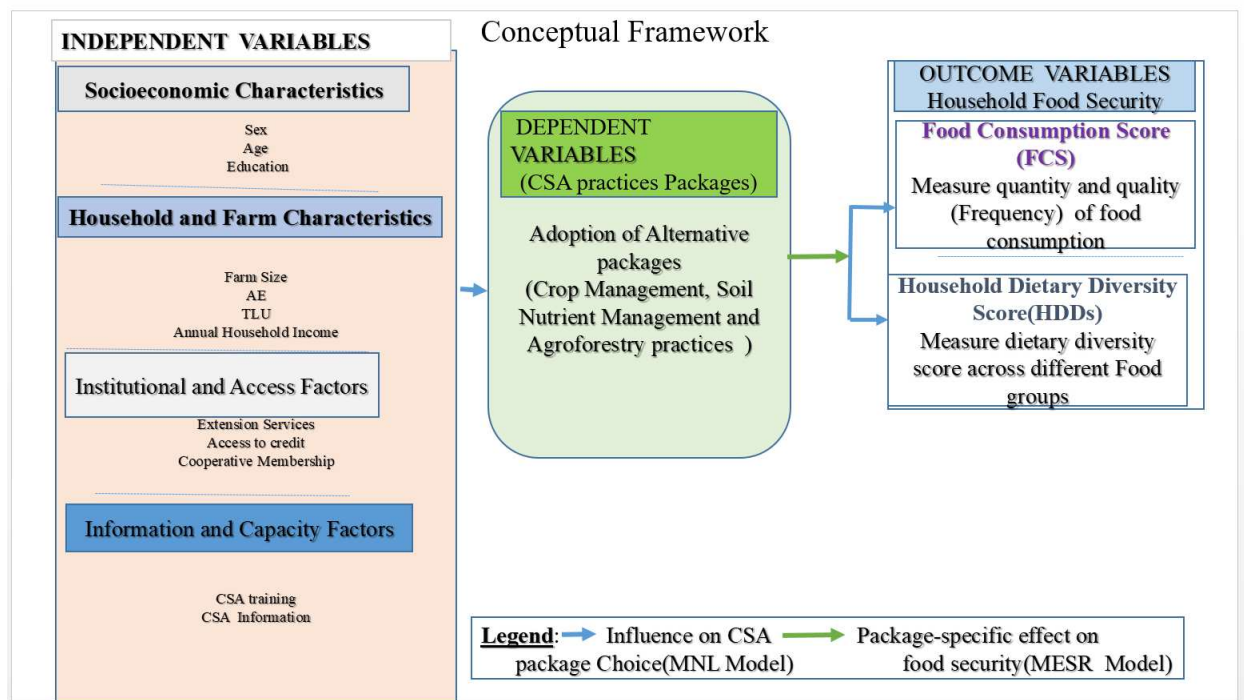


Figure 1. Conceptual Framework

3. Research Methodology

3.1 Study Area, Sampling Procedure and Sample Size Determination

A multistage sampling procedure was employed to select the study areas and sample households in southwestern Ethiopia. In the first stage, three woredas were purposively selected from three zones based on the relevance and prevalence of Climate-Smart Agriculture (CSA) practices and their coverage under the Food Systems Resilience Program (FSRP). In the second stage, six FSRP-supported kebeles were purposively selected in consultation with agricultural experts, considering their engagement in CSA-related activities and FSRP interventions. Specifically, Addis Bran and Kubito kebeles were selected from Yeki Woreda of Sheka Zone; Wana Bola and Dahara kebeles from Shishoinde Woreda of Kaffa Zone; and Kusha and Gashima kebeles from Shey Bench Woreda of Bench Sheko Zone. In the third stage, household lists were obtained from the respective kebele agricultural offices and used as sampling frames. The six selected kebeles contained a total of 4,492 households. The required sample size was determined using Cochran's (1977) formula,

$$n = \frac{Z^2 pq}{e^2} = 384$$

Where, n = sample size, Z is the standard cumulative distribution that corresponds to the desired confidence level (95%); e is the desired level of precision ($\pm 5\%$); p is the estimated proportion of an attribute present in the population with the value of 0.5 (where $q = 1 - p$).

Accordingly, 68 households were selected from Addis Bran, 99 from Kubito, 63 from Wana Bola, 45 from Dahara, 59 from Kusha, and 50 from Gashima, giving a total sample of 384 households. Finally, households were randomly selected from each kebele using the household lists as sampling frames. Primary data were collected from the selected households using a structured questionnaire covering socioeconomic and demographic characteristics, household and farm characteristics, institutional access, CSA adoption, access to agricultural information and services, and household food and nutrition security indicators.

Table 1. Distribution and proportional allocation of sampled households across FSRP-supported kebeles in southwestern Ethiopia

Zone	Woreda	Kebele	Total households ((Ni))	Proportion (%)	Allocated sample ((ni))

Sheka	Yeki	Addis Bran	790	17.59	68
Sheka	Yeki	Kubito	1,160	25.82	99
Kaffa	Shishoinde	Wana Bola	735	16.36	63
Kaffa	Shishoinde	Dahara	522	11.62	45
Bench Sheko	Shey Bench	Kusha	687	15.29	59
Bench Sheko	Shey Bench	Gashima	598	13.31	50
Total			4,492	100	384

3.2 Variable Definition and CSA Package Construction

3.2.1 Definition of Variables

The study considered household demographic, socioeconomic, farm-level, and institutional characteristics as explanatory variables influencing the adoption of Climate-Smart Agriculture (CSA) practice packages. The dependent variable in the CSA adoption model was the CSA practice package, while household food security was assessed using two outcome indicators: Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS).

The explanatory variables included demographic characteristics such as sex of the household head, age, education level, and household size measured in Adult Equivalent (AE). Farm-level characteristics included farm size and livestock ownership measured in Tropical Livestock Units (TLU). Institutional and service-related variables included access to CSA information, CSA training, extension services, access to credit, and cooperative membership. Annual household income was also included to capture the potential influence of household economic capacity on CSA adoption and food security.

3.2.2 Construction of CSA Practice Domains

CSA adoption was measured based on the agricultural practices adopted by the sampled households. The individual CSA practices were grouped into three major domains according to their primary management objectives: Crop Management (CRM), Soil Nutrient Management (SNM), and Agroforestry (AF).

The Crop Management (CRM) domain consisted of the following practices: use of improved varieties, crop rotation, intercropping, crop diversification, and row planting. These practices were considered crop management practices because they focus primarily on improving crop production, productivity, and farmers' capacity to manage climate-related production risks.

The Soil Nutrient Management (SNM) domain included use of organic manure/compost, crop residue management, terracing, bunds, contour plowing, and legume integration. These practices were classified under soil nutrient management because they contribute to maintaining and improving soil fertility, nutrient availability, soil moisture conservation, and soil productivity.

The Agroforestry (AF) domain comprised tree–crop integration, fruit-tree integration, and multipurpose tree planting for fuel wood, timber and soil-fertility benefits, and windbreaks. These practices involve integrating trees and perennial vegetation into agricultural systems to improve farm productivity, soil conservation, environmental sustainability, and resilience to climate-related stresses.

For each CSA domain, a binary adoption indicator was constructed. A household was assigned a value of 1 if it adopted at least one practice within the respective domain and 0 otherwise. Accordingly, (CRM_i) , (SNM_i) , and (AF_i) represent binary indicators of adoption of Crop Management, Soil Nutrient Management, and Agroforestry, respectively, for household (i) .

The three domain-specific indicators were then combined to construct mutually exclusive CSA practice packages:

CSA package	CRM	SNM	AF	Interpretation
CRM0SNM0AF0	0	0	0	Non-adopter
CRM1SNM0AF0	1	0	0	CRM only
CRM1SNM1AF0	1	1	0	CRM + SNM
CRM0SNM1AF1	0	1	1	SNM + AF
CRM1SNM0AF1	1	0	1	CRM + AF
CRM1SNM1AF1	1	1	1	CRM + SNM + AF

Although three binary CSA domains theoretically allow eight possible combinations, only six combinations were observed among the sampled households. The two combinations that were not observed were therefore excluded from the empirical analysis. The resulting six-category CSA

package variable was used as the dependent variable in the Multinomial Logit (MNL) model to identify factors associated with farmers' choices among alternative CSA packages.

The CRM0SNM0AF0 (non-adoption) category was specified as the reference category in the MNL model. Thus, the estimated coefficients and marginal effects indicate how household, farm, and institutional characteristics are associated with the probability of adopting each observed CSA package relative to non-adoption.

3.2.3 Measurement of Food Security Indicators

The effects of CSA practice packages on household food security were assessed using two complementary indicators: Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS). These indicators were measured using structured household-level questions covering food consumption during the previous seven days for FCS and food consumption during the previous 24 hours for HDDS.

3.2.3.1 Food Consumption Score (FCS)

The Food Consumption Score (FCS) was used as a household-level indicator of food consumption, based on the frequency and diversity of foods consumed during the seven days preceding the survey. The FCS is a composite indicator developed by the World Food Programme (WFP) that combines the frequency of consumption of different food groups with their relative nutritional weights (WFP, 2008; WFP, 2024). Respondents were asked to report the number of days during the previous seven days on which their household consumed foods from each specified food group. Following the standard WFP methodology, food items were classified into eight weighted food groups: main staples; pulses; vegetables; fruits; meat, fish and eggs; milk and other dairy products; sugar; and oil/fats plus condiments (WFP, 2008; WFP, 2024).

The main staples group included maize, maize porridge, rice, sorghum, millet, pasta, bread and other cereals, as well as enset, potatoes, sweet potatoes and other tubers. The pulses group included beans, peas, groundnuts and other nuts or legumes. The vegetable group included vegetables and leafy vegetables, while the fruit group included different types of fruits. The meat, fish and eggs group included beef, goat, poultry, and eggs. The milk and dairy group included milk, yogurt and other dairy products. The sugar group included sugar and sugar products and honey, whereas the oil/fats group included oils, fats and butter. Condiments included spices, tea,

coffee, salt, fish powder and small amounts of milk used in tea or coffee. These classifications are based on the standard WFP FCS methodology (WFP, 2008; WFP, 2024).

For each food group, the reported frequency of consumption was capped at seven days and multiplied by the corresponding standard food-group weight. The weighted values were then summed to obtain the household FCS: The general form of the FCS calculation is:

$$FCS = \sum_{j=1}^8 F_j W_j$$

Where F_j represents the frequency of consumption of food group j during the previous seven days, and W_j represents the standard weight assigned to that food group.

Higher FCS values indicate more frequent consumption of nutritionally important food groups and, therefore, relatively better household food consumption and dietary quality. The FCS was used as a continuous outcome variable in the analysis of the effects of CSA practice packages on household food security.

3.2.3.2 Household Dietary Diversity Score (HDDS)

The Household Dietary Diversity Score (HDDS) was used as a household-level indicator of dietary diversity, based on the food groups consumed by household members during the 24 hours preceding the survey. Respondents were asked whether any household member had consumed foods from each specified food group during the previous 24 hours. Each food group was coded as 1 if the household consumed at least one food item from that group and 0 otherwise. The HDDS is a qualitative measure of household food consumption and reflects the household's access to a variety of foods (Kennedy et al., 2011; FAO, 2012).

Following the standard FAO methodology, the HDDS was constructed using 12 food groups: (1) cereals; (2) roots and tubers; (3) vegetables; (4) fruits; (5) meat and organ meats; (6) eggs; (7) fish and seafood; (8) legumes, nuts and seeds; (9) milk and milk products; (10) foods prepared with oil, fat or butter; (11) sugar and honey; and (12) other foods, including condiments, coffee and tea (Kennedy et al., 2011; FAO, 2012).

The HDDS was calculated by summing the binary indicators for the 12 food groups consumed by the household during the previous 24 hours:

$$HDDSi = \sum_{j=1}^{12} D_{ij}$$

Where HDDSi represents the Household Dietary Diversity Score for household i, and D_{ij} is a binary indicator taking a value of 1 if household (i) consumed food from food group (j) during the 24-hour reference period and 0 otherwise. Thus, the HDDS theoretically ranges from 0 to 12, with higher scores indicating consumption from a greater number of food groups and, therefore, greater household dietary diversity (Kennedy et al., 2011; FAO, 2012).

The HDDS was used as a continuous outcome variable in assessing the association between alternative CSA adoption regimes and household food and nutrition security.

Accordingly, the HDDS ranges from 0 to 12, with higher scores indicating greater dietary diversity

3.2.4 Measurement of Constraints to CSA Adoption

Major constraints to the adoption of CSA practices were assessed using a structured questionnaire. Respondents were asked to identify the main constraints they experienced in adopting CSA practices. The reported constraints were grouped into five categories: high cost of inputs, limited access to credit, lack of information, lack of training, and lack of market access. The frequency of responses in each category was calculated and expressed as a percentage of the total reported responses. The resulting percentages were used to summarize the relative frequency of the constraints reported by farmers.

3.3. Analytical Framework and Econometric Strategy

The empirical analysis follows a sequential framework linking individual Climate-Smart Agriculture (CSA) practices, CSA domains, joint adoption regimes, package choice, and household food and nutrition security outcomes. First, the individual CSA practices reported by sample households were conceptually grouped into three analytically defined CSA domains: Crop Management (CRM), Soil Nutrient Management (SNM), and Agroforestry (AF). The classification was based on the agronomic function and primary management objective of each practice. For each domain, a binary indicator was constructed, taking a value of one if a household adopted at least one practice belonging to that domain and zero otherwise.

The three binary domain indicators (CRM, SNM, and AF) were then combined to identify mutually exclusive patterns of joint adoption. Although three binary domains theoretically generate eight possible combinations, only six combinations were observed in the sample. These were non-adoption (CRM0SNM0AF0), CRM only (CRM1SNM0AF0), CRM + SNM (CRM1SNM1AF0), SNM + AF (CRM0SNM1AF1), CRM + AF (CRM1SNM0AF1), and CRM + SNM + AF (CRM1SNM1AF1). The non-adoption regime (CRM0SNM0AF0) was specified as the reference category in the subsequent econometric analysis. The two theoretically possible combinations that were not observed in the sample were AF only (CRM0SNM0AF1) and SNM only (CRM0SNM1AF0).

The empirical analysis proceeded in three main stages. First, a multinomial logit (MNL) model was used to identify the factors associated with households' selection among the five observed CSA adoption regimes relative to the non-adoption regime (CRM0SNM0AF0). Specifically, the five adoption regimes were CRM only (CRM1SNM0AF0), CRM + SNM (CRM1SNM1AF0), SNM + AF (CRM0SNM1AF1), CRM + AF (CRM1SNM0AF1), and CRM + SNM + AF (CRM1SNM1AF1). Thus, the MNL model explains households' selection into alternative CSA adoption regimes and does not directly estimate their associations with food and nutrition security outcomes.

Second, a Multinomial Endogenous Switching Regression (MESR) framework was employed to estimate household food and nutrition security outcomes under the different adoption regimes while accounting for potential non-random selection into CSA regimes. Regime-specific outcome equations were specified for the non-adoption regime (CRM0SNM0AF0) and each of the five observed CSA adoption regimes: CRM only (CRM1SNM0AF0), CRM + SNM (CRM1SNM1AF0), SNM + AF (CRM0SNM1AF1), CRM + AF (CRM1SNM0AF1), and CRM + SNM + AF (CRM1SNM1AF1). The MESR framework allows unobserved factors influencing households' CSA regime selection to be correlated with unobserved factors affecting food and nutrition security outcomes. Accordingly, selection-correction terms derived from the first-stage multinomial choice model were incorporated into the regime-specific outcome equations to account for potential endogenous selection.

Third, the estimated regime-specific equations were used to generate observed and counterfactual food and nutrition security outcomes for households under each adoption regime. These

predictions were subsequently used to estimate the Average Treatment Effect on the Treated (ATT) and Average Treatment Effect on the Untreated (ATU). The ATT represents the difference between the predicted food and nutrition security outcome for households that adopted a particular CSA regime under their observed regime and the predicted counterfactual outcome they would have experienced had they instead remained in the non-adoption regime (CRM0SNM0AF0). The ATU represents the difference between the predicted counterfactual outcome that non-adopting households would have experienced had they adopted a particular CSA regime and their predicted outcome under the non-adoption regime (CRM0SNM0AF0).

Two outcome indicators were used to assess household food and nutrition security: the Food Consumption Score (FCS) and the Household Dietary Diversity Score (HDDS). The FCS provides an indicator of the frequency and nutritional importance of food-group consumption, while the HDDS captures household dietary diversity based on the number of food groups consumed.

3.4 Econometric Models

The empirical analysis was conducted using a sequential econometric framework. First, a Multinomial Logit (MNL) model was used to examine the factors associated with households' selection among the six observed CSA adoption regimes, with non-adoption as the reference category. Second, a Multinomial Endogenous Switching Regression (MESR) model was used to estimate household food-security outcomes under the different CSA adoption regimes while accounting for potential endogenous selection. Finally, the estimated regime-specific equations were used to generate observed and counterfactual food-security outcomes and to calculate the Average Treatment Effect on the Treated (ATT) and Average Treatment Effect on the Untreated (ATU). The outcome variables were the Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS).

3.4.1 Multinomial Logit Model for CSA Regime Selection

The CSA adoption decision was modeled within a random utility framework, where household *i* chooses the CSA adoption regime that provides the highest utility among the available alternatives (McFadden, 1972). In this study, the three CSA domains Crop Management (CRM), Soil Nutrient Management (SNM), and Agroforestry (AF) generated six observed adoption regimes: non-

adoption, CRM only, CRM+SNM, SNM+AF, CRM+AF, and CRM+SNM+AF. Non-adoption was specified as the reference regime.

Let U_{ij}^* denote the latent utility that household i obtains from choosing regime j , where $j=0,1,\dots,5$. The utility function is specified as:

$$U_{ij} = X_i \beta_j + \eta_{ij}$$

Where X_i is a vector of observed household, farm, and institutional characteristics, β_j is a vector of parameters associated with regime j , and η_{ij} is the unobserved error term.

Household i chooses regime j when the utility from that regime is greater than the utility from every other available regime:

$$D_i = j \text{ if } U_{ij} > U_{ik}, \forall k \neq j$$

Where D_i denotes the observed CSA adoption regime.

Assuming that the error terms follow the Type-I extreme-value distribution, the probability that household i selects regime j is given by the multinomial logit model:

$$P_{ij} = P_r(D_i = j) = \frac{\exp(X_i \beta_j)}{\sum_{k=1}^5 \exp(X_i \beta_k)}$$

With the non-adoption regime normalized as the reference category ($\beta_0 = 0$). The MNL model therefore identifies the factors associated with households' selection into each observed CSA adoption regime relative to non-adoption. Marginal effects were used to show how changes in the explanatory variables affect the probability of selecting each regime.

3.4.2 Multinomial Endogenous Switching Regression Model

The MNL model identifies the determinants of CSA regime selection but does not estimate the effect of regime adoption on food-security outcomes. Therefore, a Multinomial Endogenous Switching Regression (MESR) framework was employed to estimate food-security outcomes while accounting for potential non-random selection into CSA adoption regimes. The MESR approach is appropriate because unobserved characteristics that influence households' decisions

to adopt a particular CSA regime may also influence their food-security outcomes. Failure to account for this endogenous selection may therefore bias the estimated outcome differences (Kassie et al., 2015; Khonje et al., 2018).

Let Y_{ij} denote the potential food-security outcome of household i under regime j , where $j=0$ represents non-adoption and $j=1, \dots, 5$ represent the five adoption regimes. The regime-specific outcome equation is specified as:

$$Y_{ij} = \alpha_j + X_i \beta_j + \sigma_j \gamma_{ij} + \varepsilon_{ij}, j = 0, 1, \dots, 5$$

where Y_{ij} is the food-security outcome under regime j ; α_j is the regime-specific constant; X_i is a vector of observed household, farm, and institutional characteristics; β_j is the vector of regime-specific coefficients; γ_{ij} is the selection-correction term obtained from the first-stage MNL model; σ_j represents the covariance between the unobserved components of the selection and outcome equations; and ε_{ij} is the random error term.

For the non-adoption regime, the outcome equation is:

$$Y_{i0} = \alpha_0 + X_i \beta_0 + \sigma_0 \gamma_{i0} + \varepsilon_{i0}$$

While for each adoption regime j , the corresponding outcome equation is:

$$Y_{ij} = \alpha_j + X_i \beta_j + \sigma_j \gamma_{ij} + \varepsilon_{ij}, j = 1, \dots, 5$$

The selection-correction terms control for the correlation between unobserved determinants of CSA regime selection and unobserved determinants of food-security outcomes. The MESR equations were estimated separately for FCS and HDDS. The estimated coefficients were then used to predict both observed and counterfactual food-security outcomes for each adoption regime.

3.4.3 Estimation of ATT and ATU

After estimating the regime-specific MESR equations, the expected food-security outcomes under observed and counterfactual regimes were calculated. These predictions were used to estimate the Average Treatment Effect on the Treated (ATT) and the Average Treatment Effect on the Untreated (ATU), following the counterfactual approach commonly used in endogenous switching models (Kassie et al., 2015; Khonje et al., 2018).

For households that actually adopted regime j , the expected outcome under the regime they selected is:

$$E(Y_{ij}/D_i = j) = \alpha_j + X_i\beta_j + \sigma_j\gamma_{ij}$$

Whereas their counterfactual expected outcome under non-adoption is:

$$E(Y_{i0}/D_i = j) = \alpha_0 + X_i\beta_0 + \sigma_{j0}\gamma_{i0}$$

The Average Treatment Effect on the Treated (ATT) is therefore:

$$ATT_j = E(Y_{ij}/D_i = j) - E(Y_{i0}/D_i = j).$$

$$\text{Thus, } ATT_j = (\alpha_j + X_i\beta_j + \sigma_j\gamma_{ij}) - (\alpha_0 + X_i\beta_0 + \sigma_{j0}\gamma_{i0})$$

The ATT measures the average difference between the food-security outcomes that households actually adopting regime j are expected to achieve and the outcome they would have achieved had they remained non-adopters. A positive ATT indicates a higher predicted FCS or HDDS under the adopted CSA regime than under the counterfactual non-adoption state.

For households that remained non-adopters, the expected outcome under their observed state is:

$$E(Y_{i0}/D_i = 0) = \alpha_0 + X_i\beta_0 + \sigma_{j0}\gamma_{i0}$$

Their counterfactual expected outcome if they had adopted regime j is:

$$E(Y_{ij}/D_i = 0) = \alpha_j + X_i\beta_j + \sigma_j\gamma_{ij}$$

The Average Treatment Effect on the Untreated (ATU) is therefore:

$$ATU_j = E(Y_{ij}/D_i = 0) - E(Y_{i0}/D_i = 0)$$

Thus,

$$ATU_j = (\alpha_j + X_i\beta_j + \sigma_j\gamma_{ij}) - (\alpha_0 + X_i\beta_0 + \sigma_{j0}\gamma_{i0})$$

The ATU measures the expected change in food-security outcomes among households that did not adopt regime j , if they had instead adopted that regime. A positive ATU indicates that non-adopters would be expected to have higher FCS or HDDS under the counterfactual adoption of regime j .

The ATT and ATU were estimated separately for the five adoption regimes CRM₁SNM₀AF₀, CRM₁SNM₁AF₀, CRM₀SNM₁AF₁, CRM₁SNM₀AF₁, and CRM₁SNM₁AF₁ and for both FCS and HDDS. Throughout the analysis, the same sign convention was used: positive ATT and ATU values indicate higher food-security outcomes under the CSA adoption regime relative to the relevant non-adoption outcome

3.5 Multicollinearity and Model Diagnostics

Before estimating the econometric models, the explanatory variables were assessed for potential multicollinearity. Variance inflation factors (VIFs) were examined to assess the extent of collinearity among the explanatory variables. The MNL specification was further assessed for the Independence of Irrelevant Alternatives (IIA) assumption. In addition, the tested regression specification was assessed using the Ramsey RESET test for potential specification or functional-form misspecification and the Breusch–Pagan/Cook–Weisberg test for heteroskedasticity. The diagnostic results are presented in Supplementary Tables S1–S4 and are considered when interpreting the econometric estimates.

4. Results

4.1 Descriptive Characteristics of Sample Households by CSA Adoption Package

This section presents the descriptive characteristics of sample households across alternative Climate-Smart Agriculture (CSA) adoption packages. The study classified farmers into six mutually exclusive CSA adoption regimes based on their adoption of Crop Management (CRM), Soil Nutrient Management (SNM), and Agroforestry (AF). These include non-adopters (CRM₀SNM₀AF₀), CRM only (CRM₁SNM₀AF₀), CRM combined with SNM (CRM₁SNM₁AF₀), SNM combined with AF (CRM₀SNM₁AF₁), CRM combined with AF (CRM₁SNM₀AF₁), and the full package comprising CRM, SNM, and AF (CRM₁SNM₁AF₁).

4.1.1 Categorical Explanatory Variables

Table 2 presents the distribution of categorical explanatory variables across the different CSA adoption packages. The results show substantial differences in household characteristics and institutional access among farmers adopting different CSA packages.

The proportion of male-headed households was relatively high across all adoption categories, ranging from 70.37% among households adopting the SNM+AF package to 91.18% among households adopting the CRM+SNM package. The chi-square test indicates a statistically significant difference in gender composition across CSA adoption packages ($\chi^2 = 10.95$, $p < 0.05$).

Access to CSA information differed significantly across adoption categories ($\chi^2 = 229.38$, $p < 0.001$). Only 5.56% of non-adopters had access to CSA-related information, compared with 97.39% of households adopting the full CSA package. Similarly, participation in CSA training was considerably higher among adopters than non-adopters. While only 1.85% of non-adopters received CSA training, almost all households adopting the full package (99.35%) had participated in CSA-related training. The difference was highly statistically significant ($\chi^2 = 194.20$, $p < 0.001$).

Extension service access also varied significantly across adoption packages. Only 14.81% of non-adopters reported receiving extension services, compared with 99.4% of households adopting the full CSA package ($\chi^2 = 174.30$, $p < 0.001$). Likewise, access to credit was substantially higher among adopters of multiple CSA practices. Only 7.41% of non-adopters had access to credit, whereas 96.08% of full-package adopters accessed credit services ($\chi^2 = 173.75$, $p < 0.001$).

Cooperative membership also showed significant variation across CSA packages ($\chi^2 = 149.25$, $p < 0.001$). Approximately 12.96% of non-adopters were cooperative members, compared with 94.77% of households adopting the full CSA package. Overall, the descriptive results suggest that institutional support, including access to information, training, extension services, credit, and cooperative membership, is strongly associated with the adoption of CSA practices and more comprehensive CSA packages.

Table 2. Distribution of dummy explanatory variables by CSA adoption package

Variables	Adoption of combination a possible Combination of CSA practices						All Sample	Chi ² Value
	CRM ₀ SNM ₀ AF ₀ N= 54	CRM ₁ SNM ₀ AF ₀ N= 68	CRM ₁ SNM ₁ AF ₀ n=34	CRM ₀ SNM ₁ AF ₁ N=27	CRM ₁ SNM ₀ AF ₁ N=48	CRM ₁ SNM ₁ AF ₁ N=153	N=384	
Sex(male=1)	90.74	89.71	91.18	70.37	77.08	86.27	85.68	10.95*
Access to CSA info(Yes=1)	5.56	80.88	97.06	92.59	89.58	97.39	80.21	229.38***
CSA training(Yes=1)	1.85	57.35	79.41	70.37	75.00	99.35	71.35	194.20***
Extension service(Yes=)	14.81	76.47	82.35	77.78	87.50	99.4	78.91	174.3***
Access credit(Yes=)	7.41	48.53	64.71	70.37	89.58	96.08	69.79	173.75***

cooperative membership(Yes=1)	12.96	73.53	79.41	62.96	87.50	94.77	75.00	149.25***
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Source: Computed Survey data 2026

4.1.2 Continuous Explanatory Variables

Table 3 presents the mean values and standard deviations of continuous explanatory variables across the different CSA adoption packages. The results indicate statistically significant differences among households belonging to alternative adoption regimes.

The average age of respondents was 42.80 years, suggesting that the sampled households were predominantly middle-aged farmers. Age differed significantly across CSA packages ($F = 10.85$, $p < 0.05$). The mean age ranged from 40.22 years among households adopting CRM only to 46.52 years among those adopting the CRM+SNM package.

Education also differed significantly across adoption categories ($F = 6.90$). Non-adopters had the lowest average education level, with approximately 1.92 years of formal schooling, whereas households adopting the full CSA package had the highest average educational attainment of approximately 6.99 years. This pattern suggests that education may improve farmers' ability to acquire information, understand agricultural technologies, and adopt more complex CSA packages.

The average household size, measured in adult equivalent (AE), was 4.92. Household size differed significantly across adoption categories ($F = 9.89$, $p < 0.05$). Non-adopters had the largest average household size, while households adopting multiple CSA practices generally had relatively moderate household sizes.

Farm size showed substantial and statistically significant differences across CSA packages ($F = 28.65$, $p < 0.001$). Non-adopters cultivated an average of 1.27 hectares, compared with 2.57 hectares among households adopting the full CSA package. This finding suggests that households with larger landholdings may have greater opportunities to allocate land and resources to multiple CSA practices.

Livestock ownership, measured in Tropical Livestock Units (TLU), also differed significantly across adoption categories ($F = 43.93$, $p < 0.001$). The average livestock holding was 6.42 TLU. Non-adopters had relatively high livestock holdings, whereas households adopting different combinations of CSA practices exhibited varying levels of livestock ownership.

Annual household income also differed significantly among CSA adoption packages ($F = 69.29$, $p < 0.001$). Households adopting the CRM+AF package reported the highest mean annual income, followed by households adopting the full CSA package. These differences indicate that household economic capacity may influence farmers' ability to invest in and adopt alternative CSA technologies.

Overall, the descriptive results reveal substantial socioeconomic and farm-level heterogeneity among households adopting different CSA packages. These differences justify the use of an econometric approach that accounts for non-random selection into alternative CSA adoption regimes.

Table 3. Descriptive Statistics of Continuous Explanatory Variables by CSA Adoption Package

Variables	Adoption of combination a possible Combination of CSA practices						All Sample N=384	F- Value
	CRM ₀ SNM ₀ AF ₀ N= 54	CRM ₁ SNM ₀ AF ₀ N= 68	CRM ₁ SNM ₁ AF ₀ n=34	CRM ₀ SNM ₁ AF ₁ N=27	CRM ₁ SNM ₀ AF ₁ N=48	CRM ₁ SNM ₁ AF ₁ N=153		
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Age (years)	42.85 (10.38)	40.22 (10.40)	46.52 (13.94)	42.22 (10.70)	45.44 (8.29)	42.38 (10.53)	42.8(10.69)	10.85*
Eduction(Y ear)	1.92(2.580)	5.18(3.20)	5.35(2.94)	5.44 (3.34)	5.75 (2.40)	6.99 (2.84)	5.01 (1.7)	6.90
Adult equivalent (AE)	5.162 (2.12)	5.17 (1.52)	4.43 (1.78)	4.81 (1.76)	4.41 (1.44)	5.02 (1.76)	4.92 (1.75)	9.89*
Farm size (ha)	1.27 (1.34)	1.74 (1.21)	2.22 (1.79)	1.61 (1.06)	1.53 (.150)	2.57 (1.67)	2.01 (1.53)	28.65***
TLU	8.09 (5.06)	4.69 (3.58)	5.20 (2.34)	6.35 (3.88)	4.04 (2.72)	7.64 (4.87)	6.42 (4.46)	43.93***
Annual income (1000 ETB)	105.54 (67.86)	89.70 (104.12)	77.26 (72.65)	67.48 (41.75)	208.79 (152.46)	121.70 (84.79)	116.90 (101.70)	69.29***

Source: Computed Survey data 2026

Note: Values are mean (standard deviation). CRM = Crop Management; SNM = Soil Nutrient Management; AF = Agroforestry; AE = Adult Equivalent; TLU = Tropical Livestock Unit. $p < 0.05$; $p < 0.01$; $p < 0.001$.

4.2 Distribution of CSA Practice Packages

4.2.1 Distribution of Households across Observed CSA Practice Combinations

Table 4 presents the distribution of households across alternative CSA practice packages. Among the 384 sampled households, 54 households (14.06%) did not adopt any of the three CSA domains.

The largest proportion of households, 153 (39.84%), adopted the full CSA package consisting of CRM, SNM, and AF. This indicates that integrated adoption of multiple CSA practices was relatively common in the study area.

Households adopting CRM only accounted for 17.71% of the sample, while 12.50% adopted the CRM+AF combination. The CRM+SNM package was adopted by 8.85% of households, whereas the SNM+AF package represented the smallest adoption group, accounting for 7.03% of the sample.

The observed distribution demonstrates substantial heterogeneity in CSA adoption behavior. The predominance of the full package suggests that farmers may perceive complementary benefits from simultaneously adopting multiple CSA practices. However, the presence of non-adopters and partial adopters indicates that constraints related to resources, information, institutional support, and household characteristics may limit the adoption of more comprehensive CSA packages.

Table 4. Distribution of Farmers across Climate-Smart Agriculture Practice Combinations

CSA package	Frequency	Percent	Interpretation
CRM ₀ SNM ₀ AF ₀	54	14.06%	Farmers adopting none of the three CSA domains
CRM ₁ SNM ₀ AF ₀	68	17.71%	Farmers adopting crop management only
CRM ₁ SNM ₁ AF ₀	34	8.85%	Farmers combining soil nutrient and crop management
CRM ₀ SNM ₁ AF ₁	27	7.03%	Farmers combining soil nutrient management and agroforestry
CRM ₁ SNM ₀ AF ₁	48	12.50%	Farmers combining crop management and agroforestry
CRM ₁ SNM ₁ AF ₁	153	39.84%	Farmers adopting all three CSA domains
Total	384	100%	

4.3 Determinants of CSA Package Choice

Table 5 presents the results of the Multinomial Logit (MNL) model used to identify factors associated with farmers' choices among different Climate-Smart Agriculture (CSA) practice packages. The non-adoption category (CRM₀SNM₀AF₀) was specified as the reference category. The MNL model is appropriate when the dependent variable consists of more than two mutually exclusive and unordered alternatives, with the coefficients interpreted relative to the specified reference category (Long & Freese, 2006; Wooldridge, 2002).

Diagnostic results are reported in Supplementary Tables S1–S4. The VIF values ranged from 1.03 to 3.41, with a mean VIF of 1.87, indicating no evidence of serious multicollinearity among the explanatory variables. The Hausman–McFadden test of the Independence of Irrelevant Alternatives (IIA) assumption yielded $\chi^2(46) = 2.86$ ($p = 1.000$), providing no evidence against the IIA assumption for the comparison tested. The Ramsey RESET test also provided no evidence of omitted-variable or functional-form misspecification in the tested specification ($F(3, 368) = 0.26$, $p = 0.8563$), while the Breusch–Pagan/Cook–Weisberg test provided no evidence of heteroskedasticity ($\chi^2(1) = 1.66$, $p = 0.1976$). The IIA assumption is an important consideration in the MNL model because the model requires the relative odds between any two alternatives to be independent of the presence or characteristics of other alternatives (Hausman & McFadden, 1984).

The overall MNL model was statistically significant at the 1% level ($LR \chi^2 = 490.12$, $p < 0.001$), indicating that the explanatory variables jointly contributed to explaining variation in farmers' choices among the CSA practice packages. The model had a Pseudo R^2 of 0.3963. The estimated coefficients and marginal effects are presented in Table 5, and the results are interpreted relative to the non-adoption category.

The results show that education, adult equivalent (AE), CSA training, access to credit, and TLU significantly influenced the probability of adopting the crop management (CRM)-only package relative to non-adoption. An additional year of education increased the probability of adopting the CRM-only package by approximately 12.0% at the 1% significance level. A one-unit increase in household adult equivalent increased the probability of adopting this package by approximately 2.1% at the 5% significance level. Access to CSA training increased the probability of adopting the CRM-only package by approximately 15.7% at the 5% significance level, while access to credit increased the probability by approximately 17.5% at the 1% significance level. In contrast, a one-unit increase in TLU reduced the probability of adopting the CRM-only package by approximately 1.3% at the 1% significance level. These findings indicate that education, labor availability, training, and access to financial resources encouraged the adoption of crop management practices, whereas greater livestock ownership was negatively associated with adoption of the CRM-only package.

For the CRM+SNM package, age, farm size, TLU, access to CSA information, and annual household income significantly influenced the probability of adoption. A one-year increase in age

increased the probability of adopting the CRM₁SNM₁AF₀ package by approximately 2.0% at the 10% significance level. Similarly, an additional hectare of farmland increased the probability of adopting the package by approximately 2.0% at the 5% significance level. Access to CSA information increased the probability of adoption by approximately 14.2% at the 10% significance level, while annual household income increased the probability by approximately 3.0% at the 10% significance level. In contrast, a one-unit increase in TLU reduced the probability of adopting the CRM₁SNM₁AF₀ package by approximately 0.7% at the 10% significance level. These results suggest that older farmers and those with larger landholdings, better access to CSA information, and higher income were more likely to combine crop management with soil nutrient management.

The probability of adopting the CRM₀SNM₁AF₁ package was significantly influenced by farm size, TLU, access to CSA information, cooperative membership, and annual household income. An additional hectare of farmland increased the probability of adopting the CRM₀SNM₁AF₁ package by approximately 1.9% at the 10% significance level. A one-unit increase in TLU increased the probability of adoption by approximately 6.8% at the 10% significance level. Access to CSA information increased the probability of adopting this package by approximately 11.5% at the 10% significance level. Cooperative membership increased the probability by approximately 7.2% at the 5% significance level, while annual household income increased the probability by approximately 5.7% at the 10% significance level. These findings suggest that access to productive resources, agricultural information, farmer organizations, and household economic resources plays an important role in encouraging farmers to combine soil nutrient management with agroforestry practices.

The adoption of the CRM₁SNM₀AF₁ package was significantly associated with adult equivalent, CSA training, extension services, access to credit, TLU, and annual household income. A one-unit increase in adult equivalent increased the probability of adopting the CRM₁SNM₀AF₁ package by approximately 2.1% at the 5% significance level. Access to CSA training increased the probability of adoption by approximately 20.1% at the 1% significance level, while access to extension services increased the probability by approximately 19.7% at the 1% significance level. Access to credit also increased the probability of adopting the package by approximately 15.9% at the 5% significance level. In contrast, a one-unit increase in TLU reduced the probability of adopting CRM+AF by approximately 9.8% at the 10% significance level. Annual household income

increased the probability of adoption by approximately 7.0% at the 10% significance level. The results therefore demonstrate the importance of training, extension services, and financial access in promoting the combined adoption of crop management and agroforestry practices.

The results for the full CSA package, consisting of CRM₁SNM₁AF₁, show that education, adult equivalent, farm size, access to CSA information, CSA training, and extension services significantly influenced the probability of adoption. An additional year of education increased the probability of adopting the full CSA package by approximately 3.2% at the 1% significance level. A one-unit increase in adult equivalent increased the probability by approximately 2.0% at the 10% significance level, while an additional hectare of farmland increased the probability of adoption by approximately 3.0% at the 5% significance level. Access to CSA information increased the probability of adopting the full package by approximately 24.3% at the 10% significance level. Most importantly, access to CSA training increased the probability of adopting the full package by approximately 57.1% at the 1% significance level, representing the largest estimated effect among the explanatory variables. Access to extension services also increased the probability of adopting the full CSA package by approximately 28.1% at the 10% significance level. These findings highlight the particularly important role of training, information, and extension services in promoting the simultaneous adoption of complementary CSA practices.

Overall, the MNL results indicate that both household socioeconomic characteristics and institutional support significantly influenced farmers' choices among CSA practice packages. Institutional factors, particularly CSA training, access to CSA information, extension services, and credit, were important determinants of adoption across several packages. CSA training was the strongest factor, increasing the probability of adopting the full CRM₁SNM₁AF₁ package by approximately 57.1% at the 1% significance level. Access to CSA information and extension services also substantially increased the probability of adopting more comprehensive CSA packages. Education and farm size were likewise important, particularly for the full CSA package. These findings suggest that strengthening CSA training, agricultural extension services, information dissemination, credit access, and farmer cooperatives could increase the likelihood that smallholder farmers adopt combinations of complementary CSA practices rather than relying on individual practices alone.

Table 5: Determinants of climate-smart agriculture practice adoption: result of MNL selection model.

Variables	Adoption of and alternative Combination of CSA practices									
	CRM ₁ SNM ₀ AF ₀		CRM ₁ SNM ₁ AF ₀		CRM ₀ SNM ₁ AF ₁		CRM ₁ SNM ₀ AF ₁		CRM ₁ SNM ₁ AF ₁	
	Coef. (SE)	ME	Coef. (SE)	Me	Coef. (SE)	ME	Coef. (SE)	ME	Coef. (SE)	ME
Sex	-0.42 (0.99)	0.027	-.479 (1.14)	0.06	-1.78 (1.05)	-.034	-1.79 (1.02)	-.051	-1.68 (1.04)	-.088
Age	0.008 (0.034)	-0.004	.064 (0.04)	.020*	.035(.38)	-.002	.05 (0.36)	.001	.052 (.036)	.002
Education	0.33 (0.121)	.120***	.334 (.134)	-.006	.362 (.14)	-.003	.37 (.133)	.005	.57 (.131)	.032** *
AE	0.458 (.184)	.021**	.191 (.22)	-.013	.422 (0.23)	.005	.114 (0.15)	0.021 **	.435 (0.202)	.020*
Farm size	0.26 (.28)	.001	.539 (.31)	.020**	-.028 (0.34)	.019*	.021 (.336)	.024	.413 (0.30)	.030**
TLU	-0.32 (0.094)	-0.013***	-.337(.11)	-.007*	-.130 (0.104)	.068*	-.34 (.110)	- .098*	-.183 (0.097)	.015** *
Access to CSA_info	2.71 (1.06)	.054	4.24 (1.51)	.142*	4.22 (1.38)	.115*	2.41 (1.23)	.018	1.42 (1.35)	.243*
CSA training	2.67 (1.34)	0.157**	3.37 (1.49)	.073	3.38 (1.52)	.049	2.26 (1.50)	.201* **	6.89 (1.75)	.571** *
Extension service	-0.09 (1.29)	.004	-.307 (1.14)	.027	1.12 (1.49)	-.071	2.03 (1.58)	.197* **	1.15 (1.74)	.281*
Access credit	0.364 (1.15)	.175***	.104 (1.23)	-.060	.957 (1.29)	.0055	2.73 (1.33)	.159* *	1.48 (1.22)	.086

[illegible]

Source: Computed Survey data 2026

Note: CRM₀SNM₀AF₀= the base CSA categories, CRM₁SNM₀AF₀= Crop management only; CRM₁SNM₁ AF₀= crop management and Soil nutrient management, CRM₀ SNM₁AF₁= Soil nutrient management and Agroforestry, CRM₁ SNM₀AF₁= Crop management and Agroforestry, CRM₁ SNM₁AF₁=crop management, Soil nutrient management and Agroforestry (full packages)

4.4 Household Food and Nutrition Security Indicators across CSA Adoption Packages

The descriptive results for household food security indicators reveal considerable variation across CSA adoption packages. Household food security was assessed using the Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS).

The mean FCS differed significantly across the six CSA adoption packages ($F = 359.82$, $p < 0.001$). Non-adopters had the lowest observed mean FCS of 19.21, whereas households adopting the full CSA package had the highest observed mean FCS of 75.34. Households adopting combinations involving two CSA domains also recorded higher mean FCS values than non-adopters. These results indicate substantial differences in observed food consumption patterns across CSA adoption packages.

Similarly, mean HDDS differed significantly across the CSA adoption packages ($F = 178.60$, $p < 0.001$). The descriptive results indicate variation in dietary diversity across the adoption groups, with households in several CSA adoption packages recording higher observed HDDS values than non-adopters.

Overall, the descriptive comparisons indicate an association between CSA adoption packages and household food consumption and dietary diversity. However, these comparisons are based on observed group means and do not establish causal effects because households may differ

systematically in both observable and unobservable characteristics that influence adoption decisions and food and nutrition security outcomes. Therefore, the subsequent multinomial endogenous switching regression analysis was used to account for potential non-random selection into CSA adoption regimes and to estimate regime-specific observed and counterfactual outcomes.

Table 6: Descriptive results for the outcome variable of the sampled households

Variable s	Adoption of combination a possible Combination of CSA practices						All Sample	F- Value
FCS	CRM₀S NM₀AF₀ N= 54	CRM₁SN M₀ AF₀ N= 68	CRM₁S NM₁ AF₀ n=34	CRM₀SNM ₁AF₁ N=27	CRM₁SNM₀ AF₁ N=48	CRM₁ SNM₁AF₁ N=153	N=384	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
	19.21 (6.16)	51.44 (10.33)	54.62 (14.27)	58.11 (9.98)	59.04 (7.79)	75.34 (6.35)	58.135 (20.32)	
HDDS	1.81 (2.23)	6.15 (1.56)	7.53 (1.66)	6.74 (1.65)	6.54 (1.05)	9.680 (1.75)	7.16 (3.12)	178.60***

4.5 Estimated Counterfactual Differences in Food and Nutrition Security

The Multinomial Endogenous Switching Regression (MESR) framework was used to estimate regime-specific counterfactual differences in household food and nutrition security associated with alternative CSA adoption packages. The analysis distinguishes between the Average Treatment Effect on the Treated (ATT), which compares the predicted outcome for households observed in a given adoption regime with their predicted outcome under the counterfactual non-adoption regime, and the Average Treatment Effect on the Untreated (ATU), which compares the predicted outcome under a specific adoption regime with the predicted outcome under non-adoption for households not observed in that particular adoption regime.

Because the data are cross-sectional and observational, the estimated ATT and ATU are interpreted as model-based counterfactual differences conditional on the MESR specification and its identifying assumptions. They should therefore not be interpreted as unconditional causal effects.

4.5.1 Household Dietary Diversity Score (HDDS)

Table 7 presents the estimated Average Treatment Effects on the Treated (ATT) and Average Treatment Effects on the Untreated (ATU) for Household Dietary Diversity Score (HDDS) across the five CSA adoption regimes. All ATT and ATU estimates were positive and statistically significant at the 1% level, indicating that predicted HDDS was higher under the corresponding CSA adoption scenarios than under non-adoption.

Among households observed as CRM-only adopters (CRM1SNM0AF0), predicted HDDS was 86.57% (3.118) higher under adoption than under counterfactual non-adoption. Among non-adopters, counterfactual adoption was associated with a 69.66% (3.147) higher predicted HDDS than actual non-adoption.

For CRM + SNM (CRM1SNM1AF0), the predicted HDDS was 138.37% (4.046) higher for adopters, while non-adopters would have a 31.11% (1.406) higher predicted HDDS under counterfactual adoption. For SNM + AF (CRM0SNM1AF1), the corresponding differences were 120.42% (3.420) for adopters and 94.25% (4.259) for non-adopters. Similarly, CRM + AF (CRM1SNM0AF1) was associated with a 155.36% (4.043) higher predicted HDDS among adopters and a 38.37% (1.734) higher predicted HDDS among non-adopters under counterfactual adoption.

The full CRM + SNM + AF package (CRM1SNM1AF1) showed the largest predicted differences. Adopters had a 193.08% (4.435) higher predicted HDDS than under counterfactual non-adoption, while non-adopters had a 121.64% (5.497) higher predicted HDDS under counterfactual adoption than under actual non-adoption.

Overall, ATT estimates ranged from 86.57% (3.118) to 193.08% (4.435), while ATU estimates ranged from 31.11% (1.406) to 121.64% (5.497). The consistently positive estimates indicate substantial predicted differences in dietary diversity associated with CSA adoption, with the largest absolute differences observed for the full CSA package. The relatively large percentages reflect the low predicted HDDS values in some counterfactual scenarios; therefore, the percentages should be interpreted together with the absolute HDDS differences reported in parentheses. Given the cross-sectional observational design, these estimates represent MESR-based counterfactual differences conditional on the model specification and its underlying assumptions, rather than unconditional causal effects.

Table 7. Estimated Average Treatment Effects on the Treated (ATT) and Untreated (ATU) of CSA Practice Packages on Household Dietary Diversity Score (HDDS)

CSA Package	Adopters: Actual Outcome	Adopters: Counterfactual Non-adoption	ATT	Non-adopters: Counterfactual Adoption	Non-adopters: Actual Outcome	ATU
CRM ₁ SNM ₀ AF ₀	6.721 (0.766)	3.602 (3.196)	3.118*** (3.644)	7.670 (1.158)	4.519 (1.747)	3.147*** (2.589)
CRM ₁ SNM ₁ AF ₀	6.971 (1.116)	2.924 (3.102)	4.046*** (3.224)	5.925 (1.066)	4.519 (1.747)	1.406*** (1.702)
CRM ₀ SNM ₁ AF ₁	6.259 (1.590)	2.840 (2.929)	3.420*** (3.801)	8.777 (2.195)	4.519 (1.747)	4.259*** (2.991)
CRM ₁ SNM ₀ AF ₁	6.646 (0.837)	2.603 (2.893)	4.043*** (3.114)	6.252 (1.052)	4.519 (1.747)	1.734*** (2.220)
CRM ₁ SNM ₁ AF ₁	6.732 (1.390)	2.297 (2.027)	4.435*** (2.363)	10.016 (2.684)	4.519 (1.747)	5.497*** (3.781)

Source: Computed from survey data, 2026.

Note: Values are means with standard deviations in parentheses. ATT = Average Treatment Effect on the Treated; ATU = Average Treatment Effect on the Untreated; HDDS = Household Dietary Diversity Score; CRM = Crop Management; SNM = Soil Nutrient Management; AF = Agroforestry. *** indicates statistical significance at the 1% level.

4.5.2 Food Consumption Score (FCS)

Table 8 presents the estimated Average Treatment Effects on the Treated (ATT) and Average Treatment Effects on the Untreated (ATU) for the Food Consumption Score (FCS) across the five observed CSA adoption regimes. The results indicate substantial heterogeneity in the predicted counterfactual differences in FCS across CSA packages and household groups.

Households adopting the CRM-only package (CRM₁SNM₀AF₀) had a 17.75% (7.18) higher predicted FCS under the observed adoption regime than under counterfactual non-adoption, with the difference statistically significant at the 1% level. In contrast, among non-adopters, counterfactual adoption was associated with a 6.04% (−2.55) lower predicted FCS than non-adoption, also significant at the 1% level.

For the CRM + SNM package (CRM1SNM1AF0), adopters had an 8.54% (3.79) higher predicted FCS under adoption than under counterfactual non-adoption. Among non-adopters, counterfactual adoption was associated with an 8.85% (3.96) higher predicted FCS than non-adoption. Both estimates were statistically significant at the 1% level.

For the SNM + AF package (CRM0SNM1AF1), adopters had a 6.06% (2.68) higher predicted FCS under adoption than under counterfactual non-adoption, significant at the 1% level. However, among non-adopters, counterfactual adoption was associated with a 15.02% (−6.72) lower predicted FCS than non-adoption, also significant at the 1% level. Thus, the ATT and ATU had opposite signs for this package.

For the CRM + AF package (CRM1SNM0AF1), the predicted FCS among adopters was 11.79% (4.84) higher under adoption than under counterfactual non-adoption. Among non-adopters, counterfactual adoption was associated with a 9.94% (4.45) higher predicted FCS than non-adoption. Both differences were statistically significant at the 1% level.

For the full CRM + SNM + AF package (CRM1SNM1AF1), adopters had a 13.20% (5.64) higher predicted FCS under adoption than under counterfactual non-adoption, significant at the 1% level. Among non-adopters, counterfactual adoption was associated with a 24.51% (10.97) higher predicted FCS than non-adoption, also significant at the 1% level.

Overall, all five CSA adoption regimes had positive and statistically significant ATT estimates, ranging from 6.06% (2.68) for SNM + AF to 17.75% (7.18) for CRM-only. The ATU estimates showed greater heterogeneity, ranging from 15.02% (−6.72) lower for SNM + AF to 24.51% (10.97) higher for the full CSA package. Positive ATU estimates were observed for CRM + SNM, CRM + AF, and the full package, whereas negative ATU estimates were observed for CRM-only and SNM + AF.

These findings indicate that the predicted FCS differences associated with CSA adoption varied across both adoption regimes and household groups. The positive ATT estimates indicate higher predicted FCS under the observed adoption regimes relative to their corresponding counterfactual non-adoption scenarios. The mixed ATU estimates, however, indicate that the corresponding predicted differences among non-adopters were not uniform across CSA packages. Given the cross-sectional observational design, the ATT and ATU estimates should be interpreted as model-

based counterfactual differences conditional on the MESR specification and its underlying assumptions, rather than as unconditional causal effects.

Table 8. Estimated Average Treatment Effects of Climate-Smart Agriculture Practice Packages on Household Food Consumption Score (FCS)

CSA Package	Adopters: Actual Outcome	Adopters: Counterfactual Non-adoption	ATT	Non-adopters: Counterfactual Adoption	Non-adopters: Actual Outcome	ATU
CRM ₁ SNM ₀ AF ₀	47.63 (7.38)	40.45 (8.37)	7.18*** (8.78)	42.20 (6.02)	44.75 (7.06)	-2.55*** (10.64)
CRM ₁ SNM ₁ AF ₀	48.15 (10.68)	44.36 (7.84)	3.79*** (9.79)	48.71 (10.98)	44.75 (7.06)	3.96*** (14.30)
CRM ₀ SNM ₁ AF ₁	46.89 (6.88)	44.21 (6.19)	2.68*** (7.59)	38.03 (16.63)	44.75 (7.06)	-6.72*** (14.54)
CRM ₁ SNM ₀ AF ₁	45.92 (6.08)	41.07 (5.66)	4.84*** (8.58)	49.20 (9.57)	44.75 (7.06)	4.45*** (12.30)
CRM ₁ SNM ₁ AF ₁	48.36 (8.19)	42.72 (5.70)	5.64*** (4.67)	55.72 (6.53)	44.75 (7.06)	10.97*** (5.57)

Source: Computed Survey data 2026

Note: Values are means with standard deviations in parentheses. ATT = Average Treatment Effect on the Treated; ATU = Average Treatment Effect on the Untreated; CRM = Crop Management; SNM = Soil Nutrient Management; AF = Agroforestry.

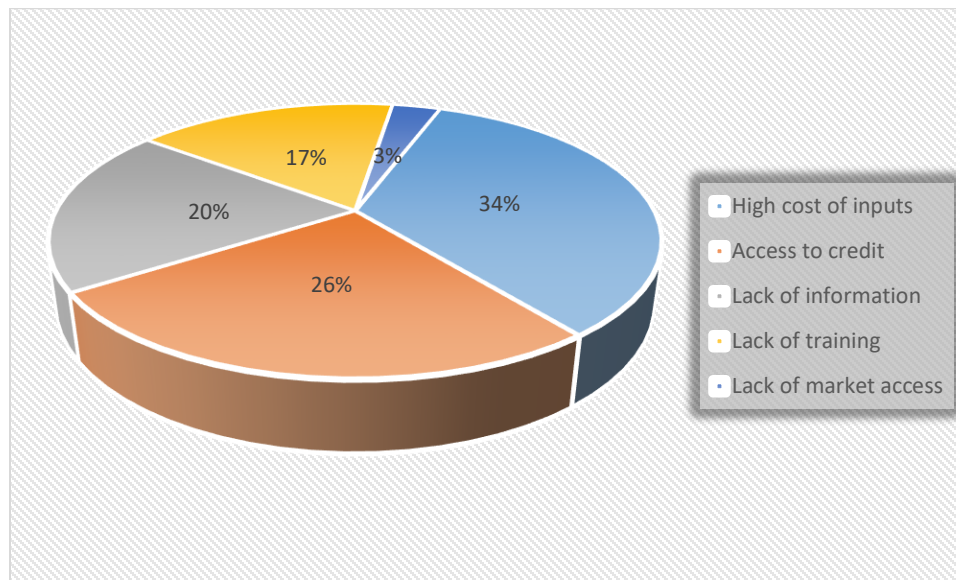
4.6 Major Constraints Associated with CSA Adoption

Figure 3 presents the major constraints reported by sampled households in relation to CSA adoption. High input costs were the most frequently reported constraint, accounting for 33.85% of responses, followed by limited access to credit (26.30%), lack of information (19.79%), lack of training (16.93%), and limited market access (3.13%). Thus, input costs and access to credit together accounted for approximately 60.15% of reported constraints, while information and training accounted for a further 36.72%.

These results indicate that financial and information-related constraints constituted a substantial share of the reported barriers to CSA adoption in the study area. The findings provide descriptive evidence on the constraints experienced by sampled households and may help identify areas for

further investigation and policy attention. However, the constraint frequencies should not be interpreted as causal determinants of CSA adoption.

Figure 3. Major constraints associated with the adoption of CSA practices.



5. Discussion

The findings indicate substantial heterogeneity in household food and nutrition security across CSA adoption regimes among smallholder farmers in southwestern Ethiopia. Descriptive results show significant differences in both Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS) across the six observed adoption regimes. Non-adopting households generally recorded lower observed FCS and HDDS than households adopting one or more CSA practice combinations, while households adopting the full CRM1SNM1AF1 package recorded relatively higher observed levels of food consumption and dietary diversity. These descriptive differences indicate systematic variation in food and nutrition security across adoption regimes, although they do not, by themselves, establish a causal relationship. Similar evidence from Ethiopia has linked multiple CSA practices, including crop residue management, compost application, and agroforestry, with household food and nutrition security (Tilahun et al., 2023; Legesse et al., 2024).

Differences in CSA adoption regimes were also associated with household socioeconomic and institutional characteristics. Education, farm size, CSA information, training, extension services,

credit access, and cooperative membership varied across adoption groups. The multinomial logit results further indicate that these characteristics were associated with the selection of different CSA packages. In particular, CSA training was positively associated with selection of the full CRM1SNM1AF1 package, while CSA information, extension services, credit, education, and farm size were associated with several adoption regimes. These findings suggest that CSA package selection is closely related to households' access to knowledge, agricultural services, financial resources, and productive assets. This interpretation is consistent with previous evidence from sub-Saharan Africa identifying extension, training, information, institutional support, and financial access as important factors associated with CSA adoption (Diallo et al., 2019; Negera et al., 2022; Mnukwa et al., 2026; Ndosi et al., 2026).

The relatively lower participation of some households in multiple CSA practices may therefore reflect constraints in accessing these resources and services. The reported constraints, particularly high input costs, limited access to credit, inadequate information, and insufficient training, may make the adoption and management of several complementary practices more difficult. Multiple CSA practices can require additional knowledge, labor, inputs, planting materials, and financial resources compared with individual practices. Previous studies have similarly identified input costs, inadequate technical knowledge, limited extension support, and financial constraints as barriers to CSA adoption (Wakweya, 2023; Ndosi et al., 2026).

The MESR estimates provide further evidence of heterogeneity in model-based counterfactual differences in household food consumption and dietary diversity across CSA adoption regimes. For FCS, the ATT estimates were positive and statistically significant across all five observed adoption regimes. The estimated ATT ranged from 2.68 FCS points for SNM+AF to 7.18 points for CRM-only adoption. For the full CRM1SNM1AF1 package, the estimated ATT was 5.64 FCS points, indicating that, among observed adopters of this package, the predicted FCS under their observed adoption regime was 5.64 points higher than the predicted outcome under the corresponding non-adoption counterfactual. The differences across packages indicate that the magnitude of the model-based counterfactual difference was not uniform across adoption regimes. Such variation may be related to differences in household characteristics, production systems, resource requirements, and the potential complementarity of practices within each package.

The FCS results are broadly consistent with previous evidence linking CSA adoption with household food security in Ethiopia. Teklu et al. (2024), for example, examined the relationship between CSA and food and nutrition security in Ethiopia, while other studies have reported heterogeneous food-security outcomes associated with multiple CSA practices (Alemayehu et al., 2024). The present study extends this literature by examining combinations of CSA domains rather than treating CSA adoption as a homogeneous treatment. This package-based perspective is important because farmers may combine practices in ways that differ in their resource requirements and potential contribution to household food consumption.

The HDDS results provide a complementary perspective by focusing on dietary diversity. All five observed CSA adoption regimes had positive and statistically significant ATT estimates. The estimated ATT ranged from 3.12 HDDS points for CRM-only adoption to 4.44 points for the full CRM+SNM+AF package. For full-package adopters, the predicted HDDS under observed adoption was therefore 4.44 points higher than the corresponding model-based non-adoption counterfactual. The positive estimates across all regimes suggest that the estimated counterfactual differences were consistently positive for observed adopters, although their magnitudes differed across packages. Because HDDS measures the number of food groups consumed, whereas FCS incorporates both consumption frequency and the relative nutritional importance of foods, the two indicators provide complementary information on household food and nutrition security.

The ATU estimates further demonstrate heterogeneity among households that were not observed adopting a particular CSA package. For FCS, the ATU was positive for CRM+SNM, CRM+AF, and the full CRM+SNM+AF package, but negative for CRM-only and SNM+AF. The largest positive ATU was estimated for the full package at 10.97 FCS points, indicating a substantial model-based difference between the predicted FCS under the adoption scenario and the predicted outcome under non-adoption for households not observed adopting that package. In contrast, the negative ATU estimates for CRM-only and SNM+AF indicate lower predicted FCS under the corresponding adoption scenarios for those non-adopter groups. This heterogeneity suggests that the predicted outcome associated with a particular package may differ according to household characteristics and adoption status.

For HDDS, all five ATU estimates were positive, ranging from 1.41 points for CRM+SNM to 5.50 points for the full CRM+SNM+AF package. Thus, the MESR estimates indicate positive model-

based counterfactual differences in dietary diversity for non-adopters under each alternative adoption scenario, although the magnitude varied substantially across packages. The differences between adoption regimes should not, however, be interpreted as evidence that one package would necessarily produce the same outcome for every household. Rather, they reflect heterogeneous counterfactual predictions conditional on the model specification and its identifying assumptions.

The relatively large differences associated with the full CRM1SNM1AF1 package may be consistent with the potential complementarity of crop management, soil nutrient management, and agroforestry. These practices can operate through different but potentially interconnected pathways, including improved soil fertility, crop productivity, production diversification, and additional sources of food or income. However, these mechanisms were not directly tested in the present study, and the cross-sectional design does not allow them to be established as causal pathways. Evidence from sub-Saharan Africa similarly suggests that the outcomes associated with combinations of CSA practices vary according to farming systems and local conditions (Fahad et al., 2022; Bekunda et al., 2022).

Overall, the findings indicate that the relationship between CSA adoption packages and household food and nutrition security is heterogeneous rather than uniform. Positive ATT estimates for both FCS and HDDS across the observed adoption regimes indicate positive model-based counterfactual differences for current adopters, while the variation in ATU estimates demonstrates that predicted outcomes also differ among households not currently adopting a given package. These findings emphasize the importance of considering household characteristics, resource availability, production conditions, and institutional support when examining CSA adoption and food and nutrition security.

Given the cross-sectional observational design, the ATT and ATU estimates should be interpreted as MESR-based counterfactual differences conditional on the model specification and its identifying assumptions rather than as definitive causal effects. In particular, the estimates do not establish that adopting a particular CSA package would necessarily cause the observed difference in FCS or HDDS for every household.

From a policy perspective, the findings suggest that improving the institutional and resource conditions surrounding CSA adoption may be important. Strengthening access to CSA training, extension services, agricultural information, credit, and farmer organizations could help address

constraints associated with the adoption and management of complementary CSA practices. At the same time, the heterogeneity of the estimated outcomes suggests that CSA interventions should consider household resources, farm characteristics, production systems, and local conditions rather than assuming that a common package will have similar implications across all households.

6. Contribution of the Study and Policy Implications

6.1 Contribution of the Study

This study contributes to the growing literature on Climate-Smart Agriculture (CSA) and household food and nutrition security in Ethiopia in several respects.

First, unlike studies that focus primarily on individual CSA practices, this study examines combinations of crop management (CRM), soil nutrient management (SNM), and agroforestry (AF). This package-based approach reflects the fact that smallholder farmers may adopt multiple practices simultaneously rather than implementing a single CSA technology in isolation.

Second, the study examines two complementary dimensions of household food and nutrition security using the Food Consumption Score (FCS) and Household Dietary Diversity Score (HDDS). Considering both indicators provides a broader assessment of household food consumption and dietary diversity and allows the study to examine whether estimated differences vary across these dimensions.

Third, the study applies a Multinomial Endogenous Switching Regression (MESR) framework to examine observed and counterfactual outcomes associated with alternative CSA adoption regimes. The framework allows estimation of the Average Treatment Effect on the Treated (ATT) and Average Treatment Effect on the Untreated (ATU), providing information on predicted outcome differences for observed adopters and corresponding counterfactual adoption scenarios for non-adopters. The heterogeneous ATT and ATU estimates demonstrate that the predicted differences in FCS and HDDS vary across CSA packages and household adoption status.

Finally, the study provides context-specific evidence from southwestern Ethiopia, where smallholder farming systems are exposed to climate variability and resource constraints. The findings provide empirical evidence that can inform further research and the design of CSA and food-security interventions in similar smallholder farming contexts.

6.2 Policy Implications

The findings have several policy implications. First, agricultural programs may benefit from considering CSA practice combinations rather than focusing exclusively on individual technologies. The observed variation across CRM, SNM, and AF combinations indicates that food consumption and dietary diversity differ across adoption regimes. Extension and development programs should therefore consider complementary practices that are technically feasible and appropriate to local farming systems.

Second, CSA training, agricultural extension, and access to reliable information should be strengthened. The multinomial logit results indicate that training, CSA information, and extension services are associated with the selection of several CSA adoption regimes, including the full CRM1SNM1AF1 package. Extension programs can provide locally adapted information on the management and combination of CSA practices, while demonstration activities may help farmers understand their implementation requirements.

Third, improving access to agricultural credit and productive resources is important, particularly for households facing financial and input constraints. The results indicate that credit access is associated with the selection of several CSA packages. Appropriate financial and input-support mechanisms could therefore help reduce constraints related to acquiring inputs, planting materials, and other resources required for multiple CSA practices.

Fourth, farmer cooperatives and agricultural information networks can support access to information, inputs, collective learning, and extension services. Strengthening farmer-to-farmer learning, demonstration plots, and cooperative-based information sharing may improve households' access to practical knowledge concerning CSA practices and their management requirements.

Finally, CSA interventions should account for heterogeneity among households and local production conditions. The heterogeneous ATU estimates indicate that model-based counterfactual differences associated with alternative packages vary among households that were not observed adopting those packages. Program design should therefore consider household resources, farm size, and access to services, production systems, and local agro-ecological conditions. Integrating CSA interventions with broader food and nutrition security initiatives may also help strengthen the potential contribution of agricultural production and diversification to household food consumption and dietary diversity.

6.3 Limitations of the Study

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional nature of the data limits the ability to establish temporal causality between CSA adoption and household food and nutrition security outcomes.

Second, although the Multinomial Endogenous Switching Regression framework accounts for potential selection processes within the specified model, the estimated ATT and ATU depend on the model specification and the validity of the underlying identifying assumptions. Accordingly, these estimates should be interpreted as model-based counterfactual differences rather than definitive causal effects.

Third, the study sites were purposively selected from FSRP-supported areas. Consequently, the findings may not be directly generalizable to other regions, agro-ecological settings, or farming systems in Ethiopia.

Fourth, the CRM0SNM1AF1 (SNM+AF) regime contained only 27 households. The relatively small number of observations in this group may reduce the precision and stability of estimates for this adoption regime.

Finally, FCS and HDDS capture important but specific dimensions of household food and nutrition security. FCS reflects the frequency and nutritional importance of food consumption, whereas HDDS captures dietary diversity. Neither indicator fully captures all dimensions of food access, utilization, stability, or nutritional adequacy. Future studies using longitudinal data, broader geographical coverage, and additional food and nutrition security indicators could provide stronger evidence on the dynamics and longer-term relationship between CSA adoption and household well-being.

Acknowledgements

The authors would like to express sincere gratitude to the Southwest Agricultural Research Institute for providing financial support to conduct this study. Their funding contribution made it possible to collect data and successfully complete the research in Kaffa, Bench sheko, and Sheka Zones. Special appreciation is also extended to the data collectors, respondents, and key informants for their valuable cooperation and willingness to share relevant information. The support and

assistance received from all individuals and institutions involved in this study are highly appreciated.

Author Contributions

Tesfaye Gafaro: writing original draft, formal analysis, conceptualization, methodology, Data curation, software, funding acquisition. **Amanuel Afeto:** Editing & review, software, conceptualization, validation, investigation. **Tariku Teka:** contributed to data collection and assisted in organizing the dataset for analysis. **Maregn Alemu:** contributed to data collection and assisted in organizing the dataset for analysis. All authors reviewed and approved the final manuscript.

Funding

The authors would like to acknowledge the Southwest Ethiopia Agricultural Research Institute for providing financial support to conduct this study.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality and ethical restrictions regarding the privacy of participating farmers. However, the data may be available from the corresponding author upon reasonable request and with permission from the relevant institution.

Ethics approval and consent to participate

The research proposal was officially reviewed and approved by the Southwest Ethiopia Agricultural Research Institute (SWEARI) through its institutional research proposal evaluation and approval process before data collection. SWEARI does not have a separate Institutional Review Board (IRB). The study received institutional scientific approval from SWEARI before data collection. or Ethics Committee for socioeconomic and agricultural survey research; therefore, no IRB approval number was issued. The study procedures were reviewed through the institute's scientific review process involving senior researchers and experts from universities and agricultural research centers. Data were collected after obtaining informed consent from all respondents. Participation was voluntary, and the confidentiality and anonymity of participants were maintained throughout the study.

Consent for publication

Not applicable. This manuscript does not contain any individual person's identifiable data, images, or personal details that require consent for publication.

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