



Impacts of Sustainable Agricultural Practices on Food Security, Nutrition, and Poverty among Smallholder Maize Farmers in Morogoro region, Tanzania

Joseph J. Mugula¹
Athman K. Ahmad, PhD²
John Msinde, PhD³
Michael Kadigi, PhD⁴

¹mugulajr@gmail.com*
²kyaruzi@sua.ac.tz
³johnmsinde@yahoo.com
⁴michael.kadigi@sua.ac.tz

¹<https://orcid.org/0009-0009-6614-6954>

²<https://orcid.org/0000-0001-5658-1543>

³<https://orcid.org/0000-0003-0375-8864>

⁴<https://orcid.org/0000-0001-6860-9902>

¹Corresponding Author, PhD student, ²Senior Lecturer, ^{3,4}Lecturer, ^{1,4}Department of Policy Planning and Management, ²Department of Agricultural Extension and Community Development, ³Institute of Development Studies, ^{1,2,4}Sokoine University of Agriculture, Morogoro, Tanzania, ³University of Dar es Salaam, Tanzania

ABSTRACT

The study utilized data from adoption pathway survey and utility maximization theory to examine the impacts of adopting sustainable agricultural practices (SAPs) on food security, nutrition, and poverty among smallholder maize farmers in the Morogoro region of Tanzania. The SAPs considered include manure, crop rotation, intercropping, crop residuals, and improved maize varieties. Using the endogenous treatment effect model, data collected from 470 farming households in Kilosa and Mvomero districts through a multi-stage sampling procedure were analyzed. Prior to data analysis, weak instrument and zero first-stage tests were employed to test the robustness and validity of the selected instruments, with results deemed satisfactory. The empirical findings indicate that the application of improved maize varieties, crop residual, and crop rotation practices had positive and significant impacts on the household's food security and nutrition. Notably, the usage of improved maize varieties alone demonstrated positive and significant impacts on poverty indicators, suggesting its potential to alleviate poverty among smallholder farmers. The study recommends the development of agricultural productivity enhancement programmes. These programmes should feature a precise targeting strategy aimed at food-insecure households and poor farming households, with the goal of eradicating hunger and nutrition deficiencies within these vulnerable groups. Furthermore, the poverty-alleviating impacts of SAPs, such as improved maize varieties, are expected to grow with increased adoption. Consequently, it is crucial to prioritize significant investments in agriculture. Strengthening and improving maize seed systems becomes imperative, aiming to guarantee the availability and affordability of enhanced maize varieties for smallholder farmers in Tanzania. This step will facilitate wider adoption and contribute to poverty reduction among farming communities.

Keywords: Endogenous treatment effect model, Food Security, Nutrition, Poverty, Sustainable Agricultural Practices, Tanzania

I. INTRODUCTION

Globally, there has been widespread acknowledgement of the beneficial impacts of sustainable agricultural practices (SAPs) on various facets such as crop yield, income, food security, and soil health (Ogada *et al.*, 2020; Pangapanga & Mungatana, 2021). The term SAP encompasses a comprehensive strategy focused on reshaping agricultural food systems to adopt climate-resilient practices that safeguard the environment, promote economic viability, and uphold social responsibility (World Bank, 2020). The SAPs examined in this study include intercropping, manure, crop rotation, improved maize varieties, and crop residual. These specific practices have been selected due to their demonstrated abilities to augment soil fertility, efficiently manage pests, build farmers' adaptive capability to climate change, and address environmental-related concerns (Bongole *et al.*, 2021). Setsofia *et al.* (2022) have referred to Sub-Saharan Africa (SSA) as one of the most

vulnerable regions to the adverse effects of climate change (World Bank, 2018). Consequently, climatic challenges such as inadequate rainfall shortages have led to low agricultural yields, reduced farm incomes, increased poverty, and heightened food insecurity among households in SSA.

The agriculture sector in Tanzania has been identified as a significant contributor to the country's overall economic growth, accounting for 26.9% (BOT 2021b). However, this sector heavily relies on rain-fed systems, leading to agricultural productivity that falls below anticipated levels and resulting in food insecurity among smallholder farming households (Kassie *et al.*, 2013). The ministry of agriculture has allocated substantial resources to enhance farm productivity by advocating for the adoption of SAPs through subsidies and training programs. In spite of the aforementioned efforts, the data illustrates persistently high levels of food insecurity and nutritional deficiencies. Approximately 34.7% of the children under the age of five years are classified as stunted, 14% as underweight, and 5% as wasted (FAO, 2019). Moreover, Tanzania ranked 95th on the global food security index, indicating inadequate progress towards achieving food-secure households. Furthermore, 8.3% of households in Tanzania are classified as having poor dietary intake (URT, 2019).

Despite the efforts of various academicians, scholars, and researchers advocating for SAP adoption amidst climate change concerns, poverty, food, and nutrition insecurity still persist in Tanzania (Bongole *et al.*, 2021). Alarming, nearly 26 million people still live below the global poverty line, while agricultural productivity remains insufficient (IMF, 2020). Considering maize as one of Tanzania's main staple crops, its production is at risk of decline due to the unpredictable effects of climate change, variability, and other adverse external factors (FAO, 2019). Consequently, this underscores the pressing need for significant production upgrades to meet the continued demand for food resources necessary to sustain the growing populace, which is expected to reach the 124 million mark by 2050 (FAO, 2022).

The Morogoro region is prized as one of the key maize-producing regions in Tanzania; however, the data show that food insecurity and nutrition deficiency in households is still high (URT, 2019). Tumaini and Msuya (2020) contend that the household dietary diversity score (HDDS) and the children's dietary diversity score were 6.18 and 1.74, respectively, in 2016. In addition, 37.7% of children aged between 0 and 59 months were reported as stunted; this figure is higher compared to the national figure (34.7%).

In addition to the aforementioned factors, this study argues that the available empirical literature on the impacts of adopting SAPs remains inconclusive. Previous studies have shown substantial contributions of adopting SAPs in production, household income, and food security (Adenle *et al.*, 2019; Bekele *et al.*, 2021; Bongole *et al.*, 2021; Ehiakpor *et al.*, 2021; Kassie *et al.*, 2013; Ma & Wang, 2020; Manda *et al.*, 2016; Ndiritu *et al.*, 2014; Ogemah, 2017; Zhou *et al.*, 2018; Rose *et al.*, 2019; Zeweld *et al.*, 2020). However, there is insufficient literature on the impact of adopting multiple SAPs consisting of manure, intercropping, crop residual, improved maize varieties, and crop rotation on food security, nutrition, and poverty in Tanzania. In addition, the methodological uniqueness of this study lies in analyzing the impacts of adopting SAPs on households' food security, nutrition and poverty by controlling both observable and unobservable variables in the study. This is crucial due to lack of control over sample selection biases during the estimation phase. Failure to account for selection biases caused by unobservable variables might lead to overestimation or underestimation of the impacts of adopting SAPs on outcome variables.

Nevertheless, this study has argued for the practical applicability of SAPs since previous studies have failed to acknowledge the impacts of individual or combined SAPs on households' food security, nutrition, and poverty in various agro-ecological conditions. Momezulu *et al.* (2023) contend that the lack of consistency among smallholder farmers in maintaining the area under SAPs stems from the perception that these practices are tedious and time-consuming. This inconsistency in the adoption process has limited the potential benefits of using SAPs, leading to yearly food insecurities, chronic poverty, and nutrition deficiencies among farming households' members. This study builds upon prior research (Bongole *et al.*, 2021; Manda *et al.*, 2018; Manda *et al.*, 2019; Momezulu *et al.*, 2023), that introduced a fresh perspective on modeling the adoption of SAPs. It extends this knowledge to address the inconclusiveness prevalent in the adoption literature. The study posits that previous research has left a modeling deficit in assessing the impacts of using agricultural technologies on various outcome variables. Therefore, it aims to bridge this gap by employing an endogenous treatment effect model to evaluate the impact of using bundled SAPs encompassing crop rotation, manure, intercropping, improved maize varieties, and crop residuals on food security, nutrition, and poverty among smallholder maize farmers in Morogoro region.

The study contributes to existing adoption literature in two key ways: First, it addresses the scarcity of literature on the benefits of using SAP interventions, aiming to guide future studies and policy frameworks amidst the ambiguity surrounding the impacts of adopting SAPs. Second, it endeavors to provide evidence-based insights into the scalability of SAP interventions. This is crucial in the ongoing discussions regarding low agricultural production levels in Africa, which have resulted in food insecurities, nutrition deficiencies, and poverty among farming households. Lastly, the findings of this study could significantly contribute to achieving Sustainable Development Goal 2, targeting the eradication of hunger, ensuring food security, promoting sustainable agriculture, and improving nutrition by 2030.

Furthermore, utility theory was used to establish the study's hypotheses on the association between the adoption of SAPs, food security, nutrition, and poverty. The conceptual hypothesis (H_0) posits that there is no association between the adoption of SAPs, food security, nutrition, and poverty among smallholder maize farmers in the Morogoro region. Meanwhile, the operational hypothesis (H_0) suggests that the adoption of SAPs does not exert significant impacts on food security, nutrition, and poverty indices.

II. LITERATURE REVIEW

2.1 The concept of sustainable agriculture

Sustainability encompasses various dimensions, such as environmental sustainability, which involves responsible stewardship of the natural systems and resources for farms to enhance environmental stability. Agricultural sustainability manifests in several facets: i) building healthy soil and preventing erosion; ii) managing water wisely. iii) Minimizing air and water pollution; iv) Storing carbon on farms; v) Increasing resilience to extreme weather; and vi) Promoting biodiversity (FAO, 2015). It is crucial to note that agricultural sustainability must meet current needs without compromising the ability of future generations to meet theirs (Coulibaly *et al.*, 2021). In other words, sustainable agriculture diverges from the industrial approach to food production while emphasizing the integration of environmental health, economics, profitability, and social equity across agricultural supply and value chains.

Theoretically, an economically and socially sustainable agricultural system enables farms of all sizes to be profitable and contribute to their local economies while ensuring food accessibility. Rust *et al.* (2021). This study focuses on achieving agroecology, which involves managing farms as ecosystems and collaborating with nature rather than opposing it. The objective is to enhance productivity and profitability while addressing the interconnectedness of environmental, economic, and social factors to establish a sustainable agricultural system.

2.2 Sustainable agricultural practices

According to FAO (2019), SAPs encompass methods that facilitate the more efficient utilization of natural resources, mitigate agriculture's impact on the environment, and enhance adaptability to climate change and variability. These practices include crop rotation, use of cover crops, increased crop diversity, minimal tillage systems, integrated pest management (IPM), integration of livestock and crops, agroforestry practices, and precision farming, among others. Achieving environmental sustainability in agriculture demands adept management of natural systems and resources, which can yield crucial public services, notably ecosystem services.

Adopting sustainable agricultural practices typically requires considerable efforts or resource investments from farmers and is often a response to concrete incentives provided by policies, market conditions, and support from local and national governments, as well as public-private partnerships (Khwidzhili & Worth, 2017; Rose *et al.*, 2019). Despite growing interest in sustainable agriculture and the proliferation of projects and policies promoting these practices globally, there has been limited evaluation of the incentives, adoption, and outcomes in food security, nutrition, and poverty. Specifically, understanding how various incentives promote adoption, whether adoption leads to significant and measurable changes in outcomes, and the factors influencing these connections remains a critical yet understudied area.

The incentives-adoption-outcomes framework provides a coherent logic for parsing and evaluating best practices related to sustainability. However, existing literature on these relationships is inconclusive and lacks clarity, particularly when considering different types of incentives.

**Table 1***Selected sustainable agricultural practices for the study*

SAPs	Description
Crop rotation	Refers to a process of growing crops which have different nutrient needs, and management, sequentially. It impedes the spread of pest, and improve soil fertility.
Intercropping	Refers to a process of growing of mixed crops, which have different characteristics and requirement on the same land at the same time. It contributes to pest control.
Manure	Defined as materials that are made from decaying animal wastes. It improves the soil and plant health.
Improved maize varieties	Refers to maize cultivars that have been selectively bred or developed through biotechnological methods to exhibit characteristics and traits that make them. Superior to traditional or unimproved maize varieties. It contributes to pest control and yield.
Crop residual	Refers to parts of a crop that remain in the field after the main harvest has taken place. These residues can include various plant materials such as stems, leaves, and roots. It benefits the soil and erosion control.

Source: Dictionary of Agriculture (2006)

2.3 Linkage between SAPs, food security, nutrition and poverty

Piñeiro et al. (2022) assert that the adoption of SAPs is crucial for enhancing agricultural productivity and the livelihoods of farming households, benefiting both micro and macro levels of the economy. Primarily, food security encompasses the availability, accessibility, utilization, and stability of food among households' members. Manda et al. (2018) contended that proper implementation of SAPs could significantly impact food availability by boosting agriculture productivity. Moreover, previous studies (Abenman *et al.*, 2018; Manda *et al.*, 2018; Mkonda, 2021; Setsofia *et al.*, 2022), have empirically suggested that effectively managed SAPs have the potential to increase food production, alleviate food insecurity, and address nutrition deficiencies by enabling the sale of surplus crops to afford better quality foods.

2.4 Empirical framework

As indicated in Table 2, a notable research gap exists due to scarcity of studies testing whether the application of bundled SAPs (manure, intercropping, crop rotation, improved maize varieties, and crop residual) yield better or comparable outcomes compared to the use of individual SAPs by using endogenous treatment effect models. It is hypothesized that bundled SAPs could significantly impact food security, nutrition, poverty indicators, with assumed variations across different locations.

Table 2

Summary of the studies related to the impacts of SAPs on food Security, nutrition and poverty globally.

Author	Practices	Country	Statistical model
Teklewoold et al. (2019)	Crop diversification, soil and water conservation, improved maize varieties (Food security and Nutrition)	Ethiopia	Endogenous switching regression
Setsofia et al. (2022)	Improved seed, fertilizer, and soil and water conservation (Food security)	Ghana	Multinomial endogenous switching regression
Sahraei et al. (2022)	Sustainable agricultural practices (Food security)	Iran	Censored regression (Tobit model)
Manda et al. (2018)	Improved maize varieties (Food security)	Zambia	Doubly robust inverse probability weighted regression adjustment method, complemented with propensity score matching
Mujeyi et al. (2021)	Minimum tillage, mulching, intercropping, manure (Food security)	Zimbabwe	Endogenous switching regression
Merga et al. (2023)	Improved Maize varieties (Food security)	Ethiopia	Endogenous treatment effect model
Manda et al. (2019)	Improved seed varieties (Poverty)	Nigeria	Counterfactual analysis
Kassie et al. (2014)	Improved maize varieties (Food security)	Tanzania	Continuous treatment approach
Nkomoki et al. (2018)	Crop diversification and agro forestry practices (Food security)	Zambia	Descriptive chi-square approach
Abdallah et al. (2021)	Zero tillage, intercropping, residual and animal manure (Food security)	South Africa	Multinomial endogenous treatment effects

2.5 Theoretical framework

This study acknowledges that previous studies on the adoption of SAPs have largely relied on the utility maximization theory as their theoretical foundation (Bongole *et al.*, 2021; Kassie *et al.*, 2013; Lasway *et al.*, 2020; Pinerio *et al.*, 2022; Wordofa *et al.*, 2021). Expanding on this foundation, the study incorporates a temporal dimension into the utility maximization decisions made by smallholder farmers. Drawing from aforementioned previous studies, this study initially assumes that a farmer would adopt SAPs, namely: (i) crop rotation; (ii) intercropping; (iii) manure; (iv) crop residual; (v) improved maize varieties, if these practices lead to the maximization of utility defined in terms of food security, nutrition, and poverty.

The assumption is that each of the smallholder financiers will attach a utility to each SAP denoted by U_{ij} based on socio-economic, institutional, and agro-ecological factors. Then, the utility derived from adopting SAPs can be presented as follows:

$$U_{ijt} = \left((\eta_{ijt}, h_i) \right) \forall j = 1 \dots 5 \text{ for } t = 1$$



The implication of this utility function is that when smallholder maize farmers decide to adopt SAPs, they do so based on their utility functions. These utility functions could be related to production functions for achieving maximum yield, thereby contributing to food security, and generating income for poverty alleviation. Thus, this study assumes that there is subsist non existences of mutually exclusivity in the faming households’ choice of SAPs, Therefore, the probability of adopting SAPs can be presented as follows:

$$P_{i1} = \Pr (U_{i1} > U_{i2}, U_{i1} > U_{i3})$$

As such, a smallholder farmer chooses to adopt SAPs that will maximize their respective utility function. This can be presented as follows:

$$U_{ijt} = V_{ijt} + \varepsilon_{ij} \forall j = 1 \dots \dots .5 \text{ for } t = 1 \dots \dots .5$$

Where: V_{ijt} explains smallholder maize farmers’ utility, and e is the error term that captures unobservable determinants of utility, and q are the parameters to be estimated.

III. METHODOLOGY

3.1 Data

The study utilized data from adoption pathway survey, a collaborative initiative involving several African countries, including Tanzania. The project aims to enhance food security and reverse declining productivity trends by comprehending the socio-economic and agricultural system characteristics influencing technology adoption. Additionally, it aims to facilitate adaptation to external factors, such as production risks within maize-based farming systems. In the initial phase of the multistage sampling process, two districts in the Morogoro region, namely Mvomero and Kilosa, were selected based on their potential for maize-legume production. Each of the two districts received the same number of sample households. The households within each district were distributed according to the size of the district's households (proportionate sampling). Subsequently, 5–13 wards were selected in each district, 1–4 villages in each ward, and 2–30 farm households in each village through a fully proportional random sampling procedure. Although the sample may not be representative of Tanzania as a whole, it is representative of the country's major maize-legume farming systems.

A well-designed and pre-tested questionnaire was employed to collect comprehensive information regarding household, plot, and village details. This included data on households' production activities, plot-specific characteristics, SAP adoption such as intercropping, manure, improved maize varieties, crop rotation, and crop residual. Additionally, the questionnaire captured demographic information, infrastructure details, food, nutritional, and poverty indicators for each household and village. The data collection process also involved observations and casual conversations with farmers to delve into their concerns and seek clarification.

Supplementary qualitative data were incorporated to complement the quantitative data collected from the smallholder maize farmers. The research was carried out during the 2017–2018 maize cropping season.

3. 2 Econometric Framework

The study first notes that smallholder maize farmers’ decisions to adopt SAPs may occur randomly. This implies the presence of potential confounding factors that could influence the adoption of multiple SAPs. Similar perspectives have been expressed by Bongole et al. (2021) and Kassie et al. (2013), highlighting that socio-economic factors significantly affect the adoption of agricultural practices such as SAPs. Consequently, there is potential for self-selection in the adoption process, wherein smallholders choose SAPs based on their utility functions. This self-selection suggests the presence of both observed and unobserved heterogeneity biases in the adoption of SAPs. Therefore, employing an endogenous switching regression model becomes pertinent as it has the ability to control for both observed and unobserved factors, mitigating the biases inherent in such a scenario.

The study follows the methodology employed by (Amadu *et al.*, 2020; Dillon *et al.*, 2019; Mgonezulu *et al.*, 2023; Ruel *et al.*, 2018; Wooldrige, 2015), in utilizing the weak instrument to test the robustness of the instrument used.

In terms of statistical modeling, this study adopted the approach presented by Mgonezulu et al. (2023) and Khanal et al. (2018), who employed the ERS in a single stage with variations in the outcome variables.

The average treatment effects of the untreated are presented as follows:

Firstly, smallholder maize farmers that participated in the adoption of SAPs J are presented by:

$$E[R_{jit} | Y = j, X_{ij}, \gamma_{ij}] = \delta_i X_{ijt} + \sigma_{j\varepsilon} \gamma_{ji} \dots \dots \dots (i)$$



Secondly, for those who didn't participate in the adoption of SAPs J:

$$E[R_{1it} | Y = 1, X_{1it}, \gamma_{1i}] = \delta_i X_{1it} + \sigma_{1\epsilon} \gamma_{1i} \dots \dots \dots (ii)$$

Then the ATT is presented as follows:

$$ATT = E[R_{jit} | Y = j, X_{ijt}, \gamma_{ij}] - E[R_{1it} | Y = j, X_{ijt}, \gamma_{ij}] = X_{ijt}(\delta_j - \delta_1) + \gamma_{ji}(\sigma_j - \sigma_1) \dots \dots \dots (iii)$$

Following Wooldridge (2015), the endogenous test, and weak instruments test, are presented as:

$$Y_{ij} = X_i \beta_i + \mu_i \dots \dots \dots (iv)$$

$$X_i = Z_i \gamma + \varepsilon_i \dots \dots \dots (v)$$

Where equation of the structural equation and equation in reduced form. As such, the study tested the null hypothesis that $\gamma = 0$ in reduced form against the alternative that $\gamma \neq 0$ rejecting the null hypothesis implies the presence of endogeneity.

3.2 Description of the outcome variables

Following Haughton & khandler (2009), the study employs: i) the head count index; (ii) the poverty gap index; (iii) the squared poverty gap index which are part of the forster-Gree Thorbecke (FGT) poverty indices and presented as follows:

$$FGT_\alpha = \frac{1}{N} \sum_{i=1}^H \left(\frac{z-y_i}{z} \right)^\alpha \dots \dots \dots (i)$$

Z presents the poverty line, N is the number of smallholder maize farmers, H is the number of farming households with income below the poverty line, y is the income of the farming households. The FGT index reduces to a headcount index, and measures incidence of poverty when 4-1, the FGT reduces to the poverty index. The headcount index and poverty line index are computed for the farming household based on the adult equivalence, and household consumption poverty line.

The study follows (FAO, 2016; Mgomzulu *et al.*, 2023) in utilizing the household dietary diversity score as a measure of nutrition security, presented as:

$$HDDS = \sum_i w_i i = 1,2,3,4,5,6,7,8,9,10 \dots \dots \dots (ii)$$

Where: W_i presents the food group consumed by the farming household, where 1 equals the farming household that consumed a particular food group, 0 otherwise. The farming household that consumed all 10 food groups in the past month would score a HDDS of 10. The Household Dietary Diversity Score (HDDS) serves as a valuable metric for assessing food access since it gauges the quality of food available to a farming household. This score quantifies the diversity of food groups consumed by the household, reflecting the variety and nutritional quality of their diet. (Abernman *et al.*, 2018). The food groups considered in this study are: (i) pulses; (ii) eggs; (iii) meat and fish; (iv) fats and oils; (v) cereals and grains; (vi) dairy; (vii) fruits and vegetables; (viii) roots and tubers; (ix) condiments; and (x) sugar. However, the HDDS model fails to capture the nutritional values of the consumed food groups.

Food consumption score (FCS) is another measure of food security, is calculated by assigning weights to various food groups based on their nutritional importance, and then multiplying these weights by the frequency of consumption for each group. This method offers a comprehensive assessment by accounting for both the diversity of food intake and the nutritional value of the consumed items. FAO (2016) contends that FCS, unlike the HDDS model, provides a complete score that can efficiently measure food consumption frequencies, dietary diversity, and nutrition values of the respective food groups. The weights assigned to the study's food groups are: staple foods such as cereals and grains (4); vegetables (1); pulse (3); meat and fish (4); fruits (1); milk and dairy products (4); fats and oil (0.5); sugar (0.5); and condiments (0). Nevertheless, the FCS method requires a 7-day recall period as opposed to the 24-hour recall period required by the HDDS model (Maxwell *et al.*, 2014; Mgomzulu *et al.*, 2022). Thus, a higher FCS score signifies higher food and nutrition security.

The study utilized a household food insecurity access scale (HFIAS) to assess access to food during the past 30 days. A higher HFIAS score indicates increased food insecurity and poor access to food among members of farming households. The HFIAS model consists of nine defined questions that are sufficient for distinguishing between food insecure and secure households. The model contends that in order to capture the accessibility to food, the respondent must respond



to the following: (i) rarely, i.e., once or twice in the past four weeks; or option (iii) often, i.e., more than ten times in the past four weeks, to the following questions asked to capture the duration of four weeks; i) in the past four weeks, did you worry that your household would not have enough food? (ii) Did you or any of the household members not eat the kind of food preferred because of a lack of resources? (iii) Did you or any household member have to eat a limited variety of food due to a lack of resources? (iv) Did you or any household member have to eat some of the food that you didn't want because of a lack of resources to obtain other types of food? (v) Did you or any household member have to eat smaller meals than you felt you needed because there was not enough food? (vi) Did you or any household members have to eat fewer meals in a day because there was not enough food? (vii) Was there ever no food to eat of any kind in your household because of a lack of resources to get food? (viii) Did you or any household member go to sleep at night hungry because there was not enough food? (ix) Did you or any household member go a whole day and night without eating anything because there was no food? The maximum score of 27 indicates that the household has responded often to all of the asked questions suggesting a higher level of food insecurity. Conversely, a minimum score of 10 indicates that the household did not face any of described food insecurity situations, suggesting a lower level of food insecurity or more secure food situation for that household.

IV. RESULTS & DISCUSSIONS

4.1 Weak instrument test

The selection of the instrument in this study was grounded in the utility theory and guided by previous adoption studies such as (Amadu *et al.*, 2020; Dillon *et al.*, 2019; Mgonezulu *et al.*, 2023). In addition, a weak instrument approach, as outlined by Wooldridge (2015) was employed to test the robustness of the selected instruments. In selecting the appropriate instrument for the study, it was hypothesized that the proportion of plots in an enumeration area should be under SAPs. Consequently, the study adopted a zero-first-stage test, an effective method to assess the validity. Following the reduced form estimation, the null hypothesis, which suggested weak validity of the instrument, was rejected at ($P < 0.01$) as shown in Table 3.

Table 3

Endogeneity Test and Weak Instrument Robust Tests for IV

Test	Statistic	P-Value
AR	$\text{Chi}_2(5) = 26.01$	0.0001
Wald	$\text{Chi}_2(5) = 11.95$	0.0021

4.2 Impact of adopting SAPs on food security and nutrition among smallholder maize farmers

Table 3:

Average treatment effect of SAPs adoption on FCS, HDDS and HFIAS

SAPs	Actual FCS dependent on SAPs adoption	Counterfactual FCS independent of SAPs adoption	ATE	Actual HDDS dependent on SAPs adoption	Counterfactual HDDS independent of SAPs adoption	ATE	Actual HFIAS dependent on SAPs adoption	Counterfactual HFIAS independent of SAPs adoption	ATE
SAPs adopters	33.111 (5.01)	32.960 (5.01)	0.151	6.325 0.38	6.136 (0.42)	0.189	5.493 (1.52)	5.310 (1.38)	0.183
Crop-rotation (ATT)	35.109 (4.71)	8.539 (6.31)	26.57***	6.521 0.27	6.138 (0.23)	0.383** *	5.852 (1.65)	5.721 (1.51)	0.131***
Intercropping (ATT)	34.781 (5.01)	19.083 (3.17)	15.698***	6.282 (0.47)	4.403 (0.51)	1.879** *	4.313 (2.01)	3.957 (2.11)	0.356***
Improved maize varieties (ATT)	36.136 (4.12)	5.680 (5.01)	30.456***	5.166 (0.42)	1.022 (0.35)	4.144** *	6.944 (1.12)	2.408 (1.88)	4.536***
Manure (ATT)	30.120 (5.01)	31.166 (6.60)	-1.046	6.005 (0.28)	5.980 (0.48)	0.025	5.317 (1.01)	5.501 (1.63)	-0.184
Crop-residual (ATT)	33.104 (5.21)	12.608 (6.61)	20.496**	5.915 (0.36)	3.119 (0.55)	2.796** *	6.471 (1.86)	5.968 (1.24)	0.503***

*Standard error in parameters * $p < 0.10$, ** $p > 0.05$, *** $p > 0.01$*

The findings in Table 3 indicate that the adopters of improved maize varieties and crop rotation practices significantly increased FCS by 30.6 and 26.5 points, respectively, than non-adopters. This suggests that non-adopters could potentially enhance their FCS by similar margins through the adoption of these practices. Improved maize varieties are particularly crucial for bolstering productivity due to their high yield traits and resilience to climate change, thus contributing to food security among smallholder farmers. These findings are consistent with studies by (Kasie *et al.*, 2014; Katushula *et al.*, 2014; Manda *et al.*, 2018), and (Merga *et al.*, 2023; He *et al.*, 2021), who contended that improved maize varieties and crop rotations had significant impacts on food security among smallholder farmers in Zambia and Ethiopia, respectively.

Furthermore, the adoption of crop residue and intercropping practices demonstrated significant associations with food security, leading to increases in FCS scores of 20.4 and 15.6 points, respectively, compared to non-adopters. Although improved maize varieties and crop rotation exhibited a more substantial contribution to food security compared to crop residual and intercropping, adopters across all practices demonstrated relatively higher FCS compared to non-adopters, indicating better food security status. These findings align with Amare *et al.* (2011) and Krishina *et al.* (2023), showcasing the significant impacts of crop residual and intercropping on food security among farming households in Tanzania and India, respectively.

In addition, crop rotation and intercropping practices exhibited significant impacts on HDDS. Specifically, adopters of crop rotation and intercropping had increases in HDDS by 0.38 and 1.879 points, respectively, compared to non-adopters. Meanwhile, adopters of crop residual and improved maize varieties recorded significant HDDS of 2.79 and 4.14 points, respectively, compared to counterfactuals. As HDDS reflect the diversity of food groups consumed within the past 24 hours, these findings suggest that adopters had more diversity in their diets compared to their counterfactuals. In addition, higher HDDS indicates greater financial returns from agricultural produce, enabling the purchase and consumption of various food groups. These findings align with the findings of Bongole *et al.* (2021) and Rehman *et al.* (2022), who contended that SAPs had significant impacts on food and nutrition security among farming households in Tanzania.

Lastly, adopters of crop rotation and intercropping practices had significant HFIAS scores of 0.13 and 0.35 points, respectively. Conversely, adopters of crop residual and improved maize varieties recorded significant HFIAS scores of 4.53 and 0.50, respectively, compared to counterfactuals, indicating that SAPs adopters had better access to food compared to non-adopters. These findings are consistent with those by Setsofia et al. (2022) and Mujeyi et al. (2021) in Ghana and Zimbabwe, respectively, in amplifying that SAPs adopters had better access to food compared to their counterfactuals.

4.3 Impact of adopting SAPs on poverty indices among smallholder maize farmers

Table 4

Average Treatment Effect of SAPs on poverty indices

SAPs	Actual FGT1 dependent on SAPs adoption	Counterfactual FGT1 independent of SAPs adoption	ATE	Actual FGT2 dependent on SAPs adoption	Counterfactual FGT2 independent of SAPs adoption	ATE	Actual FGT3 dependent on SAPs adoption	Counterfactual FGT3 independent of SAPs adoption	ATE
SAPs adopters	0.4818 0.324	0.4821 0.324	-0.0003	0.152 0.111	0.154 0.112	-0.002	0.071 0.114	0.075 0.114	0.004
Crop rotation (ATT)	0.3129 0.327	0.3148 0.326	-0.0019	0.154 0.122	0.156 0.112	-0.002	0.084 0.121	0.091 0.115	0.007
Intercropping (ATT)	0.4122 0.328	0.4131 0.327	-0.0009	0.161 0.111	0.167 0.113	-0.006	0.091 0.132	0.097 0.132	0.006
Improved maize varieties (ATT)	0.4918 0.331	0.3107 0.329	0.1811***	0.181 0.146	0.123 0.102	0.0581***	0.092 0.133	0.060 0.128	0.032***
Manure (ATT)	0.4609 0.324	0.4501 0.310	0.0405	0.152 0.111	0.125 0.160	0.027	0.071 0.114	0.061 0.127	0.010
Crop residual	0.3001 0.307	0.2909 0.326	0.0092	0.154 0.122	0.145 0.018	0.009	0.089 0.111	0.071 0.123	0.018

*Standard error in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

The findings in Table 4 demonstrate that the adoption of improved maize varieties had significant impacts on all poverty indices. Similarly, Manda et al. (2018) found that the use of improved maize varieties significantly reduced poverty among smallholder cowpea farmers in Nigeria. However, contrary to these findings, Mgonezulu et al. (2023) argued that the adoption of SAPs had no significant impact on poverty indices, suggesting that the application of SAPs might not necessarily influence poverty indicators among smallholder farmers. Notably, the varying contributions of different SAP elements to poverty could stem from the spending habits of farming households. These households might allocate their incomes to expenditures that do not directly or indirectly contribute to poverty reduction in their households.

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

The study aimed to evaluate the impacts of adopting multiple SAPs on food security, nutrition, and poverty among smallholder maize farmers in the Morogoro region. Despite government initiatives to promote SAP adoption for improving food security and poverty reduction by 2030, previous studies indicate persistent food insecurity, nutritional deficiencies, and poverty among farming households in the Morogoro region. Low adoption rates of SAPs have exacerbated these challenges by causing low maize yields, intensifying food and nutrition insecurity in farming households. Consequently, recent efforts have focused on promoting low-cost and climate-resilient SAPs.

This study introduced a novel perspective by examining the impacts of adopting SAPs on food security, nutrition, and poverty through the utilization of an endogenous treatment effect model. Empirical findings revealed that adopting crop rotation, intercropping, improved maize varieties, and crop residuals significantly improved food security and nutrition. Notably, improved maize varieties were the sole practice within the bundle that significantly impacted poverty indices. Therefore, the concurrent utilization of multiple SAPs emerges as a critical approach to enhance food security, nutrition, and poverty alleviation among farming households in diverse agro-ecological settings across Tanzania.

5.2 Recommendations

Based on the findings, the study recommends the development of agricultural productivity programs that will promote the adoption of SAPs for improved food security, nutrition, and poverty among smallholder farmers. Moreover, such programs should adopt toiled extension delivery systems and timely evaluations. This includes the formation of well-designed farmer's organizations, village savings cooperatives, and loan groups that provide the required financial muscles and information needed to adopt SAPs. Furthermore, the study recommends that future research should be conducted based on panel research design; this is crucial in assessing the sustainability of adoption decisions to SAPs and associated impacts on various outcome variables such as income, yield, food security, nutrition, expenditures, and poverty. In this regard, considerable agricultural-related investments should be made to strengthen and improve maize seed systems so as to ensure that improved seeds are readily available and accessible at affordable prices to smallholder farmers in Tanzania.

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