



Economic impact of adopting bundled SAPs on crop yield and household incomes among smallholder maize farmers in Morogoro region, Tanzania



Joseph J. Mugula ^{(a)*} Athman K. Ahmad ^(b) John Msinde ^(c) Michael Kadigi ^(d)

^(a)Department of Policy Planning and Management, Sokoine University of Agriculture, Morogoro

^(b)Ph.D., Senior Lecturer: Department of Agricultural Extension and Community Development, Sokoine University of Agriculture, Tanzania

^(c)Ph.D., Lecturer, Institute of Development Studies, University of Dar es Salaam, Tanzania

^(d)Ph.D., Lecturer, Department of Policy Planning and Management, Sokoine University of Agriculture, Morogoro, Tanzania

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ABSTRACT

This paper uses a multinomial endogenous treatment effect model and data from a sample of 470 farming households to assess the impacts of adopting sustainable agricultural practices (SAPs) on farm yield and household incomes among smallholder maize farmers in Morogoro region. Results show that combination of improved maize and crop residual significantly increased maize yield by 46%, while intercropping with crop residual (65%), improved maize seeds with manure use (58%), and maize rotation with intercropping (57%). The model estimates indicate that individual elements of SAPs increased yield by crop residual (30%), crop rotation (38%), improved maize varieties (85%), intercropping (58%), and manure (43%) whereas, the application of bundled SAPs had significant impacts on the household income via the following combinations; maize-legume rotation and crop residual (50%), improved maize and crop residual (46%), improved maize and manure (70%), maize-legumes rotation and improved maize (46%), maize rotation and intercropping (68%), maize rotation, improved maize, crop residual, and intercropping (41%), and lastly improved maize, intercropping, manure, crop residual, and crop rotation (55%). The study recommends actors involved in the design, promotion and dissemination of SAPs to find a suitable mix or combination of these practices that will enhance maize productivity and incomes, while simultaneously addressing issues related to the dis-adoption of SAPs, and climate change, by raising awareness and educating to farmers about the benefits of using SAPs and implementing mitigative measures for climate change. This includes providing of financial incentives such as loans and subsidies, as well as conducting policy reforms to evaluate and adjust policies that currently favor the use of conventional practices in Tanzania.

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Introduction

Sustainable agriculture holds significant importance within the food system as it plays a crucial role in augmenting farm revenues and ensuring household food security, particularly in emerging nations situated in Africa Setsoafia et al. (2022). The attainment of sustainable household food production in Africa is confronted with a multitude of obstacles. These include the reduction in farm sizes due to the escalating pressure caused by rapid population growth, the degradation of the environment resulting from the adverse effects of climate change, the persistent cultivation of soil without proper restorative practices, inadequate recycling of organic matter, and the limited adoption of soil fertility management and conventional farming techniques (Ahmed, 2022; Onyeneke, 2021). The aforementioned issues, in conjunction with institutional and infrastructural limitations, contribute to suboptimal agricultural productivity, reduced financial returns for farmers, inadequate access to food, and the persistence of poverty within the smallholder farming community (Ethiakpor et al., 2021).

* Corresponding author. ORCID ID: 0009-0009-6614-6954

However, it is important to note that the current increase in agricultural production worldwide is not adequately meeting the needs of the growing population, particularly in Africa, which is inhabited by more than 1.2 billion individuals. According to Thinda et al. (2021), Africa's geographical location near the equator renders it susceptible to adverse externalities, including climate change. Negative externalities, such as a shortage of rainfall, can have significant physical consequences that adversely affect various aspects of society Setsoafia et al. (2022). One of the primary areas impacted is agricultural productivity, which experiences a decline due to a number of factors such as soil infertility, climate change, unsustainable agriculture techniques. This, in turn, leads to reduced income for farmers, as their crop yields are diminished.

Additionally, the scarcity of rainfall negatively affects food security, as it hampers the ability to produce an adequate supply of food to meet the population's needs (Bongole et al., 2021). In addition, the overall economic development of a region or country can be hindered by the physical repercussions of unsustainable agricultural practices. The potential consequences of this situation are expected to have an adverse impact on farming households, as their economic sustenance is closely intertwined with agricultural activities.

The agricultural industry is facing significant pressure to fulfill the needs of an expanding global population. According to Food and Agriculture Organization (FAO, 2022), it is projected that there would be a need to augment agricultural production by 60% by the year 2050 in order to meet the escalating global food demand. The inference can be drawn that there exists a necessity for a commensurate augmentation in agricultural production, particularly for staple food crops like maize, which holds significant prominence as a cereal crop within the context of Tanzania. Maize accounts for approximately 70% of the yearly cereal production and contributes 37% to the national food basket (URT, 2019). Hence, in order to address the anticipated rise in food demand attributed to the projected population growth of over 129 million individuals by the year 2050, it is imperative to augment production levels.

A worldwide discourse has emerged around the mitigation of adverse externalities associated with agricultural Manda production, such as climate change, and conventional practices, and the enhancement of revenue for small-scale farmers. Previous research by (Adenle et al., 2019; Bekele 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) have argued that the implementation of sustainable agriculture practices (SAPs) has the potential to address the challenges associated with negative agricultural externalities. The application of SAPs is anticipated to have a significant positive impact on agricultural productivity, as well as mitigate the detrimental effects of degradation on the agroecosystem, specifically within smallholder farming systems. Theoretically, this phenomenon can be considered as an advancement of the green revolution, a historical event that resulted in a substantial rise in agricultural output on a global scale. The green revolution has been widely acknowledged for its role in stimulating the economies of several African nations.

In an effort to mitigate the aforementioned externalities, farmers have been recommended to embrace SAPs which encompass the components of the green revolution and an agronomic revolution and includes the following practices: i) improved seed (ii) crop rotation, (iii) intercropping, (iv) crop residual, and (v) manure. Nevertheless, Ocheng et al. (2021) has argued that, there is a contention that these particular sets of SAPs possess greater environmental friendliness and are linked to beneficial productivity effects, whether employed in isolation or in conjunction. Furthermore, it has been shown that the application of SAPs can enhance soil fertility and organic matter content through mitigation of runoffs and surface temperatures, the enhancement of soil moisture, and the facilitation of plant nutrient availability. Thus, Governments and development partners have persistently advocated for the application of SAPs among farmers in order to support their livelihoods while preserving the environment in Africa Adenle et al. (2019).

Nevertheless, there is insufficient empirical literatures on the impact of adopting bundled (SAPs) on income and yield in a cross-regional setting. The previous studies (Abdulai & Huffman, 2014; Adenle et al., 2019; Ahmed, 2022; Agula et al., 2018; Adegbeye et al., 2020; Kimathi et al., 2021; Yang et al., 2022; Zheng et al., 2021) have extensively examined the impact of adopting specific components or individual elements of SAPs, such as enhanced seed, irrigation, crop varieties resilient to drought, climate change, soil and water conservation methods on outcome measures such as income, outputs, consumption spending, and food security. Thus, the information is lacking on the effects of adopting packaged SAPs comprised of manure, intercropping, crop rotation, improved maize varieties and crop residual) on outcome measures, such as yield and income in Tanzanian context. Moreover, this study builds upon prior research that has concentrated on alternative indicators of household well-being, such as food security and expenditure on consumption (Ehiakpor et al., 2021; Kassie et al., 2013; Manda et al., 2018; 2019; Setsoafia et al., 2022; Usman et al., 2020).

In addition, building the empirical evidence for this holistic approach is vital to inform agricultural technology development and extension agents. The lack of context- appropriate adoption of SAPs can partly explain the continued underperformance of smallholder agriculture in Africa. Therefore, "the package" or bundling approach should be the centerpiece of Sustainable agriculture (SA), i.e., applying a bundle of SAPs to simultaneously improve crop yield and conserve and protect critical agriculture resources (Marenya et al., 2020). The focus on modeling adoption studies as a joint decision-making process is crucial, as it highlights the need for farmers to apply composite of practices.

The study was designed to offer evidence on the impact of SAPs based on farmer's production data. The aim was to determine if the promise of these SAPs is being realized on farm and at a scale. This aspect is crucial as it provides validatory data on the real-world performance of agricultural recommendations to smallholder farmers. There is a broad recognition in the literature (e.g., Khonje et

al., 2018; Manda et al., 2019; Marenya et al., 2020) that underlying conditions explain a lot of the farm variation on the impacts of SAPs. However, there are many modifiers of SAPs that need to be understood on a case-by-case basis. This is important for guiding local adaption of agricultural technologies/practices, this adaption is important for improving the performance of SAPs under heterogeneous conditions. To that extent, the objective of this paper is to assess the effectiveness of adopting multiple SAPs, by analyzing its impacts on yield and income with the aim of informing policy direction. Furthermore, the study adds to existing literature in at least two ways: First, it adds to a novel body of literature on sustainability of SAPs interventions by shaping future adoption studies and policy frameworks amidst inconclusive SAPs impact results; Second, the study delivers an evidence base of the scalability of SAPs interventions which is pertinent for current debate on low levels of agriculture productivity, and poverty in Tanzania.

The rest of the paper is organized as follows: The next section covers a review of relevant literatures. The third section discusses the methodologies applied to estimate the impacts of adopting SAPs on yield and income. Section 4 presents the estimation results accompanied by broad discussion. Section 5 concludes and draws key policy implications based on the analysis.

Literature review

Concept of sustainable agriculture practices

According to FAO (2015), resource conserving, environmentally benign, technically appropriate, economically acceptable, and socially justifiable are the salient characteristics of sustainable agriculture practices." The concept of sustainable agriculture (SA) gives economic, social, and environmental concerns that the agricultural sector must address equal weight. Today, most of societal issues are interconnected, global, and swiftly evolving; therefore, SA provides effective solutions to establish and strengthen a secure agriculture, food system, and safe energy for a healthy and sustainable future. The SAPs considered in this study are intercropping, crop rotation, crop residual, manure and improved maize varieties. These practices have been cited to be very useful in enhancing soil fertility, provision of ecosystem services and consequently safer environment.

Sustainable agriculture practices

Crop rotation (CR) refers to the agricultural technique of cultivating diverse varieties of annual or biennial crops on a given plot of land throughout consecutive growing seasons (Mohler & Johnson, 2009) The application of this particular technique has the potential to enhance agricultural productivity by means of nitrogen fixation, particularly in the context of legume crop rotation (Teklewold et al., 2013b). Moreover, it can serve as a means to sustain productivity levels in the face of adverse conditions resulting from climate change (Delgado et al., 2011). Additionally, it has been observed to mitigate the prevalence of pests and diseases (Mohler & Johnson, 2009). Intercropping, (IC), refers to the agricultural technique of simultaneously farming two or more crops on a single plot (Vandermeer, 1989). IC has been found to have several benefits in agricultural practices. It has been shown to increase productivity, mitigate the negative impacts of pests, diseases, and weeds, enhance biodiversity, and minimize soil erosion (Tlou et al., 2023). IC is widely observed in Tanzania, wherein staple crops like maize are commonly intercropped with legumes.

Crop residuals, also known as crop residues or agricultural residues, are the portions of a crop that remain in the field after the primary harvest of the economic or edible parts of the plant Fu et al. (2021) These residual materials typically include stems, leaves, stalks, and other plant matter that are left behind once the valuable parts of the crop, such as grains, fruits, or vegetables, have been harvested. Crop residuals can vary depending on the specific crop and harvesting method, but they are often considered agricultural waste or byproducts. These residues can have various uses, including as animal feed, mulch, compost, or as a source of biomass for bioenergy production. They play an essential role in sustainable agriculture and can have environmental and economic benefits when managed and utilized effectively. Manure refers to organic material, primarily animal feces, that is used as a natural fertilizer in agriculture to improve soil fertility and enhance crop growth (Rayne & Aula, 2020). It contains valuable nutrients such as nitrogen, phosphorus, and potassium, which are essential for plant development. Manure is a valuable resource in sustainable farming practices, as it can replace or supplement chemical fertilizers. Improved maize varieties refer to cultivated strains of maize that have been selectively bred or genetically modified to have specific desirable traits or characteristics (Anang et al., 2019). These improved varieties are developed to enhance crop yield, resistance to pests and diseases, adaptability to different environmental conditions, nutritional content, and other qualities that benefit both farmers and consumers.

Empirical framework

Studies estimating the impact of adopting SAPs has employed a diverse set of outcome variables. These include household income, agrochemical utilization, labor demand, crop yields, and food security (Teklewold et al., 2013b; Abdulai & Huffman 2014; Gebremariam & Wünsch 2016; Setsoafa et al., Manda et al., 2016; Amondo et al., 2019; Marenya et al., 2020; Oduniyi & Chagwiza, 2021). However, it is worth noting that the adoption of specific elements within the realm of SAPs tends to be context-specific, as there exists substantial empirical evidence showcasing the effectiveness of various combinations of SAPs tailored to different environmental conditions.

Therefore, this study aims to investigate the impact of adopting SAPs on household income and yield within the context of Tanzania.

Table 1: Summary of the empirical studies related to the impact of adopting sustainable practices worldwide.

Author	Practices	Country	Sample	Statistical model
Tekleword et al. (2013)	Conservation tillage and improved seeds	Ethiopia	900	Multinomial endogenous switching regression
Setsofia et al. (2022)	Improved seed, fertilizer, and soil and water conservation	Ghana	1284	Multinomial endogenous switching regression
Abdulai & Huffman (2014)	Soil and Water conservation technologies	Ghana	342	Multinomial endogenous switching regression
Manda et al. (2016)	Residual retention, Maize-legume rotation, and improved maize	Zambia	800	Multinomial endogenous switching regression
Amondo et al. (2019)	Drought tolerant maize varieties	Zambia	1100	Multinomial endogenous switching regression
Marennya et al. (2020)	Soil conservation, fertilizer and maize legume rotation	Ethiopia	1624	Multinomial endogenous switching regression
Geffersa et al. (2022)	Improved maize varieties	Ethiopia	1886	Triple Hurder approach
Khonje et al. (2015)	Zero Tillage	Zambia	810	Propensity score matching and endogenous switching regression models
Ahmed et al. (2022)	Improved maize varieties and manure	Ethiopia	355	Multinomial endogenous switching regression
Oduniyi & Chagwiza (2022)	Sustainable land management practices	South Africa	250	Multinomial endogenous switching regression
Gebremariam & Wünscher (2016)	Sustainable Agricultural Practices	Ghana	421	Multinomial endogenous switching regression

Theoretical framework

This study notes that previous studies on adoption of SAPs have settled their theoretical bedrocks on the utility maximization theory. The study further builds on that by considering household income and yield in a utility framework such that a household (i) maximizes utility subject to resource constraints while producing maize for home consumption and sale, a household derives utility from the returns of land allocated for SAPs. It assumed that a household adopts SAPs if the expected utility from adopting is higher than the utility form dis-adopting. Following Feder et al. (1985), The return from land were assumed to be a function of the SAPs used.

Table 2: Adoption studies, theories used for assessing adoption, and the impacts of sustainable agricultural practices.

Authors	Theory	Agricultural Country	Sector and Practice
Blythe et al. (2017)	Diffusion of innovation	Aquaculture Solomon Island	Aquaculture innovation
Goldberger et al. (2015)	Diffusion of innovation	Crop farming (organic) United States	Biological control
Vidogbena et al. (2016)	Diffusion of innovation	Crop farming (Cabbage) Benin	Pest control/management
McCarthy & Schurmann (2015)	Diffusion of innovation	Horticulture and crop farming Australia	Sustainable farming practices
Ndah et al. (2018)	Qualitative expert Assessment Tool for CA adoption	Crop farming Zambia	Conservation Agriculture (minimum tillage, permanent soil cover, crop rotation)
Zeweld et al. (2017)	Decomposed Theory of planned behavior	Crop farming Ethiopia	Sustainable agricultural practices (minimum tillage and row planting practices)
Márquez-García et al. (2018)	Theory of planned behavior	Viticulture Chile	Sustainable agriculture practices, private land conservation and
Martin et al. (2015)	Neo-institutional theory	Palm oil cultivation Malaysia	Sustainable palm oil cultivation
Borremans et al. (2018)	Agricultural Innovation System (AIS)	Agro-forestry (tree and crop combinations)	Agro forestry (combination of trees crops and /or livestock)

Table Cont'd

Brown et al. (2018a)	Livelihood Platforms Approach	Mixed crop rotations (maize/legumes) Ethiopia, Uganda, Kenya, Malawi, Zambia & Mozambique	Conservation Agriculture
Blesh & Wolf (2014)	Socio-ecological approach (Modified resource-based)	Mixed crop farming (Grain/legume) and livestock United States	Agro ecological management practices (crop rotation and mixed crops. MIRG livestock production)
Lemken et al. (2017) and Ngigi et al. (2018)	Trans-theoretical model (TTM)	Crop farming Germany	Mixed cropping (grain, cereal and legumes)
Ngigi et al. (2018)	Means End Chain analysis approach. Schwartz theory of basic values.	Crop farming Kenya	Climate smart Agricultural strategies (improved crop varieties; crop diversification, water conservation, soil conservation)
Tapsuwan et al. (2015)	Walker's (2002) causes of non-adoption	Crop farming (citrus) Spain	Use of decision support tool (bulletin) for irrigation practices
Tajeri moghadam et al.	Health belief model	Crop farming Iran	Water conservation
Manda et al. (2016)	Utility theory	Crop farming Zambia	Sustainable agriculture practices
Bongole et al. (2021)	Utility theory	Crop farming Tanzania	Climate Smart Agriculture
Wordofa et al. (2021)	Utility theory	Crop farming Ethiopia	Improved Agriculture Technologies
Kassie et al. (2013)	Utility theory	Crop farming Tanzania	Sustainable Agriculture practices
Setsofia et al. (2022)	Utility theory and Adoption Theory	Crop farming Ghana	Sustainable Agriculture Practices

The framework for generic utility is as follows:

$$U_{ij} = V_{ij} + \varepsilon_{ij}$$

Where: U_{ij} is the i^{th} farmers' highest expected utility derived from choosing alternative j , V_{ij} is the systematic utility (deterministic part) that would be maximized, X_{ij} denotes a vector of individual practices and ε_{ij} represents the random error term $j = 1, \dots, j$ and $k = 1, \dots, k$ are the alternatives being considered. It is assumed that the farmer will select a bundle of SAPs or individual practices within other alternatives based on the highest level of utility (yield and income).

Increasing maize yield is expected to enhance household income by allowing to sell surplus maize. In addition, the increased usage of SAPs could indirectly affect household income in three main ways. Firstly, by releasing land for or taking land away from production of other food crops. Second, via livestock production through the increased supply of straw for livestock feed. Third, through the effect on household energy and construction, enhanced maize production would save cash spent on fuel and constructions. If farmers used SAPs successfully (over the years), it is expected that the resulting increase in income could be capitalized to an accumulation of household assets and raise their household income status above the poverty line, (Marenya et al., 2020). The increase in household income would in turn translate to consumption expenditure. Thus, it was hypothesized a positive relationship between the adoption of SAPs, income, and yield.

Selection of the model

Smallholder farmers make decisions to adopt bundled SAPs in response to external shocks such as drought, erosion, perceived decline in soil fertility, weeds, pests, and diseases, maximize yield and thus income. Both observed factors (e.g., age, gender, education and farm size) and unobserved factors (e.g., farmers' innate abilities and motivations) may affect their decisions when choosing to adopt a single SAP or a package (Ehiakpor et al., 2021; Kassie et al., 2013; Manda et al., 2016; Teklewold et al., 2013). Due to the self-selection nature of technology adoption, farmers not adopting any SAPs and those adopting a single SAP or package may be systematically different.

The results in a selection bias issue, which should be addressed for consistently estimating the effects of SAP adoption. When technology adoption has more than two options, previous studies have used either the multi-valued treatment effects (MVT) model (Cattaneo 2010; Ma et al., 2021; Czyzewski et al., 2022) or the multinomial endogenous switching regression (MESR) model (Ahmed, 2022; Kassie et al., 2015; Oparinde 2021) to address the selection bias issues. Because of the non-parametric nature, the MVT model can only address the observed selection bias and does not account for unobserved section bias. In comparison, the MESR

model can help mitigate selection bias issues arising from both observed and unobserved factors, and thus, it was employed in this study.

Research and Methodology

Data for this study originated from a survey of 470 sample households and 662 maize plots conducted in 2017/2018 cropping seasons in Morogoro region. The survey was conducted by funded by the Australian International Food Security Research Centre (AIFSRC) and administered by the Australian Centre for International Agricultural Research (ACIAR). The International Maize and Wheat Improvement Center (CIMMYT) directed and oversaw the initiative in collaboration with universities and research institutions in five African nations (Ethiopia, Kenya, Tanzania, Malawi, and Mozambique).

A survey questionnaire was prepared and administered by trained enumerators who collected data from households through personal interviews and observations. The survey was conducted in two districts (i.e., Kilosa and Mvomero), which were targeted as the major maize and legume growing areas. The first phase of the sampling procedure (Multistage) based on their potential for maize-legume cultivation. Each district received an identical number of sample households. The distribution of households within each district was proportional to the number of households in that district (proportional sampling). An entirely proportional random sampling technique was used to select 5–13 wards in each district, 1–4 villages in each ward, and 20–30 farm households in each village from each district. Although the sample may not be representative of Tanzania as a whole, it is representative of the main maize-legume farming systems in the country.

Apart from household level data (e.g., age and education of the household head, size of the household), the survey also collected plot level data which includes the distance of the plot from the homestead, land tenure, size of the plot, soil fertility, access to markets, access to extension services. Data on crop yields, household income, and on the use of SAPs such as maize–legume rotation, residue retention, intercropping, manure, and use of improved maize varieties were collected. Total household income includes income from crops, livestock and livestock products, and off-farm income (e.g., salaries, remittances, farm labour wage income, and income from business). This provides a reliable indicator of economic well-being among smallholder farmers (Smale & Mason, 2014). Yield is defined as the total amount of maize in kgs harvested per hectare of land planted to maize in the growing season.

Econometric Framework

Agricultural technologies are usually introduced in packages that include several components. These components may complement each other, or may be adopted independently (Feder *et al.*, 1985). In most cases, farmers adopt a combination of technologies to deal with a whole range of agricultural production constraints including low crop productivity. A model developed by Feder (1982) presents one of the first attempts to deal with interrelations in the adoption of multiple agricultural technologies such as SAPs.

The focus is on the impact of adopting SAPs (crop rotation, improved varieties, residue retention, intercropping and manure) to the yield and income in the following possibilities: (i) No adoption; (ii) maize–legume rotation only; (iii) improved maize varieties only; (iv) residue retention only; (v) manure only, (vi) intercropping only (vi) Intercropping and improved seeds (vii) intercropping and crop rotation (viii) Intercropping and manure, (ix) intercropping and crop residual. (x) Improved seeds and crop rotation (xi) improved seeds and manure (xii) improved seeds and crop residual (xiii) crop rotation and manure, (xiv) crop rotation and redial retention (xv) Manure and crop residual, (xvi) intercropping and improved seeds, (xvii) manure and crop residual (xviii) crop rotation, intercropping, manure, crop residual and improved maize varieties.

We presume that the farmer chooses the SAPs combination that maximizes utility subject to land availability, labor, input costs and other farm and income constraints and information. In this case, we assume that farmers aim to maximize their utility V_{ij} by comparing the utility provided by alternative varieties. A farmer “i” will therefore choose any practice “j”, over any alternative practice. To effectively assess impact of SAPs in a joint framework, we adopt a multinomial endogenous treatments effect model proposed by Deb and Trivedi (2006b). Adoption decisions are modeled in a mixed multinomial logit selection model in the first stage and in the second stage, OLS is used with selectivity correction to estimate the impacts of SAPs on maize yields and household income. In addition, we exploit plot-level information to deal with the issue of farmers’ unobservable characteristics that are likely to affect our results. In recent studies, plot level data have been used to construct a panel and to control for farm-specific effects (Di Falco & Veronesi, 2018). Therefore, the multinomial endogenous treatment effects model consists of two stages that was used.

In the first stage of the model, a farmer chooses one of the five (5) SAPs bundles mentioned above. Following Deb and Trivedi (2006a, b), let V_{ij} denote the indirect utility associated with the j^{th} SAP bundle, $j = 0, 1, 2, \dots, J$ for household i :

$$V_{ij}^* = z_i' \alpha_j + \sum_{k=1}^J \delta_{jk} l_{ik} + n_{ij}$$

Where z_i' are a vector of household, social capital, and plot-level covariates; α_j is the vector of corresponding parameters to be estimated; n_{ij} are the independently and identically distributed error terms; l_{ik} is the latent factor that incorporates the unobserved characteristics common to the household’s adoption of bundled SAPs and outcomes (maize yields), such as the management and

technical abilities of the farmers in understanding new technologies, and the transaction costs incurred as a result of poor access to input markets because of infrastructural constraints (Abdulai & Huffman, 2014).

Following Deb and Trivedi (2006b), let $J = 0$ denote non-adopters and $V=1$ denote the adopters, while V_{ij}^* is not observed, we observe the choice of SAP bundle in the form of a set of binary variables d_j and these are collected by a vector, $d_i = d_{i1}, d_{i2}, \dots, d_{iJ}$. Similarly, let $l_i = l_{i1}, l_{i2}, \dots, l_{iJ}$.

Then the probability of treatment can be written as:

$$\Pr (d_i | z_i, l_i) = g \left(z_i' \alpha_1 + \sum_{k=1}^J \delta_{1k} l_{ik} + z_i' \alpha_2 + \sum_{k=1}^J \delta_{2k} l_{ik} + \dots + z_i' \alpha_J + \sum_{k=1}^J \delta_{Jk} l_{ik} \right)$$

Where g is an appropriate multinomial probability distribution. Following Deb and Trivedi (2006b), we posit that g has a mixed multinomial logit (MMNL) structure defined as:

$$\Pr (d_i | z_i, l_i) = \frac{\exp(z_i' \alpha_j + \delta_j l_{ij})}{1 + \sum_{k=1}^J \exp (z_i' \alpha_k + \delta_k l_{ik})}$$

In the second stage, we assess the impact of adopting the bundled SAP bundle on two outcome variables: the natural logarithm of maize yields and total household income per capita. The expected outcome equation is formulated as:

$$E(y_i | d_i, x_i, l_i) = x_i' \beta + \sum_{j=1}^J \gamma_j d_{ij} + \sum_{j=1}^J \lambda_j l_{ij}.$$

In this equation, y_i is the welfare outcome for household i ; x_i represents exogenous covariates with parameter vectors β . Parameters γ_j denote the treatment effects relative to the non-adopters. Specifically, coefficients γ_j gauge the effects of bundled SAPs on the welfare of farm households. If the decision to adopt bundled SAPs is endogenous, assuming d_{ij} to be exogenous results in inconsistent estimates of γ_j . Since $E(y_i | d_i, x_i, l_i)$ is a function of the latent factors l_{ij} , the outcome is affected by unobserved characteristics that also affect selection into treatment. When k_j , the factor-loading parameter, is positive (negative), treatment and outcome are positively (negatively) correlated through unobserved characteristics; i.e., there is positive (negative) selection, with γ_j and λ_j the associated parameter vectors, respectively. Since the outcome variables are continuous, we assume that they follow a normal (Gaussian) distribution function. The resulting model will be estimated using a Maximum Simulated Likelihood (MSL) approach.

Findings and Discussions

The analysis delves into the estimation of average treatment effects (ATE) concerning SAPs and their implications for maize yields and household incomes. To facilitate meaningful comparisons, the study examines these outcome variables under two distinct assumptions: exogenous and endogenous adoption decisions regarding SAPs as measures of yield and income.

Table 2: Multinomial endogenous treatment effects model estimates of SAPs impact on maize yields and household income

Package (<i>Exogenous</i>)	Ln maize per yield	Ln household income per capital
Crop residuals	26% (0.14) *	25% (0.18)
Maize-legume rotation	36% (0.14) **	48% (0.18) **
Improved maize varieties	38% (0.13) ***	26% (0.16)
Maize-legume Intercropping	58% (0.14) ***	62% (0.18) ***
Manure use	43% (0.17) **	-12% (0.22)
Maize-legume rotation and crop residual	58% (0.27) **	58% (0.27) **
Improved maize varieties and crop residual	46% (0.16) ***	46% (0.16) ***
Intercropping and crop residual	67% (0.29) ***	39% (0.35)
Manure and crop residual	43% (0.17) **	-12% (0.22)
Maize-legume rotation and Manure	-6% (0.18)	29% (0.27)
Improved maize and Manure use	58% (0.14) ***	62% (0.18) ***
Intercropping and Manure use	17% (0.22)	46% (0.27) *
Maize-legume rotation, intercropping, improved maize and manure use	80% (0.17) ***	43% (0.24) *
Maize rotation and improved maize	17% (0.22)	46% (0.27) *
Maize rotation and intercropping	57% (0.20) ***	75% (0.24) ***
Maize rotation, improved maize, Crop residual and Intercropping	33% (0.23)	69% (0.31) **

Intercropping and improved seeds	30% (0.23)	33% (0.23)
Improved maize, intercropping, manure, crop residual, and crop rotation.	51% (0.20) ***	38% (0.24) ***
Package (Endogenous)	Ln maize per yield	Ln household income per capital
Crop residuals	30% (0.14) *	25% (0.18)
Maize-legume rotation	38% (0.14)	48% (0.18) **
Improved maize varieties	85% (0.18) ***	65% (0.16) **
Maize-legume Intercropping	58% (0.14) ***	48% (0.18) ***
Manure use	43% (0.17) **	17% (0.22)
Maize-legume rotation and crop residual	49% (0.27) **	50% (0.27) **
Improved maize and crop residual	46% (0.16) ***	46% (0.16) ***
Intercropping and crop residual	65% (0.29) ***	39% (0.35)
Manure and crop residual	44% (0.17)	17% (0.22)
Maize-legume rotation and Manure	6% (0.18)	17% (0.27)
Improved maize and Manure use	58% (0.14) ***	70% (0.18) ***
Intercropping and Manure use	17% (0.22)	46% (0.27)
Maize-legume rotation, intercropping, improved maize and manure use	80% (0.17) ***	43% (0.24) *
Maize rotation and improved maize	52% (0.22)	46% (0.27) *
Maize rotation and intercropping	57% (0.20) ***	68% (0.24) ***
Maize rotation, improved maize, Crop residual and intercropping	33% (0.23)	41% (0.31) **
Intercropping and improved seeds	55% (0.23)	47% (0.23)
Improved maize, intercropping, manure, crop residual, and crop rotation.	74% (0.20) ***	55% (0.24) ***
Package (Selection term)	Ln maize per yield	Ln household income per capital
Crop residuals	0.19 (0.11) *	0.43 (0.15)
Maize-legume rotation	0.51 (0.15)	0.27 (0.11)
Improved maize varieties	0.43 (0.12)	0.47 (0.20)
Maize-legume Intercropping	-0.22 (0.24)	-0.51 (0.19) *
Manure use	0.64 (0.1)	0.23 (0.10)
Maize-legume rotation and crop residual	0.37 (0.13)	-0.33 (0.13)
Improved maize and crop residual	-0.10 (0.10)	0.27 (0.17)
Intercropping and crop residual	0.12 (0.18) *	-0.18 (0.25)
Manure and crop residual	-0.29 (0.12) *	0.11 (0.10)
Maize-legume rotation and Manure	0.18 (0.09)	-0.10 (0.18)
Improved maize and Manure use	0.23 (0.12)	0.51 (0.21)
Intercropping and Manure use	-0.25 (0.19)	-0.22 (0.24) **
Maize-legume rotation, intercropping, improved maize and manure use	0.24 (0.29)	0.37 (0.13) *
Maize rotation and improved maize	0.21 (0.14)	0.43 (0.12) **
Maize rotation and intercropping	-0.11 (0.10)	0.12 (0.10) *
Maize rotation, improved maize, Crop residual and Intercropping	0.16 (0.17)	-0.29 (0.14)
Intercropping and improved seeds	-0.19 (0.13)	-0.20 (0.16)
Improved maize, intercropping, manure, crop residual, and crop rotation.	-0.17 (0.31) *	0.23 (0.18)

Notes: The baseline is farm households that did not adopt any SAP. Sample size is 690 plots and 470 households and 300 simulation draws were used. *** $P < 0.01$, ** $P < 0.05$, * $P < 0.1$. Robust standard errors in parentheses. Fixed effects at plot level are included.

Under the premises of exogenous SAP adoption, the findings reveal that, on average, adopters of bundled SAPs experience significantly higher maize yields (most of the packages reported a contribution of over 45%) compared to non-adopters. Most notably,

these results exhibit positive and statistically significant impacts across various SAP packages. Consistent to the findings of Setsoafia et al. (2022) who found that combination of sustainable agriculture practices had significant impacts on income and food security among smallholder farmers in Ghana. Furthermore, the findings suggests that when adoption decisions are considered external to other factors, SAPs packages tend to have a favorable influence on crop yields and, consequently, household incomes.

Moreover, the study acknowledges the potential limitations of drawing causal inferences solely based on the assumption of exogenous SAP adoption. This approach overlooks the influence of unobservable confounding variables that may skew the results. To address this concern, the analysis introduces a multinomial endogenous treatment effects model to control for unobserved heterogeneity.

Upon accounting for these unobservable factors, the study uncovers several noteworthy findings. Most notably, the adoption of multiple SAPs such as (crop rotation and crop residual), (intercropping and crop residual), (improved maize and manure), (crop rotation, intercropping), (improved maize and manure use), (maize rotation and intercropping), and (maize rotation and improved maize) exhibits a robust and positive impacts on maize yields and household income compared to the adoption of individual SAP components. Interestingly, this holds true except for the adoption of improved maize and intercropping, which surprisingly outperforms the more comprehensive SAP package comprising five practices. This finding corroborates with (Manda et al., 2016; Setsoafia et al., 2022; Wordofa et al., 2021), who contended that improved technologies such as improved maize varieties had significant impacts on the household income due to their high yield attributes.

Furthermore, the findings in Table 2 highlight the presence of negative selection bias in the factors leading to SAPs adoption, indicating that unobservable characteristics that increase the likelihood of SAP adoption are associated with lower welfare levels than would be expected under random assignment. Conversely, positive selection bias is evident in the income equation, suggesting that unobserved variables that increase the likelihood of adopting the five SAPs are associated with higher income levels.

In the context of applying multiple SAPs, such as crop rotation, retention of crop residues, in conjunction with enhanced maize varieties, there was an observed average augmentation in maize crop yield of approximately 67% among adopters. The extent of these yield enhancements appears somewhat below the initial projections, as it was anticipated that the incorporation of improved maize varieties would result in more substantial gains in production. The observed discrepancy in yield gains may potentially be ascribed to various factors such as the presence of pest and disease within agricultural settings, which could significantly limit the expected outcomes from adopting the aforementioned SAPs. Similarly, Zewerd et al. (2020), found that the presence of pests and diseases in farms had significant negative impacts on the yield in Ethiopia.

Additionally, adopting a comprehensive package consisting of all five SAPs resulted in a 74% yield increase. Notably, there was no significant effect on maize yields when applying maize-legume rotation in isolation, consistent with previous findings of Jalli (2021), who found that crop rotation had insignificant contribution when applied under certain climatic and farm conditions. Comparing these results with those obtained under the exogeneity assumption, it becomes apparent that controlling for unobservable characteristics leads to generally higher estimates. This implies that neglecting to account for endogeneity could underestimate the true impact of SAP adoption on yields and income.

The findings in Table 2 show that, on average, adopters of multiple SAPs reported substantially higher incomes, ranging from 41% to 75%. The SAPs package comprising of improved maize and manure exhibited the most significant income effect. Maize-legume rotation, when combined with improved maize varieties, significantly contributed to the household income by 70%. Surprisingly, adopting all five SAPs as a package had lower income impacts compared to SAP packages involving improved maize combined with either maize-legume rotation or residue retention, suggesting that adopting a more comprehensive SAP package may not necessarily guarantee higher income, echoing similar findings by (Manda et al., 2016) who argued that more extensive agricultural practices do not consistently translate into greater net revenues. The observed outcomes could also be ascribed to the financial aspect of maize production. Under ceteris paribus, each additional agricultural practice introduces a notable increment in both production expenses and revenue, as indicated by the marginal rate of return. The production expenses associated with SAPs could potentially have diminishing effects on the expected income. Furthermore, psychological factors could play a role, where farmers' perceptions, beliefs, and motivations may hinder their willingness to fully invest in the comprehensive adoption process. Consequently, this partial commitment could result in reduced crop yields and overall income.

Furthermore, it was found that combination of improved maize and crop residual significantly increased maize yield by 46%, while intercropping with crop residual (65%), improved maize seeds with manure use (58%), and maize rotation with intercropping (57%). The model estimates indicate that individual elements of SAPs increased yield by crop residual (30%), crop rotation (38%), improved maize varieties (85%), intercropping (58%), and manure (43%). Low contribution of crop residual and manure to the yield could be attributed by their improper use by smallholder farmers. For example, using lower than recommended amounts or application of low-quality manures hence, fail to achieve the maximum potential output expected. The findings are in line with those by Du et al., (2020), who reported that manure application had significant impacts on the farm yield in China.

Application of bundled SAPs had significant impacts on the household income via the following combinations; maize-legume rotation and crop residual (50%), improved maize and crop residual (46%), improved maize and manure (70%), maize rotation and improved maize (46%), maize rotation and intercropping (68%), maize rotation, improved maize, crop residual, and intercropping (41%), and lastly improved maize, intercropping, manure, crop residual, and crop rotation (55%).

The model estimates show that adoption of all five SAPs had positive and significant impact on yield and household incomes. The magnitude of the impact of adopting all five SAPs is larger than that of adopting a single or two SAPs. Specifically, the application of improved maize, intercropping, manure, crop residuals, and crop rotation increased the yield and household income by 74% and 55%, respectively. The findings are supported by previous studies such as Tekleword et al. (2013b) in pointing out that the adoption of multiple SAPs has larger impacts on welfare measures than adopting only a few SAPs but contrary to Manda et al. (2016) who argued that the adoption of all elements in the package doesn't guarantee maximum yield or incomes. The reasoning behind the argument centers on unobserved variables, such as management skills and other socioeconomic factors, which may have an impact on the outcome variables.

Conclusions

The findings reveal that SAPs adopted in combination or as a package are more effective than those adopted in isolation except for the improved seeds. The adoption of the package that includes improved maize only and the bundle consisting of improved maize and residue retention resulted in the highest yield and income effects, respectively. Similarly, adoption of a comprehensive package of all the SAPs provides the second highest increase in yield. Although improved maize seeds resulted in the highest benefits in smallholder farmer's welfare, it entails the use of manures, which may be expensive for most small-scale farmers. The findings support relatively inexpensive soil enhancing practices such as the combination of residual, crop rotation with improved maize varieties could significantly increase maize yields and incomes of smallholder farmers in Morogoro region.

In the wake of the ever-increasing cost of external input such as fertilizer, there is need for policy makers and researchers to look for cheaper methods of increasing yield and incomes for small-scale farmers. For instance, the utilization of SAPs such as manure or crop residues as alternatives to chemical fertilizers may face hindrances. Farmers might refrain from employing these practices due to factors such as limited awareness regarding their benefits, resource constraints, or prevailing government policies that prioritize and incentivize the use of chemical fertilizers.

Policy Implications

The impact estimates highlight the fact that a more comprehensive package would not always result in greater benefits than less comprehensive packages. Consistent with the knowledge intensive nature of most of the SAPs, the results suggest that information dissemination should be one of the strategies to improve the adoption of SAPs among smallholder maize farmers. Moreover, removal of barriers to information would greatly help in encouraging adoption of SAPs. It is also important for the actors involved in the design, promotion and dissemination of SAPs to find a suitable mix or combination of these practices that will enhance maize productivity and incomes, while simultaneously addressing issues related to the dis-adoption of SAPs, and climate change, by raising awareness and educating to farmers about the benefits of using SAPs and implementing mitigative measures for climate change. This includes providing of financial incentives such as loans and subsidies, as well as conducting policy reforms to evaluate and adjust policies that currently favor the use of conventional practices in Tanzania.

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Reference

- Abdulai, A., Huffman, W. (2014). The adoption and impact of soil and water conservation technology: an endogenous switching regression application. *Land Econ*, 90, 26–43
- Abro, Z.A., Debela B.L., Kassie, M. (2019). The joint impact of improved maize seeds on productivity and efficiency: implications for policy. Global Food Discussion Paper 128, University of Goettingen. <http://www.uni-goettingen.de/de/213486.html>.
- Adegbeye, M.J., Reddy, P.K., Obaisi, I. (2020). Sustainable agriculture options for production, greenhouse gasses and pollution alleviation, and nutrient recycling in emerging and transitional nations—an overview. *J Clean Prod*, 242, 118–319
- Adenle, A.A., Wedig, K., Azadi, H. (2019). Sustainable agriculture and food security in Africa: the role of innovative technologies and international organizations. *Technol Soc*, 58,101143
- Agula, C., Akudugu, M.A., Dittoh, S., Mabe, FN. (2018). Promoting sustainable agriculture in Africa through ecosystem-based farm management practices: evidence from Ghana. *Agric Food Secur*, 7(5)
- Ahmed, M.H. (2022). Impact of improved seed and inorganic fertilizer on maize yield and welfare: evidence from Eastern Ethiopia. *J Agric Food Res*, 7, 100266. <https://doi.org/10.1016/j.jafr.2021.100266>

- Amondo, E., Simtowe, F., Rahut, D.B., Erenstein, O. (2019). Productivity and production risk effects of adopting drought-tolerant maize varieties in Zambia. *Int J Clim Chang Strateg Manag*, 11, 570–591. <https://doi.org/10.1108/IJCCSM-03-2018-0024>
- Anang, B. T. (2019). Are adopters of improved rice varieties more productive than non-adopters? Empirical evidence from northern Ghana. *Ghana Journal of Development Studies*, 16 (1), 92–107.
- Bekele, R.D., Mirzabaev, A., Mekonnen, D. (2021). Adoption of multiple sustainable land management practices among irrigator rural farm households of Ethiopia. *L Degrad Dev*, 32, 5052–5068. <https://doi.org/10.1002/ldr.4091>
- Blesh, J., Wolf, S.A. (2014). Transitions to agroecological farming systems in the Mississippi River Basin: Toward an integrated socioecological analysis. *Agric. Hum. Values*, 31, 621–635.
- Blythe, J., Sulu, R., Harohau, D., Weeks, R., Schwarz, A.M., Mills, D., Phillips, M. (2017). Social dynamics shaping the diffusion of sustainable aquaculture innovations in the Solomon Islands. *Sustainability*, 9, 126.
- Bongole, A. (2021). Climate Smart Agricultural Practices and Food Security: A case of Mbeya and Songwe regions in Tanzania. Doctoral thesis. Sokoine University of Agriculture.
- Borremans, L., Marchand, F., Visser, M., Wauters, E. (2018). Nurturing agroforestry systems in Flanders: Analysis from an agricultural innovation systems perspective. *Agric. Syst*, 162, 205–219. CrossRef
- Brown, B., Nuberg, I., Llewellyn, R. (2018). Constraints to the utilization of conservation agriculture in Africa as perceived by agricultural extension service providers. *Land Use Policy*, 73, 331–340.
- Brown, B., Nuberg, I., Llewellyn, R. (2018). Further participatory adaptation is required for community leaders to champion conservation agriculture in Africa. *Int. J. Agric. Sustain*, 16, 286–296.
- Cattaneo, M.D. (2010). Efficient semiparametric estimation of multi-valued treatment effects under ignorability. *J Econom*, 155, 138–154. <https://doi.org/10.1016/j.jeconom.2009.09.023>
- Czyżewski, B., Poleyn, J., Brelik, A. (2022). Political orientations, economic policies, and environmental quality: multi-valued treatment effects analysis with spatial spillovers in country districts of Poland. *Environ Sci Policy*, 128:1–13. <https://doi.org/10.1016/j.envsci.2021.11.001>
- Deb, P., & Trivedi, P. K. (2006). Specification and simulated likelihood estimation of a non-normal treatment-outcome model with selection: Application to health care utilization. *The Econometrics Journal*, 9(2), 307–331. doi:10.1111/j.1368-423x.2006.00187.x
- Delgado, D., Jorge, J., Groffman, P., Nearing, M., Goddard, T., Reicosky, D.C., Lal, R., Kitchen, N., Rice, C., Towery, D. & Salon, P. (2011). Conservation practices to mitigate and adapt to climate change. *J. Soil Water Conserv*, 118A-126A.
- Di Falco, S., Feri, F., Pin, P., & Vollenweider, X. (2018). Ties that bind: Network redistributive pressure and economic decisions in village economies. *Journal of Development Economics* 131, 123–131. <https://doi.org/10.1016/j.jdeveco.2017.12.001>
- Ehiakpor, D.S., Danso-Abbeam, G., Mubashiru, Y. (2021). Adoption of interrelated sustainable agricultural practices among smallholder farmers in Ghana. *Land use policy*, 101, 105142
- FAO. (2015). The state of food security in the world. *Food and Agriculture Organization of the United Nations*.
- FAO. (2016). Methods for estimating comparable rates of food insecurity experienced by adults throughout the world. *Food and Agriculture Organization*. <https://www.fao.org/3/c-i4830e.pdf>.
- FAO. (2022). Leveraging automation in agriculture for transforming agrifood systems. Rome, FAO
- Farooq, M., & Siddique, K. (2015). Conservation Agriculture: Concepts, Brief History, and Impacts on Agricultural Systems. 10.1007/978-3-319-11620-4_1.
- Feder, G. (1982). Adoption of interrelated agricultural innovations: Complementarity and the impacts of risk, scale, and credit. *American Journal of Agricultural Economics*, 64(1), 94–101.
- Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, 33 (2), 255–298.
- Fu, B., Ling, C., Hongying, H., Ping, Qu & Zhenggui, W. (2021) Impacts of crop residues on soil health: a review, *Environmental Pollutants and Bioavailability*, 33,1, 164-173, DOI: 10.1080/26395940.2021.1948354
- Gebremariam, G., Wünscher, T. (2016). Combining sustainable agricultural practices pays off: evidence on welfare effects from Northern Ghana. *African Association of Agricultural Economists (AAAE)*
- Goldberger, J.R., Jones, R.E., Miles, C.A., Wallace, R.W. (2015). Inglis, D.A. Barriers and bridges to the adoption of biodegradable plastic mulches for US specialty crop production. *Renew. Agric. Food Syst*, 30, 143–153.
- Goldberger, J.R., Jones, R.E., Miles, C.A., Wallace, R.W., Inglis, D.A. (2015). Barriers and bridges to the adoption of biodegradable plastic mulches for US specialty crop production. *Renew. Agric. Food Syst*. 30, 143–153.
- Jalli, M., Huusela, E., Jalli, H., Kauppi, K., Niemi, M., Himanen, S. & Jauhiainen, L. (2021). Effects of Crop Rotation on Spring Wheat Yield and Pest Occurrence in Different Tillage Systems: A Multi-Year Experiment in Finnish Growing Conditions. *Front. Sustain. Food Syst*, 5, 647335. doi: 10.3389/fsufs.2021.647335
- Kassie, M., Jaleta, M., Shiferaw, B. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: evidence from rural Tanzania. *Technol Forecast Soc Change*, 80, 525–540. <https://doi.org/10.1016/j.techfore.2012.08.007>
- Kassie, M., Khonje, M., Manda, J., & Alene, A. D. (2015). Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World Development*, 66, 695–70
- Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of Adoption and Impacts of Improved Maize Varieties in Eastern Zambia. *World Development*, 66, 695–706. doi: 10.1016/j.worlddev.2014.09.00

- Kimathi, S.M., Ayuya, O.I., Mutai, B. (2021). Adoption of climate-resilient potato varieties under partial population exposure and its determinants: Case of smallholder farmers in Meru County, Kenya. *Cogent Food Agric*, 7, 66. <https://doi.org/10.1080/23311932.2020.1860185>
- Krishna, V. V., & Veettil, P. C. (2014). Productivity and efficiency impacts of conservation tillage in northwest Indo-Gangetic Plains. *Agricultural Systems*, 127, 126–138. doi: 10.1016/j.agry.2014.02.004
- Lemken, D., Spiller, A., von Meyer-Höfer, M. (2017). The case of legume-cereal crop mixtures in modern agriculture and the transtheoretical model of gradual adoption. *Ecol. Econ*, 137, 20–28.
- Ma, W., Wang, X. (2020). Internet use, sustainable agricultural practices and rural incomes: evidence from China. *Aust J Agric Resour Econ*, 64, 1087–1112. <https://doi.org/10.1111/1467-8489.12390>
- Manda, J., Alene, A. D., Tufa, A. H., Abdoulaye, T., Wossen, T., Chikoye, D., & Manyong, V. (2019). The poverty impacts of improved cowpea varieties in Nigeria: A counterfactual analysis. *World Development*, 122, 261–271. doi: 10.1016/j.worlddev.2019.05.027
- Manda, J., Alene, AD., Gardebroy, C. (2016) Adoption and impacts of sustainable agricultural practices on maize yields and incomes: evidence from rural Zambia. *J Agric Econ*, 67,130–153. <https://doi.org/10.1111/1477-9552.12127>
- Manda, J., Gardebroy, C., Kuntashula, E., & Alene, A. D. (2018). Impact of improved maize varieties on food security in Eastern Zambia: A doubly robust analysis. *Review of Development Economics*, 22(4), 1709-1728. <https://doi.org/10.1111/rode.1251>
- Marenya, P.P., Gebremariam, G., Jaleta, M., Rahut, DB. (2020). Sustainable intensification among smallholder maize farmers in Ethiopia: adoption and impacts under rainfall and unobserved heterogeneity. *Food Policy*, 95,101941. <https://doi.org/10.1016/j.foodpol.2020.101941>
- Márquez-García, M., Jacobson, S.K., Barbosa, O. (2018). Wine with a bouquet of biodiversity: Assessing agricultural adoption of conservation practices in Chile. *Environ. Conserv*, 34–42.
- Martin, S., Rieple, A., Chang, J., Boniface, B., Ahmed, A. (2015) Small farmers and sustainability: Institutional barriers to investment and innovation in the Malaysian palm oil industry in Sabah. *J. Rural Stud*, 40, 46–58.
- Martin, S., Rieple, A., Chang, J., Boniface, B., Ahmed, A. (2015). Small farmers and sustainability: Institutional barriers to investment and innovation in the Malaysian palm oil industry in Sabah. *J. Rural Stud*, 40, 46–58.
- McCarthy, B., Schurmann, A. (2015) Sustainable horticulture in North Queensland: Resistance to the adoption of innovations? *J. New Bus Ideas Trends* 13, 15–38.
- Merga, G., Million S., Fresenbet, Z. (2023). Welfare impact of improved maize varieties adoption among smallholder farmers in Amuru district of Horo Guduru Wollega, Ethiopia, *Cogent Economics & Finance*, 11, 1, 10.1080/23322039.2023.2207923,
- Moghadam, M.T., Raheli, H., Zarifian, S., Yazdanpanah, M. (2020). The power of the health belief model (HBM) to predict water demand management: A case study of farmers' water conservation in Iran. *J. Environ. Manag*, 263, 110388.
- Moghadam, M.T., Raheli, H., Zarifian, S., Yazdanpanah, M. (2020). The power of the health belief model (HBM) to predict water demand management: A case study of farmers' water conservation in Iran. *J. Environ. Manag*, 263, 110388.
- Ndah, H.T., Schuler, J., Diehl, K., Bateki, C., Sieber, S., Knierim, A. (2018) From dogmatic views on conservation agriculture adoption in Zambia towards adapting to context. *Int. J. Agric. Sustain*, 16, 228–242.
- Ndiritu, S.W., Kassie, M., Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49, 117–127. <https://doi.org/10.1016/j.foodpol.2014.06.010>
- Ngigi, M.W., Muller, U., Birner, R. (2018). Farmers' intrinsic values for adopting climate-smart practices in Kenya: Empirical evidence from a means-end chain analysis. *Clim. Dev*, 10, 614–624.
- Ochieng, J., Afari-Sefa, V., Muthoni, F., Kansime, M., Hoeschle-Zeledon, I., Bekunda, M., & Thomas, D. (2021). Adoption of sustainable agricultural technologies for vegetable production in rural Tanzania: trade-offs, complementarities and diffusion. *International Journal of Agricultural Sustainability*, 20, 1-19. 10.1080/14735903.2021.1943235.
- Oduniyi, O. S., Chagwiza, C. (2021). Impact of adoption of sustainable land management practices on food security of smallholder farmers in Mpumalanga province of South Africa. *GeoJournal*. <https://doi.org/10.1007/s10708-021-10497-0>
- Ogemah, V.K. (2017). Sustainable agriculture: Developing a common understanding for modernization of agriculture in Africa. *Afr J Food Agric Nutr Dev*, 17, 11673–11690. <https://doi.org/10.18697/ajfand.77.16560>
- Ojo, T.O., Ogundeji, A.A., Belle, J.A. (2021). Climate change perception and impact of on-farm demonstration on intensity of adoption of adaptation strategies among smallholder farmers in South Africa. *Technol Forecast Soc Change*, 172,121031. <https://doi.org/10.1016/j.techfore.2021.121031>
- Olson, J.C., Reynolds, T.J. (2018). The means-end approach to understanding consumer decision making. In *Understanding Consumer Decision Making: The Means-End Approach to Marketing and Advertising Strategy*, Reynolds, T.J., Olson, J.C., Eds., Lawrence Erlbaum Associates: Mahwah, NJ, USA, pp. 145–162.
- Onyeneke, R.U. (2021) Does climate change adaptation lead to increased productivity of rice production? Lessons from Ebonyi State, Nigeria. *Renew Agric Food Syst*, 36,54–68. <https://doi.org/10.1017/S1742170519000486>
- Oparinde, L.O. (2021). Fish farmers' welfare and climate change adaptation strategies in southwest, Nigeria: application of multinomial endogenous switching regression model. *Aquac Econ Manag*, 25,450–471. <https://doi.org/10.1080/13657305.2021.1893863>
- Rayne, N., Aula, L. (2020) Livestock Manure and the Impacts on Soil Health: A Review. *Soil Systems*. 4(4), 64. <https://doi.org/10.3390/soilsystems4040064>

- Rose, D.C., Sutherland, W.J., Barnes, A.P. (2019). Integrated farm management for sustainable agriculture: lessons for knowledge exchange and policy. *Land Use Policy*, 81, 834–842. <https://doi.org/10.1016/j.landusepol.2018.11.001>
- Setsoafia, E., Ma, W., & Renwick, Alan. (2022). Effects of sustainable agricultural practices on farm income and food security in northern Ghana. *Agricultural and Food Economics*, 10. 10.1186/s40100-022-00216-9.
- Smale, M., & Mason, N. (2014). "Hybrid Seed and the Economic Well-Being of Smallholder Maize Farmers in Zambia," *Journal of Development Studies*, 50(5), 680-695.
- Tapsuwan, S., Hunink, J., Alcon, F., Mertens-Palomares, A.N., Baille, A. (2015). Assessing the design of a model-based irrigation advisory bulletin: The importance of end-user participation. *Irrig. Drain*, 64, 228–240.
- Teklewold, H., Kassie, M., Shiferaw, B., Köhlin, G. (2013b). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: impacts on household income, agrochemical use and demand for labor. *Ecol Econ*, 93, 85–93. <https://doi.org/10.1016/j.ecolecon.2013.05.002>
- Thinda, K.T., Ogundej, A.A., Belle, JA., Ojo, T.O. (2021). Determinants of relevant constraints inhibiting farmers' adoption of climate change adaptation strategies in South Africa. *J Asian Afr Stud*, 56, 610–627. <https://doi.org/10.1177/0021909620934836>
- Tlou, E., Mogale, K.K. Ayisi, L. M., Yehenev G., Kifle, K.E. (2023) "Understanding the Impact of the Intercropping System on Carbon Dioxide (CO₂) Emissions and Soil Carbon Stocks in Limpopo Province, South Africa" *International Journal of Agronomy*, 15, <https://doi.org/10.1155/2023/6307673>
- URT (2019). Ministry of agriculture national food security bulletin. Dodoma, Tanzania.
- Usman, Z. K., Oluseyi, O., & Rafiat, O. (2021). Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria. *International Soil and Water Conservation Research*, 9(2), 241-248.
- Vandermeer, J, H. (1989). The ecology of intercropping. New York: Cambridge University Press <http://www.loc.gov/catdir/toc/cam026/87033830.html>
- Vidogbena, F., Adegbidi, A., Tossou, R., Assogba-Komlan, F., Martin, T., Ngouajio, M., Simon, S., Parrot, L., Garnett, S.T., Zander, K.K. (2016). Exploring factors that shape small-scale farmers' opinions on the adoption of eco-friendly nets for vegetable production. *Environ. Dev. Sustain*, 18, 1749–1770.
- Wordofa, M.G., Hassen, J.Y., Endris, G.S. (2021). Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. *Agric & Food Secur*, 10, 5. <https://doi.org/10.1186/s40066-020-00278-2>
- Yang, Q., Zhu, Y., Liu, L., Wang, F. (2022). Land tenure stability and adoption intensity of sustainable agricultural practices in banana production in China. *J Clean Prod*, 338, 130553. <https://doi.org/10.1016/j.jclepro.2022.130553>
- Zeweld, W., Van Huylenbroeck, G., Tesfay, G. (2020). Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: empirical evidence from Northern Ethiopia. *Land Use Policy*, 95, 103799. <https://doi.org/10.1016/j.landusepol.2019.01.002>
- Zeweld, W., van Huylenbroeck, G., Tesfay, G., Speelman, S. (2017). Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *J. Environ. Manag*, 187, 71–81.
- Zheng, H., Ma, W., Li, G. (2021). Learning from neighboring farmers: Does spatial dependence affect adoption of drought tolerant wheat varieties in China? *J Agric Econ Can D'agroeconomie*, 69, 519–537. <https://doi.org/10.1111/cjag.12294>
- Zhou, X., Ma, W., Li, G. (2018). Draft animals, farm machines and sustainable agricultural production: insight from China. *Sustainability*, 10, 3015. <https://doi.org/10.3390/su10093015>

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