Determinants of Adoption of Bundled Sustainable Agriculture Practices among Small-Scale Maize Farmers in Mvomero and Kilosa Districts, Tanzania

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Abstract

The study, using data set from the adoption pathway survey and utility maximization theory examined the determinants of adoption of bundled sustainable agriculture practices (SAPs) among smallholder maize farmers in Tanzania. The SAPs considered include crop rotation, intercropping, manure, improved seeds, and crop residual. Using the Multivariate probit model, data collected from 470 farming households from Kilosa and Mvomero districts through a multi-stage sampling procedure were analyzed. Before data analysis, validity and reliability tests were performed and deemed satisfactory. The empirical results show that age, gender, family size, education level, farm size, livestock ownership, access to extension services, production shocks, and distance from the market had a significant impact on the adoption of multiple SAPs. In addition, the results show that six pairwise correlation coefficients among SAPs were statistically significant, implying that smallholder maize farmers adopt SAPs concurrently. These findings implore policymakers and agricultural development organizations to take these significant factors into account when planning, advocating for, and supporting the adoption of multiple SAPs. Furthermore, the simultaneous adoption of SAPs necessitates that each of the practices be viewed as a package that contributes to the expansion of farmer's options and the maximization of synergistic effects between them. Thus, agricultural policymakers should focus on enhancing smallholder farmers' household characteristics by reviewing agriculture policies with the inclusion of extension services to come up with a package that is tailored to the perceived actual needs of farming households and designing farm management usage programme based on the farmer's household characteristics.

Keywords: Sustainable agriculture practices; Multiple adoptions; multi-variate probit model; Utility theory; Tanzania

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1.0 Introduction

Introduction Increased global population, rising food prices, and diminishing food production resources are all critical factors that necessitate the development of innovative and sustainable food production practices if food security is to be enhanced. The world's population is projected to reach 9.1 billion by 2050 (up from 8 billion in 2022), with a projected increase in food production, primarily in staple crops, for the 821 million people who still face chronic food insecurity (WHO, 2018). Concurrently, agricultural productivity must be increased, particularly in developing nations, while minimizing environmental damage. According to WFP (2018), to meet the rising global food demand by 2050, agricultural production must increase by 60% from its current level. The implication is that an increase in agricultural production, particularly of staple crops, is required to meet the projected food demand. It is also a fact that over 60% of global agricultural production is done by small-scale farmers (FAO, 2016). In this understanding, policymakers and scholars have consistently advocated for the facilitation and encouragement of smallholder farmers to adopt sustainable agricultural practices (SAPs) as a way to sustainably increase food production. (Kassie *et al.*, 2015; Selejio and Lasway, 2019; Tessema *et al.*, 2018; Tsinigo and Behrman, 2017).

The escalating issue of food insecurity in poor nations; the unprecedented rise in food prices on a global scale; soil erosion and fertility loss; and biodiversity depletion, all of which create spiraling difficulties in sustaining natural resources, are additional factors that have led to the consideration of adopting SAPs. Keeping in mind the difficulties posed by climate change and the drawbacks of conventional agriculture. Multiple risks impact agricultural production in East Africa, compelling smallholder farmers to adopt multiple SAPs to mitigate production-related risks (Kassie, 2017). A typical smallholder farmer is required to adopt SAPs based on rational consideration of their attributes. Consequently, the adoption of a specific SAP can be used concurrently with or independently of another practice. For instance, the vast majority of improved seed varieties are promoted in a package that includes fertilizer, irrigation, and pesticides. It is crucial to account for the independence of SAPs across multiple adoptions in order to avoid underestimating or overestimating the determining factors.

One of the most important food and cash crops in Tanzania is maize, which is produced extensively within the nation. The crop occupies roughly 26% of arable land, more than 70% of cereal planted area, and is cultivated by more than 65% of agricultural households (URT, 2017). Smallholder farmers account for 85% of the crop's total production in the country (URT, 2017), emphasizing the significance of both the maize crop and smallholder farmers to the overall performance of the agriculture sector in Tanzania. Nevertheless, according to the Tanzania National Bureau of Statistics (2019), the overall production in the maize sector of the economy had increased by 4% annually due to the expansion of cultivated areas, despite a 2.7% decrease in productivity. This suggests a negative correlation between maize production and productivity at the farm level. Notably, one of the primary causes of low maize productivity in the majority of African countries is the low adoption rate of sustainable practices, which reduces incomes and contributes to food insecurity and poverty among smallholder farming households (Kassie *et al.*, 2015; Lasway *et al.*, 2020).

Previous adoption studies have mainly focused on the measurement of small-scale farmers' adoption choice of a single agricultural technology or practice, including the use of improved seeds and crop rotation manure (Ghimirea *et al.*, 2015; Lasway *et al.*, 2019; Lyimo *et al.*, 2014; Mwalupaso *et al.*, 2019; Nchinda *et al.*, 2020; Shiferaw and Tesfaye, 2006; Simtowe *et al.*, 2016). Ignoring the fact that they can be adopted in combinations as complements or substitutes. The previous studies gave recommendations for single technology adoption, yet maize production is faced with a myriad of challenges. There is still a gap in regard to what influences the adoption of multiple technologies by smallholder maize farmers. Furthermore, the adoption of multiple SAPs by households in African countries has currently received consideration, but empirical evidence is still inadequate, particularly in the Tanzanian context (Beyene *et al*., 2017; Di Faclo *et al*., 2022; Lasway *et al*., 2019). In addition, if the interdependence of various SAPs is not taken into account, the effects of an exogenous decision on the use of SAPs by farming households may be under or overestimated (Bongole, 2021). Nevertheless, the adoption of multiple SAPs by farming households in Tanzania in response to socioeconomic, institutional, and geographical factors in maize production is insufficiently documented.

Consequently, it is essential to conduct a study on the modeling of adoption decisions across multiple SAPs. Adoption studies (Bongole, 2021; Bybee-Finley and Ryan, 2018; Di Falco *et al*., 2010) have documented the significance of good agriculture practices (GAP) in enhancing soil structure and productivity. This has influenced the selection of SAPs. Understanding the barriers and enabling conditions for the adoption of SAPs will aid in the designing and formulation of strategies and agricultural policies that can be used to accelerate SAP dissemination and help protect agricultural production and food security in Tanzania.

The study makes the following contributions: First, given that SAPs are hardly widely adopted by smallholder farmers in developing countries, the drivers of adoption identified in this study, if paid attention to, will help address farmers' adoption challenges thereby helping to increase their yields and incomes. Given that maize is one of the major staple foods, amongst other welfare benefits, this will contribute to ensuring food and nutrition security and, for that matter, contribute to meeting the Africa Union's Agenda 2063 as well as achieving the sustainable development goals on poverty and zero hunger. Finally, the findings from the study are relevant to policymakers, maize scientists such as CIMMYT and TARI, and extension personnel who may consider the findings as a mechanism for improving agricultural productivity in Tanzania.

The remainder of this study is organized as follows. Section 2 reviews the literature on Sustainable Agriculture Practices. Whereas section 3 presents methodology, section presents and discusses the estimated results. Section 5 concludes.

2. Literature Review

2.1 Concept of Sustainable Agriculture Practices (SAPs)

The major attributes of sustainable agriculture practices as put forward by the Food and Agriculture Organization (FAO) are: (1) they are resource-conserving; (2) they are environmentally friendly, (3) technically appropriate, (4) economically acceptable, and (5) socially justifiable. A sustainable agriculture practice is defined as "an agricultural system that aims to eliminate or reduce the use of environmentally harmful agricultural practices." The concept of sustainable agriculture accords equal weight to the significant economic, social, and environmental issues that the agricultural sector must address. Today, the majority of societal issues are interconnected, global, and evolving rapidly; consequently, sustainable agriculture offers effective solutions to establish and strengthen a secure agriculture, food system, and safe energy for a healthy and sustainable future.

2.2 Theoretical framework

In this paper, the adoption of SAPs by small-scale maize farmers to enhance productivity is grounded in the theory of utility maximization. This theory assumes that decision-makers, in this case, small-scale farmers, choose between practice bundles by comparing their expected utility values. This indicates that a small-scale farmer will adopt a specific agricultural practice (SAP) when the expected utility of adopting that practice is greater than that of adopting another practice. Thus, a small-scale farmer selects a method that maximizes the expected utility. For example, a small-scale farmer ($i = 1,2, 3..., n$) decides whether or not to adopt some or all of the available productivity-enhancing technologies (j), i.e. ($j = 1,2, 3..., j_n$).

The expected utility of a small-scale farmer is presented by the equation $U = (j_i, K)$; at which j_i signifies agricultural practice bundle, and K represents the small-scale maize farmer's socio-economic factors such as access to extension services, credit accessibility, education, age, and livestock ownership. Previous studies may have obscured the reality faced by decision-makers who are often faced with technology/practice alternatives that may be adopted simultaneously and/or sequentially as complements, substitutes, or supplements. Multiple SAP adoption analysis is possible when other agricultural practices are adopted exogenously. However, when multiple SAPs adoption decisions are considered in conjunction with other decisions, the approach may underestimate or overestimate the influence of various factors on the adoption decisions.

The above point suggests that the number of SAPs adopted may not be independent, but path-dependent: the choice of SAPs adopted by farmers more recently may be partially reliant on their earlier technology decisions. Several empirical studies, such as Teklewold *et al.* (2017), assume that farmers evaluate a set (or bundle) of possible practices and select the practice bundle that maximizes expected utility. Thus, the adoption decision is inherently multivariate, and attempting univariate modelling excludes economically relevant information contained in interdependent and simultaneous adoption decisions.

2.3 Empirical Literature on studies related to the adoption of SAPs.

The issues depicted in Table 1 regarding the adoption of agricultural technologies have been the subject of prior research. However, none of these studies have investigated the adoption of SAPs as a package of five practices in maize production, particularly in Tanzania. As efforts continue to scale up the adoption of SAPs in Tanzania and Africa, it is crucial to comprehend how complex factors, such as household characteristics, influence the adoption of SAPs in diverse contexts. The study was conducted in two districts of the Morogoro region (Kilosa and Mvomero), each of which has a different predominant agro-ecological zone.

Table 1: Summary of the empirical studies related to the adoption of Sustainable practices worldwide

Authors	**Country**	**Practice**	**Sample Size**	**Theory/assumption**	**Statistical model**	**Significant/ goodness fit**
Timprasert *et al.* (2014)	Thailand	IPM	220	Utility maximization	Logit	R^2=0.554
McNamara (1991)	United States	IPM	376	Diffusion of innovation	Logit	R^2=0.764
Blake *et al.* (2007)	United States	IPM	217	Profit maximization	Stepwise regression model	R^2=0.655
Moser *et al.* (2008)	Israel, Italy and Germany	IPM	106	Utility maximization	Logit	R^2=0.230
Hashemi and Damalas (2010)	Iran	IPM	90	Utility maximization	Logit	R^2=0.337
Kassie *et al.* (2013)	Tanzania	Soil conservation	681	Rational choice theory/Utility maximization	Multivariate probit	X^2=249.51
D'Souza *et al.* (1993)	United States	Soil conservation	600	Utility maximization	Logit	R^2=0.10
Teckleword (2013)	Ethiopia	Soil conservation	898	Utility maximization	Multivariate and ordered probit	X^2=119.553
Mbaga-semugalawe and Folmer (2000)	Tanzania	Soil conservation	300	Profit maximization and sociological decision	Logit	R^2=0.40
Bekele and Drake (2003)	Ethiopia	Soil conservation	145	Utility maximizing	Multinomial logit	X^2=277.2
Wauters *et al.* (2013)	Belgium	Soil conservation	160	Theory of planned behaviour	Logit	R^2=0.538
Marenya and Barrett (2007)	Kenya	Soil conservation	123	Random Utility	Multivariate probit	R^2=0.25
Voh 1982	Nigeria	Soil conservation	541	Behavior theory	Stepwise regression	R^2=36.61
Wollin and Anderson (2014)	Honduras	Organic farming	241	Spatial dependence	Probit	X^2=229.17
Mzoughi (2011)	France	Organic farming	243	Moral social theory	Multinomial probit	R^2=0.17
Thapa and Rattanasuteerakul (2011)	Thailand	Organic farming	172	Diffusion of innovation	Linear and logistic regression	Correction prediction=83%
Lappal and Kelley (2013)	Ireland	Organic farming	546	Utility maximization and behavioral theory	Multinomial logit	Correction prediction=65%
Parra-lopez *et al.*(2007)	Spain	Organic farming	322	Diffusion of innovation	Logit	R^2=0.89
Best (2009)	Germany	Organic farming	657	Theory of rational choice	Logit	X^2=129.3
Chatzimichael *et al.* (2014)	Greece and Germany	Organic farming	282	Utility maximization	Logit	R^2=0.5144

Granpat *et al.* (2014)	Trinidad	GAP	196	Farming systems model	Categorical regression	$R^2=76.1$
Mankeb *et al.* (2014)	Thailand	GAP	189	Theory of planned behaviour	Stepwise multiple regression	$R^2=0.557$
Kersting and Wollin (2012)	Thailand	GAP	231	Utility maximization theory	Bivariate probit	Correction prediction=71%
Lemeilleur (2013)	Thailand	GAP	228	Utility maximization	Probit	$R^2=0.450$
Bongole (2021)	Tanzania	CSA	1549	Utility maximization	Multinomial regression model	$X^2=125$
Oyetunde *et al.* (2020)	Nigeria	GAP	2113	Utility maximization theory	Multivariate and ordered model	$R^2=0.062$
Mutaysira *et al.* (2018)	Ethiopia	GAP	600	Theory of planned behaviour	Ordered probit model	$X^2=104$

3.0 Methodology

3.1 Econometric Framework

According to Beyene *et al.* (2017), smallholder farmers can employ agricultural practices singly or in tandem. Teklewold *et al.* (2017) argued that when farmers use or decide to use new practices, they are confronted with alternatives and trade-offs. To assess the determinants of the adoption of multiple SAPs, we rely on the assumption of the interdependence of different SAPs, suggesting that the decision to adopt SAPs is inherently multivariate. Following the studies conducted by (Kassie et al,2017; Teklewold *et al.* 2013) we employed a Multivariate Probit Model (MVP) approach to assess the determinants of the adoption of multiple SAPs at the farm household level. Unlike other dichotomous models, the MVP model can account for unobservable factors that affect farm households' adoption decisions by allowing for correlation across error terms of latent equations (Ndiritu *et al*., 2014). These correlations permit error terms for positive correlation (complementarity) and negative correlation (substitutability) between the various SAPs (Bedeke *et al*., 2019).

This econometric technique simultaneously models the influence of the set of explanatory variables on each of the various practices, allowing the unobserved and/or unmeasured factors (error terms) to be freely correlated. Complementarities (positive correlation) and substitutes (negative correlation) between different practices may be a source of correlation. The observed outcome of bundled SAPs adoption can be modelled using a random utility formulation. Consider the i^th^ farm household ($I=1\ldots I_n$) facing a decision on whether or not to adopt a set of interdependent SAPs on plot p^th^ ($P=1\ldots p_n$).

Let $\boldsymbol{U_0}$ represent the benefits to the farmer from other practices, and let U_k represent the benefit of adopting the k^th^ SAP: where *k* denotes choice of crop rotation (R), Maize legume intercropping (T), improved crop variety (V), Crop residual (C) and manure (M). The farmer decides to adopt the k^th^ SAP on plot p if $Y^*_{ipk} = U_k - U_o > 0$. The net benefit ($Y^*_{ipk}$) that the farmer derives from the adoption of kth SAP is a latent variable determined by observed household, plot, and location characteristics X'_{ip} and the error term.

$$\varepsilon_{ip}: = X'_{ip}\beta_k + \varepsilon_{ip}(k =, T, V, C, M) \qquad (1))$$

Using the indicator function, the unobserved preferences in equation (i) translate into the observed binary outcome equation for each choice as follows:

$$Y_{ipk} = \begin{cases} 1 & \text{if } Y^*_{ipk} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad (k = R, T, V, C, M)$$

In the multivariate model, where the adoption of several bundled SAPs is possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity which is given by:

$$\boldsymbol{\Omega} = \begin{bmatrix} 1 & \rho_{\mathrm{RV}} & \rho_{\mathrm{RF}} & \rho_{\mathrm{RM}} & \rho_{\mathrm{RT}} \\ \rho_{\mathrm{VR}} & 1 & \rho_{\mathrm{VF}} & \rho_{\mathrm{VM}} & \rho_{\mathrm{VT}} \\ \rho_{\mathrm{FR}} & \rho_{\mathrm{FV}} & 1 & \rho_{\mathrm{FM}} & \rho_{\mathrm{FT}} \\ \rho_{\mathrm{MR}} & \rho_{\mathrm{MV}} & \rho_{\mathrm{MF}} & 1 & \rho_{\mathrm{MT}} \\ \rho_{\mathrm{TR}} & \rho_{\mathrm{TV}} & \rho_{\mathrm{TF}} & \rho_{\mathrm{TM}} & 1 \end{bmatrix}$$

In contrast to MVP models, univariate-probit models ignore the potential correlation among the unobserved disturbances in the adoption equations, as well as the relationships between the adoption of different SAPs.

With the mentioned above considered, farmers can use multiple SAPs to generate income, attain food security and reduce poverty. This indicates that decision to use a certain SAP is essentially multivariate, and the use of univariate modelling would eliminate valuable information about the interdependent and simultaneous adoption of these practices (Aryal *et al*., 2018). This is very important because ignoring these interdependencies can lead to inconsistencies in policy recommendations (Beyene *et al*., 2017).

3.2 Data source

This study utilizes data from the Adoption Pathways project, which was funded by the Australian International Food Security Research Centre (AIFSRC) and managed by the Australian Centre for International Agricultural Research (ACIAR). The International Maize and Wheat Improvement Center (CIMMYT) implemented and directed the project in collaboration with five African countries (Ethiopia, Kenya, Tanzania, Malawi, and Mozambique), universities and research institutes.

The project aims to improve food security and break the downward productivity spiral by gaining an understanding of the socioeconomic and agricultural system characteristics that influence technology adoption and adaptation to external factors, such as production risks, in maize-based smallholder farming systems. One of the project's objectives includes: generating evidence on the socio-economic impact of the adoption of multiple and complementary technologies on different groups of farming households using econometric and household economic models; Following our data cleansing procedure (490), we analyzed a total of 470 farming households. Smallholder maize farmers who practised at least one of the five SAPs during the cropping season were required to submit a completed questionnaire for the data to be filtered.

We utilize detailed primary household and plot survey data from 470 farm households and 662 plots in 20 villages from two districts. The survey was conducted via one-on-one interviews with a structured survey questionnaire administered by enumerators with knowledge of the local farming system and language.

In the first phase of the sampling procedure (Multistage), 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). 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 used to capture detailed household, plot and village information on the household’s production activities, plot specific characteristics including SAP adoption, demographic and infrastructure information for each household, and village. For each plot, the respondent recounted the type of SAPs practiced, such as intercropping, crop rotation, crop residual, improved seed varieties and manure during the sample year. Further information was gathered through observations and casual conversation with farmers to probe issues of concern to farmers and also for clarification. The additional data gathered was useful to interpret some of the quantitative data collected from the farmers. The research was carried out in 2017/ 2018 maize cropping season.

As for the production shocks such as, rainfall shock variables derived from respondents' subjective rainfall satisfaction. The individual rainfall index was constructed to measure the farm-specific experience related to rainfall in the preceding three seasons, based on such questions as whether rainfall came and stopped on time, whether there was enough rain at the beginning and during the growing season and whether it rained at harvest time. Five Responses to each of the questions (yes or no) were coded as favorable or unfavorable rainfall outcomes and averaged over the number of questions asked (five questions), so that the best outcome would be equal to 1 and the worst to 0. The data also includes non-rain shocks, such as crop pests, and diseases occurrence within the last five years.

Table 2: Description of Variables Used in the Study

Variable	Description	Hypothesized sign
Age of the household	Age of Household Head in Years	Positive/Negative
Education of the household head	0=If the household is illiterate 1=If the household received a primary education 2=If the household received a secondary education 3=If the household received a university education 4=If the household received a technical education	Positive/Negative
Household size	Number of members in the household	Positive/Negative
Gender of the household head	1= If the household head is a male, 0= if female	Positive/Negative
Farming experience	Number of years of farming (years)	Positive
Farm Characteristics		
Farm size	Total farm size (Acre)	Positive
Soil fertility	1 (if the plot has fertile soil)[1], 0= if otherwise	Positive
Production shocks	1= If the plot has experienced production shock in the last 5 years, 0 = if otherwise	Positive/Negative
Geographical location		
Kilosa	Kilosa District (1= yes; 0 = no)	Positive/Negative
Mvomero	Mvomero District (1= yes; 0 = no)	Positive/Negative
Institutional Characteristics		
Group membership	1 = If the farmer is a member to farmers organization, 0 = Otherwise	Positive
Extension services	1 = if the farmer has access to extension services, 0 = otherwise	Positive
Distance to the market	Distance from farm household to the market (in kilometers)	Negative
Household wealth	Total asset value of major farm equipment and household furniture ('000 TShs)	Positive
Land ownership	1=If the farmer is the owner of the land, 0 = otherwise	Positive
Access to credit	1=If the farmer has access to credit, 0= otherwise	Positive
Livestock ownership	Total livestock herd	Positive/Negative
Food insecurity	Household food insecurity status	Positive

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[1] = Soil fertility is somewhat subjective and region- dependent. Unfortunately details about how fertility was measured and what constitutes fertile soil are infrequently reported.

3.3 Preliminary diagnostics of the variables used in the analysis

Using a white test, the problem of heteroskedasticity for the hypothesized independent variables was examined. The white test was chosen over the Breusch-Pagan test because it incorporates the magnitude and direction of the change for nonlinear forms of heteroskedasticity (Wooldridge, 2010). The results showed that the chi^2 value of 130 was not statistically significant, indicating that there was no heteroskedasticity problem. Accordingly, it was determined that the MVP model should be employed for the analysis.

In addition, tests for statistical issues such as multicollinearity were conducted for each variable included in the model. Wooldridge (2010) defines multicollinearity as the correlation of two or more predictor variables in a regression model. The Variance Inflation Factor (VIF) was employed to examine the multicollinearity issue. VIF analysis revealed that there was no linear relationship between the explanatory continuous variables because VIF values were less than 10. (Where any number above 10 would indicate the existence of multicollinearity). Due to the fact that contingent coefficients were always less than 0.75, it was determined that there was no significant linear relationship between categorical variables used in the model and their results.

4.0 Results and Discussion

4.1 Complementarities and substitutability of SAPs

The simultaneous usage of SAPs shows a likelihood of correlation (interdependence) to and Appendix 3 shows the estimates. The result of the likelihood ratio test (Chi^2 (15) = 63.9175; Prob > chi^2 = 0.000) rejects the null hypothesis of zero covariance of the error terms across the equations.

Significant and positive correlations exist between residue retention and crop rotation, organic manure and crop rotation, intercropping and residue retention, and intercropping and organic manure ($P<0.1$). Additionally, the use of combinations of organic manure and drought-resistant maize seeds is positive and statistically significant ($P<0.05$). This suggests that agricultural households view these SAPs as supplements (i.e., farming households apply these technologies simultaneously).

The explanatory variables were entered into the Multivariate probit model (MVP) to examine the effect of using SAPs either in isolation or in combination. The MVP results (Table 4) show the probability of chi-square where likelihood ratio statistics are highly significant at $p < 0.01$, indicating that the model has strong explanatory power.

4.2 Determinants of the adoption of multiple SAPs

The study applied a multivariate probit regression model to determine the drivers for the adoption of multiple SAPs. In this study, an unordered multivariate probit model is useful because it can take care of categorical dependent variables (such as nominal categories of dependent variables having multiple selections). The model estimates the impact of individual variables on the likelihood of adopting a particular type of SAPs. (Appendix 2)

The probability of adopting intercropping and manure tended to increase among older farmers while the probability of adopting improved seed and manure increased among younger farmers. The differentials in these preferences may be attributable to the capacity of younger farmers to comprehend the application of modern agricultural practices, such as the use of improved maize seeds. These findings are supported by Bedeke *et al.* (2019), who found that younger farmers were more likely to use improved seed varieties because of their high yield attributes. Contrary to Beyene and Kassie (2017), who reported that older farmers were willing to adopt improved maize varieties due to their comparative advantage in terms of capital accumulated, number of extension contacts/visits, creditworthiness, land ownership and experience.

In the case of gender, female-headed households were less likely to adopt improved seeds and intercropping practices whereas male headed households were significantly more likely to adopt crop rotation, improved seeds, and intercropping. In a way, this is suggestive of female farmers' lagging roles in the adoption of SAPs. This could be a result of having multiple roles within the family which could lead to a lack of participation in farmer groups which are essential for providing agricultural information. Further, we ascribe this to a male- dominated hierarchical cultural set up where males tend to benefit more than females (Bolinder et al.2020). This trend is seen in small scale farming systems in other regions in Africa as well, where male headed households are more likely to have more resources to facilitate the adoption of agricultural technologies such as improved seeds than female headed households. Thus, unequal access to resources can hinder women from adopting SAPs. This corroborates with the findings of Agegnehu and Amede (2017).

Household size was significant in driving the adoption of manure and intercropping at ($P< 0.05$). Household size can be a proxy for the labour availability within the household. The application of some of the SAPs such as manure, and intercropping has high labor demand. Thus, the larger households can supply family labor and as a result, they can adopt labour-intensive SAPs such as manure and intercropping. Similarly, Wainaina (2016) found out that the household's size increased the probability of adopting agricultural technologies in Kenya.

Land ownership had a significant influence on the adoption of manure, improved seeds, and crop residual. This form of the relationship (manure and crop residual) suggests that land ownership promotes both soil-conserving and yield-enhancing practices. Further, a title deed is an imperative proxy of security and land rights which are identified as key components that encourage long-term investments on the farm. Therefore, smallholder farmers who have a secure tenure system will have an incentive to invest in SAPs such as manure and crop residual. Consistent with (Adimassu *et al.*, 2016; Bambino, 2018: Nigussie *et al.*, 2017) who reported that land ownership had a positive and significant impact in driving the adoption of manure.

Production shocks had a positive and significant influence on the adoption of the intercropping, improved seeds, and organic manure. This shows that households consider adopting SAPs as a way to protect their farms against common production shocks such as pests, disease attacks, reduced moisture content of the soil, and rainfall shortage. The coefficients of production shocks suggest that farm households are likely to adopt both improved seeds and manure at ($P<0.05$). Another plausible explanation for this could be that households' use improved seed and manure for immediate high-yield impact rather than long-term effect as supported by Manda *et al*. (2017).

Farming households that had access to extension services were more likely to adopt manure, improved seeds, and crop rotation. Extension services are endogenous to the adoption of SAPs, especially in providing awareness and demonstration of agricultural practices. For example, the use of manure and improved seeds requires information on usage and application which may be complex and may not yield the needed result if not followed appropriately as argued by Chalise *et al*. (2019). As such, access to extension services through training, contacting the extension workers, and visiting demonstration sites could be influential in households' decision to adopt multiple SAPs.

Farming households that were located closer to markets were more likely to adopt intercropping and manure, Travel time from plot to residence also influences animal manure which is more common on closer plots. Transporting manure is more difficult to distant plots, compared to chemical fertilizer. Studies from elsewhere have shown a negative relationship between market access and animal manure (Jansen *et al.*, 2006; Pender and Gebremedhin 2007). Similarly, Kassie *et al.* (2011) and Mwalupaso (2019), found a positive association between manure use and plot distance in Ethiopia and Zambia respectively.

The food insecurity status of farming households was significant to SAPs' adoption. Results show that farming households that are prone to food insecurity are likely to adopt intercropping and manure practices at ($P<0.05$). Food-insecure households are more focused on increasing yield using basic land practices (relatively cheap ones such as manure) and common high-yield SAPs such as improved seeds. This collaborates with the findings of Masuka *et al.* (2017), who found a positive relationship between food insecurity status and animal manure.

The level of education of the household head was significant and positively associated with the likelihood of adopting improved seeds ($P<0.05$). Household heads who had attained a higher level of education were more likely to adopt improved seeds than household head who had attained a lower level of education. This underpins the idea that education indicates the capacity to make adoption decisions. Similarly, Gido *et al*. (2015) reported that highly educated individuals tended to be innovative and calculated risks for proper farm adjustments which include the adoption of agricultural technologies.

Livestock ownership measured by Tropical Livestock Unit was significant to the adoption manure and livestock ownership at ($P<0.01$). This indicate that households with high TLU were more likely to adopt manure to a greater extent compared to those with lower TLU. A plausible explanation for this is that livestock such as cattle are a significant source of manure. Therefore, as expected, the adoption of manure is likely to increase as the number of livestock per household increases. Consistent with Usman *et al*. (2021), who found that large number of livestock owned by the farming household was a significant factor in the adoption of organic manure in Ethiopia.

Plot characteristics such as soil characteristics and the farm size were significant to the adoption of (intercropping crop rotation) and (improved seeds, crop residual) at ($P<0.05$ and $P<0.01$) respectively. These practices are more prevalent on larger plots. The results show that crop rotation and crop residual are more likely to be adopted on plots with poor fertile soils, while intercropping is more likely to be adopted on plots with moderately fertile soils. These findings suggest that, for SAPs to be successful, they must address site-specific characteristics, thus the decision to choose and adopt SAP is influenced by the contextual condition of the specific site in addition to other factors.

Adoption also varies by district. The positive coefficient for Mvomero dummies for the adoption of animal manure, crop rotation and improved seeds suggests a higher probability of adoption if a farm household is located in the Mvomero district compared to intercropping and manure practices which are found to be significant among farming households located in Kilosa district.

Access to credit was found to be positive and significant to the probability of adopting improved maize varieties. The result signified the positive role of credit access on the adoption of improved seeds as farmers with access to credit were more likely to invest in improved seeds. Agricultural technologies are capital and labour intensive whereas access to credit alleviates this financial constraint. Accordingly, Usman *et al*. (202) reported that access to credit had a significant and positive effect in explaining farmer's technology adoption initiatives.

5.0 Conclusion and Recommendation

Adoption is a key issue that plays a major role in farming communities. Multivariate probit model was employed and found that age, gender, family size, education level, farm size, livestock ownership, access to extension services, production shocks, access to credit and distance from the market correlated with the adoption of SAPs. Finally, the results show a very strong and robust relationship between variables of gender, age and family size and the adoption of SAPs. Since some of the SAPs are labour intensive, it is not surprising that the adoption is low amongst older people and women who are constrained with labour due to the multiple roles. Generally, Women in a typical farm household in Tanzania have limited access to family labour due to gender related issues. The fact that family size appears to be one of the main underlying factors in determining the adoption then women seem to be affected most.

The following recommendations are suggested to improve the level of adoption of SAPs among small scale maize farmers in the study area. Land market should be well developed by the Government and all key stakeholders to improve access especially for women maize farmers in order to enhance the adoption of SAPs. Similarly, The Ministry of Agriculture should intensify campaign about SAPs as well as provide appropriate training programs for maize farmers to enhance the adoption. Again, since the use of SAPs is both labour and capital intensive, Government through rural financial institutions should provide credit facilities to maize farmers to enhance the adoption of such practices. Furthermore, the youth need to be encouraged to partake in trying improved technologies and best practices. In particular, policies and programme that are geared towards developing, promoting and disseminating SAPs should make a provision for farmers who are less endowed with productive resources by reviewing agriculture policies with the inclusion of extension services to come up with a package that is tailored to the based on the farmer's household characteristics.

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Appendix 1: Definitions of SAPs Used in the Study

	Definition	A practice in which growing more than one crop is grown across time (Teklewold *et al.*, 2019).
Crop rotation	Adaption	Helps in improving soil health, decreasing the occurrence of pests and diseases, improving crop diversification and preventing soils erosion (Teixeira *et al.*,2018)
	Mitigation	According to Teklewold *et al*. (2019) crop rotation decreases the application of nitrogenous fertilizers when leguminous crops are introduced. It also maintains and/or improves soil carbon stocks.
	Productivity	Improvements in farm productivity of pasture, feed and food crops (Teixeira *et al.*,2018)
	Household welfare	Improved income and food security due to improved agricultural productivity Teklewold *et al.*, (2019)
Intercropping	Definition	The act of growing two or more crops per unit of land area simultaneously.
	Adaption	It controls weeds, improves water holding capacity, contributes to reducing crop failure risk increases food availability and dietary diversity (Teklewold *et al.*, 2019).
	Mitigation	Maintains or improves soil carbon stock or organic matter content, and reduces the need for chemical fertilizer (Hassen *et al*., 2017).
	Productivity	According to Teklewold *et al*. (2019), intercropping improves productivity, hence promoting sustainable utilization of resources such as land and water; diversifies income sources.
	Household welfare	Enhanced income and food security due to enhanced productivity (Hassen *et al*., 2017).
Organic Manure	Definition	It is the application of animal wastes on the farm (Teklewold *et al*., 2019).
	Adaption	Improves soil structure and its water-holding capacity with minimum leaching (Khaitov *et al.*, 2019).
	Mitigation	Increases carbon storage in soils, and reduces the need for synthetic fertilizers and related GHG emissions (Khaitov *et al*., 2019).
	Productivity	Increases crop yields and income.
	Household welfare	Improved household income and food security as a result of improved productivity.
Improved Maize Seeds	Definition	Are seeds which can produce at least 1–3 tons/ha after suffering water stress for nearly six weeks (Magorokosho *et al*., 2009)
	Adaption	The seeds can withstand abiotic stress (Masuka *et al.*, 2017).
	Mitigation	This leads to a reduction in emissions due to the lowering of the usage of fuel for irrigation.
	Productivity	Contributes to reductions in production costs, enabling production and yield stability even in the scarcity of water for irrigation (Masuka *et al*., 2017).
	Household welfare	Addressing food security and income (Bellon and Taylor, 1993).
Crop residual	Definition	Is considered to be crop remains which are left in the field after harvest (Bolinder *et al*., 2020).
	Adaption	Enhances soil moisture, fertility and reduces soil erosion (Chalise *et al*., 2019).
	Mitigation	Increases carbon storage in soils, reduces use of synthetic fertilizers and related GHG emissions. (Bolinder *et al*., 2020).
	Productivity	Increases crop yields and income (Bolinder *et al*., 2020).
	Household welfare	Addressing food security and income (Page *et al*., 2019).

Appendix 2: Coefficient estimates of the multivariate probit model

Variables	**Rotation**		**Variety**		**Manure**		**Crop residual**		**Intercropping**	
	Coefficient	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**
Household Characteristics										
Age of the household head	0.026	0.139	0.181**	0.146	0.308*	0.216	-0.159	0.144	0.052**	0.161
Education of the household head	0.001	0.014	0.202**	0.013	-0.480	0.021	-0.006	0.013	-0.023	0.016
Household size	0.015	0.015	0.012	0.014	0.072***	0.026	-0.001	0.012	0.036**	0.017
Gender of the household head	0.005*	0.003	0.001**	0.003	0.003	0.004	-0.004	0.003	0.013***	0.004
Farm Characteristics										
Farm size	0.017	0.010	0.019	0.010	0.006*	0.014	0.019**	0.010	0.005**	0.012
Soil fertility	0.283***	0.097	0.143	0.099	0.073	0.136	-0.157	0.101	0.364***	0.123
Farm distance	-0.034	0.034	-0.001	0.014	0.009	0.029	-0.025	0.018	0.013	0.017
Production shocks	0.172	0.860	1.562**	0.806	7.932***	1.956	-1.248	0.912	3.493***	1.488
Geographical location										
Kilosa	0.192**	0.098	-0.069*	0.082	0.143*	0.128	0.112	0.085	-0.070	0.108
Mvomero	0.035	0.115	0.061	0.100	0.085***	0.127	-0.047	0.098	0.232*	0.134
Institutional Characteristics										
Food insecurity index	0.002	0.005	-0.004	0.003	0.021*	0.108	0.012	0.005	0.002**	0.006
Access to extension services	0.078***	0.102	0.170**	0.092	0.318**	0.166	0.038	0.149	0.023	0.120
Distance to the market	0.081	0.123	0.037	0.125	0.092***	0.179	-0.026	0.119	0.230*	0.137
Land ownership	0.294	0.116	0.075**	0.101	0.087*	0.159	0.010*	0.101	-0.022	0.122
Access to credit	-0.117	0.191	0.430***	0.156	-0.089	0.258	-0.094	0.151	0.020	0.179
Livestock ownership (TLU)	-0.057	0.092	0.253***	0.082	6.973***	0.381	-0.459	0.086	0.009	0.096
Constant	0.104	0.113	0.005	0.106	0.297*	0.168	0.081	0.115	0.199	0.130

*Wald chi square (72) =125.00; Log likelihood=-254.44248; Prob> chi square=0.0001

*, **, and *** indicate statistical significance at $p < 0.1$, $p < 0.05$ and $p < 0.01$ respectively

Appendix 3: Complementarities and substitutability of SAPs: Correlation coefficient of the error term matrix

	Crop rotation	**Improved seeds**	**Residue retention**	**Organic Manure**	**Intercropping**
Crop rotation	1				
Improved seeds	0.0713* (0.0522)	1			
Residue retention	0.204*** (0.0461)	0.032 (0.0401)	1		
Organic Manure	0.181*** (0.0500)	0.113** (0.0410)	0.0244 (0.0415)	1	
Intercropping	0.0597 (0.0511)	-0.0101 (0.0420)	0.110*** (0.0426)	0.128*** (0.0413)	1

The Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = 0: chi2 (15) = 61.1010 Prob > chi2 =0.0000 Standard errors in parentheses