

Sokoine University of Agriculture



PhD Thesis

**Sustainable Agricultural Practices:
Implications on Maize Yields,
Household Incomes, and Food
Security**

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May, 2024

**SUSTAINABLE AGRICULTURAL PRACTICES: IMPLICATIONS
ON MAIZE YIELDS, HOUSEHOLD INCOMES, AND FOOD
SECURITY**

*Thesis Submitted to Sokoine University of Agriculture in
Fulfilment of the Requirements for the Degree of Doctor of
Philosophy*

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EXTENDED ABSTRACT

Sustainable agricultural practices (SAPs) are often promoted as a way to improve sustainable development in agriculture, resulting in subsequent economic growth and development on both national and global scales. The global endorsement of the Sustainable Development Goals (SDGs) has directed attention towards initiatives to expand the utilization of SAPs in developing nations. These countries are facing challenges due to population expansion and increased household incomes, which are negatively impacting the sustainability of natural resources. Nevertheless, the current information is insufficient to clarify the implementation of bundled SAPs comprised of intercropping, crop rotation, manure, improved maize seeds, crop residual practices, and associated impacts on several end measures, such as crop yields, household incomes, and food security among smallholder maize farmers in Tanzania. This argument is driven by an integrative framework that merges the theories of utility maximization with the diffusion of innovation. Consistent with prior research, this approach recognizes adoption as a complex activity by a number of factors. Motivated by this phenomenon, the study examined (a) rate and intensity of adoption of bundled SAPs; (b) determinants of adoption of bundled SAPs; (c) impact of adopting bundled SAPs on yields and household incomes; (d) impact of adopting multiple SAPs on food security, nutrition, and poverty indices among smallholder maize farmers in Morogoro region. The data were collected through household and key informants' interviews. The structured questionnaires were administered to 470 farming households in Kilosa and Mvomero districts in Morogoro region. Data were analyzed using descriptive and quantitative methods.

The multivariate regression analysis was used to analyze the determinants of adoption of multiple SAPs. The results reveal 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 influence on the adoption of multiple SAPs. Moreover, the results demonstrate that there were six significant pairwise correlation coefficients across SAPs, indicating that smallholder maize farmers have the potential to adopt SAPs concurrently. The findings support the study's claim that the adoption of bundled SAPs is significantly influenced by socio-economic and institutions factors.

Ordered probit analysis was employed to analyze the adoption intensity of bundled SAPs. The findings reveal that education level, occupation, farming experience, sex of the household head, farm size, plot ownership, geographical area, participation in farmers' organizations, and production diversity, significantly impacted the degree to which SAPs are adopted. Moreover, there were notable disparities in the degree of adoption intensity in contrast to the adoption rates. The findings are in line with the study's claim that socio-economic factors have significant impact on the number of SAPs adopted.

An analysis utilizing multinomial switching regression to analyze the impact of adopting bundled SAPs on crop yields and household incomes demonstrates that the adoption of multiple SAPs had significant economic impacts on both maize yields and household incomes through various combinations comprised of manure, improved maize varieties, crop residual, intercropping, and crop rotation.

The endogenous switching regression model was employed to assess the impacts of adopting SAPs on food security, nutrition and poverty indices. The findings reveal that the adoption of improved maize varieties, crop residue use, and crop rotation practices had significant and positive impacts on household's food security and nutrition. In addition, the adoption of improved maize varieties had the most significant impact on poverty indicators, highlighting its capacity to mitigate poverty among small-scale farmers.

The study suggests these. Policymakers and agricultural development organizations need to take these significant factors into account when planning, promoting, and enabling the implementation of SAPs. Second, when developing methods to spread the adoption of SAPs, it is crucial to consider the interrelatedness of these SAPs and ascertain an efficient combination of various practices to enhance maize production and household incomes.

Third, increasing awareness, providing education to farmers regarding the advantages of using SAPs, and implementing strategies to alleviate the impacts of climate change. Fourth, the implementation of initiatives aimed at enhancing agriculture production through the adoption of SAPs. These initiatives should implement a targeted approach aimed at reaching food-insecure households and disadvantaged agricultural households, with the goal of eradicating hunger and correcting nutritional deficiencies among these vulnerable populations.

Keywords: *Sustainable agricultural practices (SAPs), Yields, Incomes, Food security, Smallholder maize farmers, Tanzania.*

IKISIRI KUU

Kanuni endelevu za kilimo (SAPs) mara nyingi hukuzwa kama njia ya kuboresha maendeleo endelevu katika kilimo, na kusababisha ukuaji wa uchumi na maendeleo katika viwango vya kitaifa na kimataifa. Uidhinishaji wa kimataifa wa Malengo ya Maendeleo Endelevu (SDGs) umeelekeza umakini kwenye mipango ya kupanua matumizi ya SAPs katika mataifa yanayoendelea. Nchi hizi zinakabiliwa na changamoto kutokana na ongezeko la watu na ongezeko la mapato ya kaya, jambo ambalo linaathiri vibaya uendeleo wa maliasili. Hata hivyo, taarifa za sasa hazitoshi kufafanua utekelezaji wa SAPs na athari zinazohusiana na hatua kadhaa za mwisho, kama vile mavuno ya mazao, mapato ya kaya, na usalama wa chakula miongoni mwa wakulima wadogo wa mahindi nchini Tanzania. Hoja hii inaendeshwa na mfumo shirikishi unaunganisha nadharia za uboreshaji wa matumizi na uenezaji wa uvumbuzi. Sambamba na utafiti wa awali, mbinu hii inatambua kuasili kama shughuli changamano kwa sababu kadhaa. Utafiti ulichunguza (a) kiwango na ukubwa wa kupitishwa kwa SAPs zilizounganishwa; (b) vigezo vya kupitishwa kwa SAPs zilizounganishwa; (c) athari za kutumia SAPs kwenye mazao na mapato ya kaya; (d) athari za kutumia SAPs nyingi kwenye uhakika wa chakula, lishe na fahirisi za umaskini miongoni mwa wakulima wadogo wa mahindi mkoani Morogoro. Takwimu zilikusanywa kupitia mahojiano ya kaya, ya watoa taarifa muhimu. Dodoso hilo lilitolewa kwa sampuli ya kaya 470 za wakulima wadogo wa mahindi katika wilaya za Kilosa na Mvomero mkoani Morogoro. Takwimu zilichambuliwa kwa kutumia njia za maelezo na za kiasi.

Mbinu ya multivariate probit ilitumiwa kuchanganua viashiria vya kupitishwa kwa SAPs zilizounganishwa. Matokeo yanaonyesha kuwa umri, jinsia, ukubwa wa familia, kiwango cha elimu, ukubwa wa shamba, umiliki wa mifugo, upatikanaji wa huduma za ugani, misukosuko ya uzalishaji, na umbali kutoka sokoni, vilikuwa na ushawishi mkubwa katika kupitishwa kwa SAPs nyingi. Zaidi ya hayo, matokeo yanaonyesha kuwa kulikuwa na migawo sita muhimu ya

uwiano wa jozi katika SAPs, ikionyesha kuwa wakulima wadogo wa mahindi wana uwezo wa kutumia SAPs kwa wakati mmoja. Matokeo yanaunga mkono madai ya utafiti kwamba kupitishwa kwa SAPs zilizounganishwa kunaathiriwa kwa kiasi kikubwa na mambo ya kiuchumi ya kijamii na taasisi.

Uchanganuzi wa matokeo kwa mbinu ya ordered probit ulionesha kuwa kiwango cha elimu, kazi, uzoefu wa kilimo, jinsia ya mkuu wa kaya, ukubwa wa shamba, umiliki wa shamba, eneo la kijiografia, ushiriki katika mashirika ya wakulima, na tofauti za uzalishaji, huathiri kwa kiasi kikubwa kiwango ambacho SAPs hupitishwa. Zaidi ya hayo, kulikuwa na tofauti kubwa katika kiwango cha kuasili kinyume na viwango vya kuasili. Matokeo yanawiana na madai ya utafiti kwamba mambo ya kiuchumi ya kijamii yana athari kubwa kwa idadi ya SAPs zilizopitishwa.

Mbinu ya endogenous switching regression ilitumika kuchanganua athari za kutumia SAPs zilizounganishwa kwenye mavuno na mapato ya kaya. Matokeo yanaonesha kuwa kupitishwa kwa SAPs nyingi kuna athari kubwa ya kiuchumi kwa zao la mahindi na mapato ya kaya kupitia michanganyiko mbalimbali inayojumuisha samadi, aina bora za mahindi, mabaki ya mazao, mseto, na mzunguko wa mazao.

Uchanganuzi wa matokeo kwa kutumia mbinu ya endogenous treatment effect katika kutathmini athari za kutumia SAPs kwenye usalama wa chakula, lishe na fahirisi za umaskini, unaonesha kuwa kupitishwa kwa aina bora za mahindi, matumizi ya mabaki ya mazao, na kanuni ya kubadilisha mazao zilikuwa na athari kubwa na chanya katika usalama wa chakula na lishe ya kaya za wakulima wadogo wa mahindi. Kupitishwa kwa aina bora za mahindi kulikuwa na athari kubwa zaidi katika viashiria vya umaskini, ikionyesha uwezo wake wa kukabiliana na umaskini miongoni mwa wakulima wadogo.

Utafiti unapendekeza haya. Watunga sera na mashirika ya maendeleo ya kilimo wanapaswa kuzingatia mambo haya muhimu

wakati wa kupanga, kukuza na kuwezesha utekelezaji wa SAPs. Pili, wakati wa kuandaa mbinu za kueneza upitishwaji wa SAPs, ni muhimu kuzingatia uhusiano kati ya SAPs hizi na kuhakikisha mchanganyiko mzuri wa mbinu mbalimbali ili kuimarisha uzalishaji wa mahindi na mapato ya kaya.

Tatu, kuongeza uelewa, kutoa elimu kwa wakulima kuhusiana na faida za kutumia SAPs, na kutekeleza mikakati ya kupunguza athari za mabadiliko ya tabianchi. Nne, utekelezaji wa mipango inayolenga kuimarisha uzalishaji wa kilimo kupitia kupitishwa kwa SAPs. Juhudi hizi zinapaswa kutekeleza mkabala uliolengwa unaolenga kuzifikia kaya zisizo na uhakika wa chakula na kaya zisizokuwa na uwezo wa kilimo, kwa lengo la kutokomeza njaa na kurekebisha upungufu wa lishe miongoni mwa watu hawa walio katika mazingira magumu.

Maneno muhimu: Kanuni endelevu za kilimo, Mavuno, Mapato, Usalama wa chakula, Wakulima wadogo wa mahindi, Tanzania.

DECLARATION

I, Joseph Jovin Mugula, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work done within the period of registration and that it has neither been submitted nor is being concurrently submitted in any other institution.

Joseph Jovin Mugula
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The above declaration is confirmed by:

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DEDICATION

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LIST OF PUBLISHED PAPERS

- PAPER 1: Mugula, J.J., Ahmad, A.K., Msinde, J., & Kadigi, M. (2023). Determinants of Adoption of Bundled Sustainable Agriculture Practices among Small-Scale Maize Farmers in Mvomero and Kilosa Districts, Tanzania. *African Journal of Economic Review*, 11(4).....34
- PAPER 2: Mugula, J. J., Athman, A. K., Msinde, J., and Kadigi, M. (2023). Adoption Intensity of Bundled Sustainable Agricultural Practices among Small-Scale Maize Growers in Morogoro Region, Tanzania. *East African Journal of Management and Business Studies* 3(1), 37-52.....55
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LIST OF ABBREVIATIONS AND SYMBOLS

ASDP	Agricultural sector development programme
ATT	Average treatment on treated
CA	Conventional Agriculture
CF	Conceptual Framework
CIMMYT	International Maize and Wheat Improvement Center
CP	Conventional Practices
E.g.	For Example
EU	Expected Utility
FAO	Food and Agriculture Organization

FCS	Food Consumption Score
GAPs	Good Agriculture Practice
GDP	Gross Domestic Product
HDD	Household Dietary Diversity
HFIAS	Household Food Insecurity Access Scale
HFS	Household Food Security
MESR	Multinomial Endogenous Switching Regression
MVP	Multivariate Probit Model
OS	Organic Scheme
SA	Sustainable Agriculture
SAPs	Sustainable Agricultural Practice/S
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
SUA	Sokoine University of Agriculture
TARI	Tanzania Agricultural Research Institute
URT	United republic of Tanzania
USAID	United States Agency for International Development
VIF	Variation Inflation Factor
WB	World Bank
WFP	World Food Programme
%	Percentage
<	Less than
>	Greater than

CHAPTER ONE

1.0 General Introduction

This chapter provides the theme for assessing the adoption of multiple sustainable agricultural practices (SAPs), using the Tanzanian agriculture sector as a case study. Though many attempts have been made to understand why the adoption rates of SAPs are low, there remain four research gaps. Responding to these, the objectives of this thesis are to: (1) assess the determinants of the adoption of multiple SAPs; (2) determine the adoption rate and intensity of multiple SAPs; (3) assess the impact of adopting SAPs on the crop yields and household incomes of smallholder maize farmers; and (4) examine the relative impacts of the adoption of SAPs on food security, nutrition and poverty. The outcomes will produce an improved understanding of farm-level adoptive behavior and impacts of adopting SAPs on the mentioned outcome variables, thereby providing refined policy guidance for augmenting the adoption of SAPs among smallholder maize farmers in Tanzania.

1.1 Background Information

Enhancing agricultural sustainability stands as one of the primary objectives of the global development agenda (FAO, 2022). Even though current agricultural practices are said to have a major impact on reducing poverty and ensuring food security, some of them are seen as unsustainable. For instance, producing a single crop over time on the same plot of land is known as monocropping, and it is an economically advantageous technique (Ali *et al.*, 2021). However, it lowers the quality of the soil and makes crops more susceptible to insect and disease outbreaks. Consequently, monocropping may increase reliance on synthetic pesticides and fertilizers in the long run, even though it may be productive in the short term (Ali *et al.*, 2021). These non-renewable inputs have negative externalities when used excessively, aggressively, or incorrectly; they are intended for crop protection and plant growth. The overuse of synthetic fertilizers alters the pH, humus, topsoil and soil's capacity to retain water.

It also prevents plants' ability to absorb nutrients essential for human health from reaching their root systems (Rajani, 2019).

These deteriorations exacerbate issues with food security, nutrition, and compaction, as well as soil erosion. Synthetic insecticides applied incorrectly can cause pest resistance to break down and attract new pests (Sudo *et al.*, 2018). Consequently, the management of pests and illnesses requires more treatments or the development of new pesticides, thereby increasing the danger to farmer health and food safety globally (Thakur *et al.*, 2021).

According to the prior discussion, conventional farming methods and other unsustainable agricultural practices are deemed problematic (Sumberg & Ginner, 2022). They lower crop and soil quality and jeopardize farmer health at the farm level. Farm productivity suffers when these parameters are significantly impacted (Antle & Pingali, 1994). Significant expenditures on the environment and health care are associated with food contamination and water pollution at the off-farm level, respectively (Apergis *et al.*, 2020). Food security and poverty challenges are further entwined with these problems. Consequently, a strong argument is made in favor of achieving sustainable agricultural development.

Globally, the necessity of sustainable agricultural development is now on everyone's national and international agenda (FAO, 2022). "The management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations" is what defines sustainable agricultural development according to FAO (1995). Additionally, it has sparked plans that emphasize how productive exploitation in both developed and developing nations should be balanced with environmental wellness. Relevant policies are working to shift farmer behavior in that direction by encouraging smallholder farmers worldwide to adopt SAPs.

1.2 Sustainable Agricultural Practices (SAPs)

According to FAO (1995), SAPs are socially and technically acceptable, resource-conserving, environmentally non-degrading, and economically feasible. SAPs are typically focused on the economical use of natural resources.

Reducing dependence on artificial inputs, reduces externalities related to the environment and society. The implementation of conservation tillage, cover crops, mulches, organic fertilizers, and composts enhances crop yield partly by preventing soil erosion and retaining more organic matter (Chan & Praty 1998; Seitz *et al.*, 2019). Crop protection is improved by the use of intercropping, crop rotation, and integrated pest management (IPM) in part due to the disruption of pest cycles and decreased frequency of pest outbreaks (Richard *et al.*, 2022). These are but a few instances of how SAPs are perceived to provide a range of advantages while also encouraging environmental and productivity gains.

SAPs have been promoted with consideration for the unique environments of the various nations or areas. For instance, the European Conservation Agriculture Federation has branded conservation tillage, cover crops and mulches, and crop rotation as "conservation agriculture" in response to the problem of soil degradation in Europe (Baumgart-Getz *et al.*, 2012). These conservation methods address general production-based sustainability issues and are referred to as "best management practices". Other sustainable methods include intercropping, organic fertilizers and composts, IPM, precision technologies, and waste-nutrient and water-related systems (Adnan *et al.*, 2018). In that broad sense, Tanzania, for example, has benefited from the promotion of these practices as SAPs under the Agriculture sector Development Program (ADP) of the Sustainability in Action project.

1.3 Current State of Sustainable Agricultural Practices Globally

SAP adoption rates are low in both developed and developing countries (Tey *et al.*, 2017). Developed nations are at the forefront of

the structural advancement of SAPs. The Australian adoption trend has been described as slow in many regions (Pierer, 2021), and other European countries have not seen more than 10% of their farmland being cultivated using SAPs (FAO, 2022). In contrast, it has been reported that the U.S. best management practices have been used in a limited fashion (Baumgart-Getz *et al.*, 2012; Reimer *et al.*, 2012). Developing nations have not seen a widespread adoption of SAPs.

The promotion of SAPs has not been particularly successful in African nations (Usman, 2021). Although a small number of developing nations have experienced somewhat better development, their advancement is still insufficient. Researchers in Iran (Asadi *et al.*, 2017), Pakistan (Wareem *et al.*, 2020), Zambia (Nkomoki *et al.*, 2018), and Tanzania (Ochieng *et al.*, 2021) have made similar observations, despite the lack of official statistics for African nations.

In light of this, the adoption rates of SAPs that have been recorded do not adequately justify the billions of dollars and shillings as well as the substantial effort that has been invested in highlighting their advantages. Disappointed, policymakers have begged for an understanding of the phenomenon (Pannell *et al.*, 2006; Wordofa, 2021). The possibility of a deeper comprehension of farmer behavior, which influences SAPs adoption decisions and the impacts of using these practices, is what spurs this thesis. Opportunities to expand SAPs adoption in Tanzania will be highlighted through the use of the agriculture industry as a case study. This will have significant ramifications for other nations, particularly developing ones.

1.4 Sustainability Issues in the Tanzanian Agriculture Sector

Soil erosion and climate change pose the biggest threats to sustainability in Tanzania's agricultural industry (Shirima *et al.*, 2018). The majority of staple farms use open farming techniques (Chapman *et al.*, 2021). They clean soil and perform earthwork as part of their field preparation. Farmlands' exposed soils make them vulnerable to erosion. Additionally, farmlands see two to three cropping cycles per year due to their extensive use (URT, 2018).

Farmlands are instantly ready for the following cropping cycle following the previous cycle. Soil erosion is exacerbated by this intensive use of farmlands. The interception of rain-shelters, land slopes, and excessive rainfall are other elements that contribute to soil erosion. A significant obstacle to sustainability is the adverse consequences of intensive farming practices employed in Tanzania's agricultural industry (Mkonda, 2021). Due to the commercialization of the cultivation of staple crops, synthetic pesticides, herbicides, and fertilizers are now required to maintain agricultural yields.

Local farmers always struggle to decide what kinds, how often, and how much of inorganic fertilizers, insecticides, and herbicides to use for soil management, crop protection, and weed control, respectively (Chapman *et al.*, 2021). As a result, these inputs are frequently used improperly.

The two sustainability problems that were previously discussed have had some very detrimental consequences. Soil erosion reduces the fertility of the soil (Chapman *et al.*, 2021). Irrigation systems become sluggish due to cumulative soil erosion. Synthetic fertilizers, pesticides, and herbicides have contaminated soil and river systems (Barrow *et al.*, 2010). These occurrences frequently function as catalysts for the adoption of different unsustainable production techniques. Farmers that use them excessively run the possibility of health problems from residue contamination on fresh food, which also endangers the health of consumers (Ssemugabo *et al.*, 2022). There are more externalities connected to unsustainable production methods in exchange for productivity, although these are only a few instances. Corrective action is essential since it is evident that unsustainable production practices have detrimental externalities that seriously affect the sustainability of agriculture.

1.5 Promotion of Sustainable Farming Methods within Tanzania's Agricultural Industry

The Tanzanian agriculture industry has made a concentrated effort to support sustainable development in response to a number of

externalities. In agriculture and development initiatives, sustainability has been outlined as a roadmap to advance sustainability in the near future. Versatile SAPs, such as conservation tillage, intercropping, cover crops/mulches, crop rotation, organic fertilizers/composts, and integrated pest management, form the cornerstone of the pertinent agricultural policy measures. Together with additional standards, these SAPs are also being promoted in Tanzania through the Good Agricultural Practices Scheme (GAPs) and the Organic Scheme (OS). Since adopting these SAPs is voluntary, smallholder maize farmers are free to decide whether to do so or not.

By employing locally available natural resources more effectively, the recommended SAPs seek to offset the effects of exogenous inputs (such as machinery, artificial fertilizers, artificial insecticides, and so on) (Luo *et al.*, 2016). Benefits include managing biological interactions, protecting crops and the environment (primarily through genetic resource diversification and organic matter management), and improving soil (especially by managing soil biotic activity and organic matter). These characteristics indicate that these SAPs do not jeopardize environmental health or productivity. However, because of the complexity of their use, they do necessitate better use of farm management strategies (Lee, 2005; Luo *et al.*, 2016). For example, choosing specific crop species from a range of alternatives, assessing their relative agronomic and economic advantages, determining the best crop species combinations and rotations, scheduling the use of labor inputs and their timing, and adjusting marketing strategies are just a few of the management decisions involved in intercropping and crop rotation. Similar labor, skill, and knowledge requirements apply to other SAPs.

Tanzanian smallholder farmers have not embraced SAPs in large numbers thus far (Bongole *et al.*, 2021). A lower adoption rate for crop rotation, conservation tillage, and integrated pest management (IPM) should be observed. Such accomplishments are seen as minor when compared to other nations because some smallholder farmers still have access to local indigenous technical farming knowledge and

abilities. Nonetheless, Tanzania's organic and Good Agricultural Practices Schemes have not advanced to a suitable level. Combining these images, it is clear that, like in other industries and nations, the adoption of unsustainable production methods has remained considerable (Kassie *et al.*, 2013).

In light of the aforementioned, it is important to comprehend how Tanzania's agriculture sector adopts SAPs. This thesis, despite being a case study, is dedicated to looking for wider implications for improving the development of sustainable agriculture in other fields and nations.

1.6 Research Gaps

The adoption of SAPs has traditionally been viewed as a result of simple decision-making, with rational farmers adopting recommended practices after being informed. However, research has focused on economic theories to understand factors leading to SAP adoption but has omitted non-economic considerations such as environmentally non-degrading, resource conserving, and socially acceptable solutions. Farmers often rely on personalized, intuitive, expert systems in farm management. Some scholars argue that the current body of research may have reached its limit in understanding voluntary SAP adoption, as the current state of knowledge is not easily transposed to policy. However, the results on factors consistently determining SAP adoption are inconclusive, calling for further research to generate more insights and clear policy directions. This thesis aims to address these gaps by identifying and narrowing relevant research gaps.

1.6.1 Research Gap 1

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 & Ryan, 2018; Di Falco *et al.*, 2010) have documented the significance of good agriculture practices (GAPs) 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.

Based on this argument, *the first research gap* of this study concerns the inadequacy of both approaches in explaining adoption of multiple SAPs. An integrative attempt is needed not only to evaluate the significance of both economic and social principles, but also to render a clearer picture on their relative importance in influencing the adoption of SAPs.

1.6.2 Research Gap 2

In light of diminishing availability of land caused by a burgeoning population, SAPs intensification remains pivotal in addressing inefficiencies within the food production system. Therefore, to be able to intensify domestic maize production, identifying and resolving the socio-economic and institutional factors that contribute to the low uptake of the relevant technologies need to be empirically done.

In this regard, several attempts have been made and some empirical research on determinants of the adoption of agricultural technologies in Tanzania and elsewhere have been done (Ghimire *et al.*, 2015; Grabowski *et al.*, 2016; Lyimo *et al.*, 2014; Mwalupaso *et al.*, 2019; Nchinda *et al.*, 2020; Simtowe *et al.*, 2016; Selejio & Lasway, 2019).

It is unfortunate that only a handful account of research (Bongole, 2021; Kassie *et al.*, 2013) focused on the extent of adoption of the same. Increasing the intensity of adopting existing practices can significantly enhance productivity. This approach often proves more beneficial than introducing complex and challenging new agricultural technologies. Leveraging and maximizing the potential of current agricultural practices through increased usage and optimized application can bring about tangible and immediate improvements in productivity while minimizing the complexity and challenges associated with adopting entirely new agricultural technologies (Ruzzante *et al.*, 2021).

Due to a lack of rigorous research evidence, context heterogeneity and the risk of bias in the limited sample of existing research, it is difficult to formulate evidence-based policies to increase the intensity of the adoption of sustainable agricultural practices. Based on this argument, *the second research gap* of this study concerns the inadequacy of approaches in explaining adoption intensity of multiple SAPs.

1.6.3 Research Gap 3

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 (Ethiakpor *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 (Marennya *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, this, in turn, points to *the third research gap* of this study. This research gap emphasizes that the impact of SAPs adoption on crop yields and incomes also needs to be well understood in addition to unpacking adoptive behavior.

1.6.4 Research Gap 4

This study argues that the available empirical literature on the impacts of adopting SAPs remains inconclusive. Previous studies have shown substantial contributions of adopting SAPs in production, household income, and food security (Adenle *et al.*, 2019; Bekele *et al.*, 2021; Bongole *et al.*, 2021; Ehiakpor *et al.*, 2021; Kassie *et al.*, 2013; Ma & Wang, 2020; Manda *et al.*, 2016; Ndiritu *et al.*, 2014; Ogemah, 2017; Zhou *et al.*, 2018; Rose *et al.*, 2019; Zeweld *et al.*, 2020).

However, there is insufficient literature on the impact of adopting multiple SAPs consisting of manure, intercropping, crop residual, improved maize varieties, and crop rotation on food security, nutrition, and poverty in Tanzania. In addition, the methodological uniqueness of this study lies in analyzing the impacts of adopting SAPs on households' food security, nutrition, and poverty indices by controlling both observable and unobservable variables in the study. This is crucial due to the lack of control over sample selection biases during the estimation phase.

Failure to account for selection biases caused by unobservable variables might lead to an overestimation or underestimation of the impacts of adopting SAPs on outcome variables. Nevertheless, this study has argued for the practical applicability of SAPs since previous studies have failed to acknowledge the impacts of individual or combined SAPs on households' food security, nutrition and poverty in various agro-ecological conditions.

Mgomezulu *et al.* (2023) contend that the lack of consistency among smallholder farmers in maintaining the area under SAPs stems from the perception that these practices are tedious and time-consuming. This inconsistency in the adoption process has limited the potential benefits of using SAPs, leading to yearly food insecurities, chronic poverty, and nutrition deficiencies among farming households' members. This study builds upon prior research (Bongole *et al.*, 2021; Manda *et al.*, 2018; Manda *et al.*, 2019; Mgomezulu *et al.*, 2023) that introduced a fresh perspective on modeling the adoption of

SAPs. It extends this knowledge to address the inconclusiveness prevalent in the adoption literature. The study posits that previous research has left a modeling deficit in assessing the impacts of using agricultural technologies on various outcome variables. It aims to bridge this gap by employing an endogenous treatment effect model to evaluate the impact of using bundled SAPs encompassing crop rotation, manure, intercropping, improved maize varieties, and crop residuals on food security, nutrition, and poverty indices among smallholder maize farmers in Morogoro region. Therefore, *the fourth research gap* of this study is a response to the impacts of adopting SAPs on food security, nutrition, and poverty indices.

1.7 Objectives

In this thesis, the adoption of SAPs is hypothesized to involve complex decision-making and unmeasured impacts on outcome variables such as maize yields, household incomes, and food security. Therefore, this study aims to produce a better understanding of the issues, using smallholder maize farmers in the Tanzanian agriculture sector. This is achieved by responding to the four research gaps identified in the earlier section.

1.7.1 Specific Objectives

Specifically, the study intended to:

- i. Assess the determinants of adoption of multiple SAPs among smallholder maize farmers in the study area.
- ii. Assess the rate and intensity of adoption of multiple SAPs among smallholder maize farmers in the study area.
- iii. Evaluate the impact of adopting multiple SAPs on yields and incomes of smallholder maize farmers in the study area.
- iv. Evaluate the impact of adopting multiple SAPs on food security, nutrition, and poverty indices among smallholder maize farmers in the study area.

1.7.2 Research Hypotheses

This study is directed by the following four hypotheses;

1. H_0 : Socio-economic, institution factors does not have significant influence on the adoption of multiple SAPs.
2. H_0 : The rate and intensity of adoption of multiple SAPs aren't significantly influenced by socio-economic, institutional and farm factors.
3. H_0 : The adoption of multiple SAPs does have significant impact on crop yields and household incomes.
4. H_0 : The food security, nutrition and poverty indices aren't significantly influenced by the adoption of multiple SAPs.

1.8 Theoretical Framework

1.8.1 Economic category

Research in the economic category is based on branches of an economic theory. Although there may be minor differences in their underlying assumptions, all of them are based on the notion of maximizing utility. According to the theory, farmers use the most optimal production methods to maximize their utility given their limited resources. The theory is more permissive than a profit maximization framework (Lynne *et al.*, 1988). Therefore, profit may not fully encompass the concept of utility. An emergent utility refers to a combination of efforts, ideas and actions aimed at ensuring both financial stability and environmental sustainability. Here, farmers are perceived as rational individuals who want to maximize their utility by efficiently utilizing their available resources.

Economic study relies on a decision algorithm that is specifically designed for individual farmers. The theory can be categorized into two primary paradigms: (1) the innovation-diffusion paradigm, and (2) the economic constraints paradigm (Utility maximization theory).

The innovation-diffusion paradigm suggests that the availability of information along with other socio-economic factors is the primary determinant of adoption decisions (Argawal, 1983). The foundation of this paradigm is upon the notion of diffusion of innovation (DOI) as

proposed by Rogers (2003). The statement presupposes that an invention is both suitable and financially advantageous, with adoption being dependent on effectively communicating the pertinent information to potential adopters (Adesina & Zinnah, 1993; Makokha *et al.*, 1999). Once provided the information, rational farmers would be inclined to embrace them based on their economic and social characteristics. The paradigm has been successful in facilitating profit-driven innovations, but has been less effective in the context of SAPs. This discrepancy arises due to their divergent orientations. Therefore, it is uncertain whether the assumption of this paradigm has been fulfilled for SAPs. This assertion is substantiated by a consistent observation across multiple studies: the lack of a substantial correlation between information accessibility and the adoption of SAPs (Warriner & Moul, 1992). This is true despite the fact that farmers have had sufficient access to knowledge. Consequently, this framework is less effective in elucidating the acceptance of SAPs.

Furthermore, the economic constraint paradigm argues that the decisions to adopt are influenced by the uneven distribution of resources (Aikens *et al.*, 1975, Tey *et al.*, 2017). Resource endowments in this context encompass not just tangible resources such as credit availability, farm size, and information, but also intangible traits such as education and farm location possessed by the potential adopters. According to the principle of utility maximization, farmers are considered to make logical decisions while being limited by the resources, they have available. Their decision to adopt is influenced by various factors such as socio-economic conditions, agro-ecological factors, institutional factors, and access to information.

Adoption should occur when a farmer has superior resource allocations, although the impact of these allocations may vary in different instances of SAPs (Schreinemachers *et al.*, 2009). Therefore, the assessment of the matter should encompass non-economic elements (Norris & Batie, 1987). Attitude, as a

psychological element, plays a significant role when SAPs fail to provide immediate direct advantages (Lynne *et al.*, 1988). This has been demonstrated by several studies, such as those conducted by Willison (1997) and Willock *et al.* (1999). Nevertheless, its incorporation may be theoretically inaccurate (Beedell & Rehman, 2000).

1.9 Conceptual Framework

A conceptual framework (CF) is a descriptive representation of the variables to be involved in a study and their probable linkages. The CF for this study is presented in Fig. 1 and it comprises Independent Variables (IVs) and the Dependent Variable (DV). Drawing from earlier research (Teklewold *et al.*, 2013; Manda *et al.*, 2016, Mgomezulu *et al.*, 2023). CF demonstrate how a set of socio-economic factors such as like age, gender, size of family, farm size, and level of education influence the adoption of bundled SAPs comprised of crop rotation, manure, crop residual, intercropping, and improved maize varieties. In addition, the adoption of bundled SAPs is assumed to be closely correlated to economic factors such as asset ownership, market accessibility, and resource constraints (Beyene *et al.*, 2017; Teklewold *et al.*, 2017). Additional categories of variables, such as whether the household belongs to a farmer groups, extension services, plot-level factors such as soil fertility level indicators are hypothesized to be influential to the adoption of SAPs.

Guided by the theory of utility maximization, maize yields, household incomes and food security are assumed to be impacted by the use of bundled SAPs via direct consumption and the sale of excess crops. Higher crop yields and profitability are crucial in creating household incomes. Reduced food insecurity and poverty are directly correlated with increased incomes and yields. In conclusion, the conceptual framework illustrates the factors that influence the choice to adopt packaged SAPs. Additionally, it illustrates the possible channels by which smallholder maize farmers' income, production, and food security could be impacted by adopting SAPs.

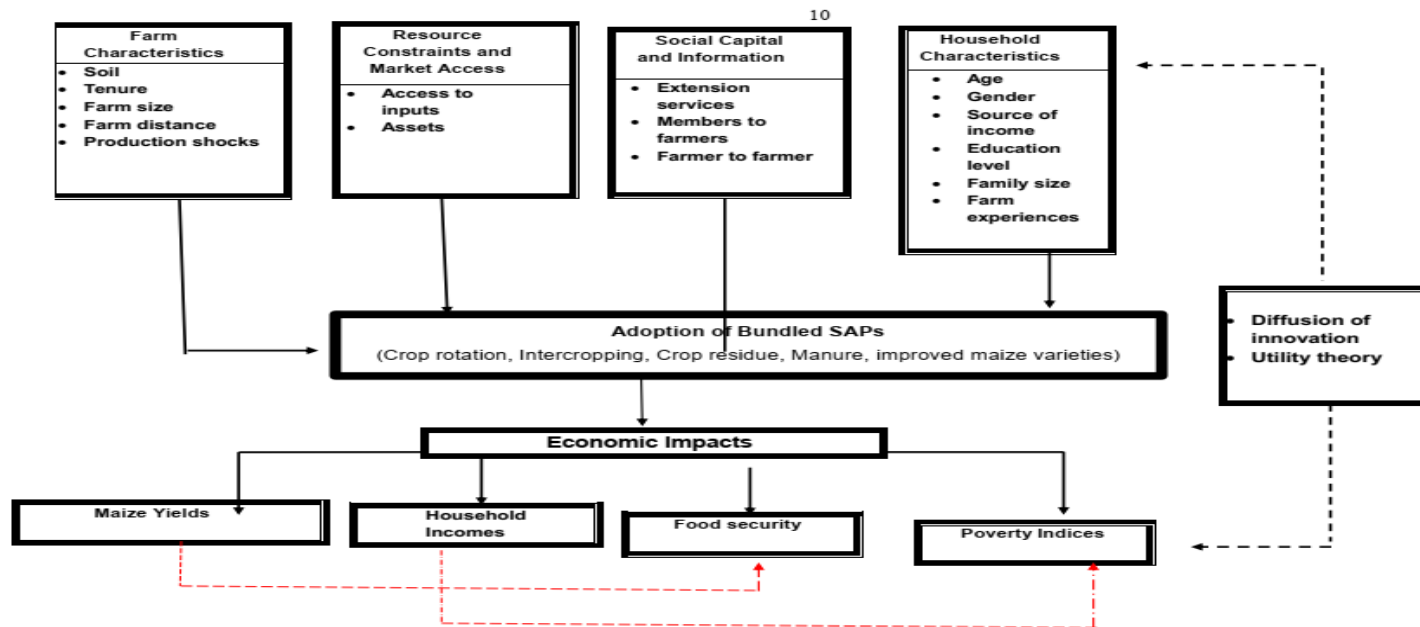


Figure 1: Conceptual framework of the study

Figure 1: Conceptual framework of the study

1.10 Significance

Gaining a deeper comprehension of adopter behavior at the farm level will provide more precise policy recommendations for enhancing SAP adoption. This need is essential since there is still a significant gap in the research regarding what should be prioritized in SAPs and how to communicate these insights to policymakers. Thus, by addressing the aforementioned research gaps and achieving the research goals, this thesis aims to build on earlier research.

1.10.1 Significance of Objective 1

The research adds to the body of adoption literature in two significant ways: In order to inform upcoming research and policy frameworks in the face of uncertainty over the impacts of adopting SAPs, it first tackles the paucity of literature on the advantages of implementing SAP interventions. Secondly, it aims to offer evidence-based perspectives on how scalable SAP interventions can be. This is significant given the current conversations about Africa's low agricultural production levels, which have led to food insecurity, malnutrition, and poverty in farming communities. Last but not least, the results of this research may play a major role in accomplishing Sustainable Development Goal 2, which aims to end hunger, guarantee food security, advance sustainable agriculture, and enhance nutrition by 2030.

1.10.2 Significance of Objective 2

The research contributes in the following ways: First, as smallholder farmers in underdeveloped nations seldom adopt SAPs, focusing on the adoption drivers our study found can help address farmers' adoption obstacles and ultimately boost their incomes and yields. In addition to providing other welfare benefits, maize is a major staple food, so this will help ensure food and nutrition security, meet the objectives of the Africa Union's Agenda 2063, and achieve the sustainable development goals of eradicating poverty and hunger. Lastly, politicians, maize experts like CIMMYT and TARI, and extension workers may all benefit from the study's findings and use them as a basis for raising Tanzania's agricultural output.

1.10.3 Significance of Objective 3

Which SAPs will provide higher net returns will be determined by examining the relative effects of SAP adoption on yield and household income. Since agriculture is a business and a source of income, this endeavor is essential. Furthermore, SAPs differ in terms of startup costs and functions. Regarding these features, the results will offer empirical insights into the factors that influence the adoption of specific SAPs and which SAPs, when adopted, typically result in higher earnings. Potential adopters may be persuaded to consider particular SAPs as an appealing "starter pack" if it is discovered that they are more profitable. It is hoped that more farmers would feel confident enough to invest in sustainable agriculture in light of this scientific evidence. Factors related to their adoption can direct the promotion of the "starter pack" (comprised of the profitable SAPs which could be adopted in small numbers). Consequently, the study's results provide light on the various SAPs' rates of return on investment and aid in the identification of potential adopters' traits and marketing tactics.

1.10.4 Significance of Objective 4

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

1.10.5 General Significance of the Thesis

Overall, this thesis will help paint a clearer and more comprehensive picture of the problems related to SAP implementation. Getting relative

policy insights on (1) which factors are more influential to the adoption of SAPs (2) which SAP is more productive, (3) which aspects are more influential, and (4) which SAP is more effective in reducing food insecurity and poverty is the main study orientation. This important data will support the formulation of relevant policies and serve as a manual for efficient local management in Tanzania's agriculture industry. Even though it is a case study, this thesis will also have wider policy consequences for nations with comparable circumstances. More significantly, academics will then have better tools to create guides that will support the promotion of domestic SAPs.

1.10.6 Justification of the Study

The study is in line with the Sustainable Development Goals specifically goal number one (poverty reduction), goal number two (ending hunger), goal number eight (decent work and economic growth), and goal number twelve (responsible consumption and production). The identification of influential factors to the adoption of bundled SAPs along with impact assessment of SAPs on the yields, incomes and food security is critical, it is hoped that the study will serve as a significant knowledge base. The findings of this study will provide information that can be used in either predicting the reactions of potential adopters to bundled SAPs or modifying either the SAPs bundles or ways in which they are presented to be more congruent with the motivational triggers of potential adopters.

Further, the improved understanding of constraining conditions of smallholder maize farmers to the adoption of multiple SAPs and evidence of the impact of such practices will be important for drafting pro-poor policies that can influence the adoption of bundled SAPs among farmers and help them in improving their farm yields, incomes and food security while sustaining a healthy environment.

1.11 General Methodology

The study utilized a collection of data from the Adoption Pathway Project that include 470 farm households two districts in Tanzania. Using a survey questionnaire and one-on-one interviews during the 2017–2018 cropping season, the survey was carried out by skilled and knowledgeable enumerators who were conversant in both the local

language and the farming system. Additionally, a pre-test survey was carried out outside of the sample areas to evaluate each enumerator's aptitude at administering the questionnaire and tailoring it further to the specifics of Tanzania. Each respondent was given an overview of the interview's objectives, confidentiality of the information, and duration at the outset of the procedure. They were then asked if they would be willing to participate in the interview.

Farmers were also given the option to depart at any moment during the interview process for a variety of reasons, but this did not present an issue, and as a consequence, 100% of them responded. Mvomero and Kilosa, from the eastern zone, were the two districts chosen in the first step of the sampling method based on their potential for producing maize. An equal number of sample homes were assigned to each of the two zones. A zone's households were dispersed among the two corresponding districts based on the size of each district's household (proportionate sampling). Fully proportionate random selection was used for the next steps of the sample procedure, which involved selecting 1-3 wards per district, 1-4 villages within each ward, and 2–30 farm households within each village. The sample can be used to illustrate Tanzania's main maize-legume farming systems, even though it might not be entirely representative of the nation. Comprehensive household, plot, and village data were surveyed.

The respondent described the types of SAPs used in each plot during the sample year, including crop rotations, animal manure, crop residual, intercropping, and improved seeds. Data was gathered on the fertility of the plot's soil, its depth, slope, and size in acres, as well as the walking distance in minutes between the plot and the household residence.

Plot tenure status, crop output predictions, and inputs related to each category of SAPs were among the additional data gathered at the plot level. Age, gender, education level, family size, asset ownership, membership in farmers' organizations, consumption expenditures, and the household's distance from input and output markets and extension offices are among the key socio-economic data collected from farming households. Other important data include production constraints (such as crop pests, diseases, and input availability), and the amount of land the

household owns. In our instance, improved access to inputs and finance provided by public institutions may result from relationships with agricultural officials and municipal administration.

Furthermore, the regression models incorporate the distance to the extension office, which might function as a stand-in for access to extension services. Farmers may have better access to extension information on SAPs if they live closer to the extension office. These variables are generated from respondents' subjective pleasure with rainfall. Using questions like whether rain fell and stopped on schedule, if there was adequate rain at the start and during the growing season, and if it rained during harvest, the individual rainfall index was created to assess the rainfall experience unique to each farm over the previous three seasons. Binary responses (yes or no) to each question were coded as favorable or unfavorable rainfall outcomes.

1.11.1 Data Analysis

Data analysis is the computation of certain measures along with searching for patterns of relationship that exist among data-groups (Kothari, 2004). STATA statistical software was used to analyze the objectives of the study.

1.11.2 Analytical Framework

i) Adoption rate and intensity of bundled SAPs

Descriptive analytical methods were used to analyze the adoption rate and adoption intensity of bundled SAPs among smallholder maize farmers while determinants to the adoption intensity were determined using the ordered probit model.

$$y^i = x' \beta + \varepsilon$$

Where y^* is unobserved and is given by:

$$\begin{cases}
 i: y=0 & \text{if } y^i \leq 0 \\
 i: 1 & \text{if } 0 < y^i \leq \alpha_1 \\
 i: 2 & \text{if } \alpha_1 < y^i \leq \alpha_2, \\
 & i: \\
 i: J & \text{if } \alpha_{j-1} \leq y^i
 \end{cases}$$

Where values of y are observed α and are unknown parameters to be estimated. We assume that ε follows a normal distribution with zero mean and unit variance. Then the probabilities of each outcome can be expressed as:

$$\begin{aligned} \dot{Pr}(y=0 | x) &= \Phi(-x' \beta) \\ \dot{Pr}(y=1 | x) &= \Phi(\alpha_1 - x' \beta) - \Phi(-x' \beta) \\ \dot{Pr}(y=2 | x) &= \Phi(\alpha_2 - x' \beta) - \Phi(\alpha_1 - x' \beta) \\ \dot{Pr}(y=J | x) &= 1 - \Phi(\alpha_{J-1} - x' \beta) \end{aligned}$$

ii) Determinants of adoption decisions to bundled SAPs

In a single-equation statistical model, information on a farmer's adoption of one SAP does not alter the likelihood of adopting another SAP. However, the MVP approach simultaneously models the influence of the set of explanatory variables on each of the different practices, while allowing for the potential correlation between unobserved disturbances, as well as the relationship between the adoptions of different practices (Green, 2002).

The observed outcome of bundled SAPs adoption can be modelled following a random utility formulation. Consider the i^{th} farm household ($i=1 \dots N$) facing a decision on whether or not to adopt the available SAPs on plot p ($p=1 \dots, P$).

Let 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 use (M). The farmer decides to adopt

the k th SAP on plot p if $Y_{ipk}^{\dot{c}} = U_k - U_0 > 0$. The net benefit ($Y_{ipk}^{\dot{c}}$) that the farmer derives from the adoption of k th SAP is a latent variable determined by observed household, plot and location characteristics X_{ip}' and error term ε_{ip} :

$$Y_{ipk}^{\dot{c}} = X_{ip}' \beta_k + \varepsilon_{ip} \dot{c} \dots \dots \dots \text{(i)}$$

Using the indicator function, the unobserved preferences in equation (i)

translate into the observed binary outcome equation for each choice as follows:

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

In the multivariate model, where the adoption of several 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:

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

iii) Examine the impacts of adopting bundled SAPs on crop yields and household incomes

The multinomial endogenous treatment effects model was employed to assess the economic impact of adopting the bundled SAPs 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 λ_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

iv) **The impacts of adopting SAPs on food security, nutrition, and poverty indices**

The multinomial endogenous treatment effects model was utilized to assess the impacts of adopting SAPs food security, nutrition, and poverty indices among smallholder maize farmers.

The expected outcome equation of the average treatment effects of the untreated is formulated as:

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

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

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

$$E \hat{\epsilon} \dots \dots \dots (ii)$$

Then the ATT is presented as follows:

$$\hat{\epsilon}$$

1.12 Study Limitations

This thesis only provides a limited understanding of the relationships between SAPs. According to recent studies, there is a relationship between adoption choices for instance, research has shown that compost and conservation tillage work well together, which were not covered in this study. One might use other SAPs in place of organic fertilizers or composts, such as cover crops or manure. It is unclear, therefore, how and why SAPs are used in these formats. In the hopes that this could lead

to improved guidelines for encouraging sustainable agriculture, future participatory studies should try to grasp their practicality.

Two districts were included in the study; however, the remaining 7 districts were not covered. Thus, broader survey coverage should be the goal of future research projects. In addition to the broad conclusions of this thesis, subsequent studies should aim to generate specific local insights for different contexts (e.g., nations and industries). This thesis' emphasis on defining the traits of "more likely" adopter groups has a disadvantage. This research does not assess "less likely" adopter groups, even when applying their prioritization as an exercise result in a policy focus on such targets.

1.13 Organization of the Thesis

This thesis is organized based on published papers per Sokoine University of Agriculture guidelines for preparing and submitting thesis and other scientific publications, the fifth edition. Each of the published papers stands as an independent chapter. Overall, the entire thesis comprises six chapters. Chapter one covers the background information on the study topic, research gaps, objectives, the research hypotheses, significance of the study, theoretical and conceptual framework, the general methodology, and the study limitations. The rest of the thesis is organized as follows:

Chapter two presents the first paper titled "*Determinants of adoption of multiple SAPs among smallholder maize farmers in Morogoro region*". Chapter three presents the second paper titled "*Adoption intensity of bundled SAPs among smallholder maize farmers in Morogoro region*". Chapter four presents the third paper titled "*Economic Impact of Adopting Bundled SAPs on Crop yields and Household Incomes among Smallholder Maize Farmers in Morogoro Region*". Chapter five presents the fourth paper titled "*The impact of adopting multiple SAPs on food security, nutrition, and poverty among smallholder maize farmers in Morogoro region, Tanzania*". Chapter six contains a summary of the findings, the general conclusion, recommendations, theoretical and policy implications, and suggestions for further research.

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CHAPTER TWO PAPER I

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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

JEL Classification Codes: Q12

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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 (Ghimire *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.

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 <i>et al.</i> (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 <i>et al.</i> (2007)	United States	IPM	217	Profit maximization	Stepwise regression model	R ² =0.655
Moser <i>et al.</i> (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 <i>et al.</i> (2013)	Tanzania	Soil conservation	681	Rational choice theory/Utility maximization	Multivariate probit	X ² =249.51
D'Souza <i>et al.</i> (1993)	United States	Soil conservation	600	Utility maximization	Logit	R ² =0.10
Tecklewold (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (2014)	Greece and Germany	Organic farming	282	Utility maximization	Logit	R ² =0.5144

Granpat <i>et al.</i> (2014)	Trinidad	GAP	196	Farming systems model	Categorical regression	R ² =76.1
Mankeb <i>et al.</i> (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 <i>et al.</i> (2020)	Nigeria	GAP	2113	Utility maximization theory	Multivariate and ordered model	R ² =0.062
Mutaysira <i>et al.</i> (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 ($i=1... I_n$) facing a decision on whether or not to adopt a set of interdependent SAPs on plot p^{th} ($P=1... p_n$).

Let 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 $Y_{ipk}^* = U_k - U_0 > 0$. The net benefit (Y_{ipk}^*) that the farmer derives from the adoption of k^{th} SAP is a latent variable determined by observed household, plot, and location characteristics X'_{ip} and the error term

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

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

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

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:

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

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

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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 head	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

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 χ^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 <i>et al.</i> , 2019).
Crop rotation	Adaption	Helps in improving soil health, decreasing the occurrence of pests and diseases, improving crop diversification and preventing soils erosion (Teixeira <i>et al.</i> , 2018)
	Mitigation	According to Teklewold <i>et al.</i> (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 <i>et al.</i> , 2018)
	Household welfare	Improved income and food security due to improved agricultural productivity Teklewold <i>et al.</i> , (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 <i>et al.</i> , 2019).
	Mitigation	Maintains or improves soil carbon stock or organic matter content, and reduces the need for chemical fertilizer (Hassen <i>et al.</i> , 2017).
	Productivity	According to Teklewold <i>et al.</i> (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 <i>et al.</i> , 2017).
Organic Manure	Definition	It is the application of animal wastes on the farm (Teklewold <i>et al.</i> , 2019).
	Adaption	Improves soil structure and its water-holding capacity with minimum leaching (Khaïtov <i>et al.</i> , 2019).
	Mitigation	Increases carbon storage in soils, and reduces the need for synthetic fertilizers and related GHG emissions (Khaïtov <i>et al.</i> , 2019).
	Productivity	Increases crop yields and income.
Improved Maize Seeds	Household welfare	Improved household income and food security as a result of improved productivity.
	Definition	Are seeds which can produce at least 1–3 tons/ha after suffering water stress for nearly six weeks (Magorokosho <i>et al.</i> , 2009)
	Adaption	The seeds can withstand abiotic stress (Masuka <i>et al.</i> , 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 <i>et al.</i> , 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 <i>et al.</i> , 2020).
	Adaption	Enhances soil moisture, fertility and reduces soil erosion (Chalise <i>et al.</i> , 2019).
	Mitigation	Increases carbon storage in soils, reduces use of synthetic fertilizers and related GHG emissions. (Bolinder <i>et al.</i> , 2020).
	Productivity	Increases crop yields and income (Bolinder <i>et al.</i> , 2020).
	Household welfare	Addressing food security and income (Page <i>et al.</i> , 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 $\rho_{21} = \rho_{31} = \rho_{41} = \rho_{51} = \rho_{61} = \rho_{32} = \rho_{42} = \rho_{52} = \rho_{62} = \rho_{43} = \rho_{53} = \rho_{63} = \rho_{54} = \rho_{64} = 0$: $\chi^2(15) = 61.1010$ Prob > $\chi^2 = 0.0000$ Standard errors in parentheses

CHAPTER THREE

PAPER II



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Adoption Intensity of Bundled Sustainable Agricultural Practices among Small-Scale Maize Growers in Morogoro Region, Tanzania

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Abstract: The study examined the adoption rate and intensity of bundled sustainable agricultural practices (SAPs) among smallholder maize farmers in Tanzania. The SAPs considered include crop rotation, intercropping, manure, improved seeds and crop residual. Using descriptive techniques and ordered probit model, data was collected from 470 farming households from Kilosa and Mvomero Districts through a multi-stage sampling procedure. The results show that education level, occupation, farming experience, sex of the household head, farm size, plot ownership, geographical location, membership in farmers' organization and production diversity had significant impacts on the adoption intensity of multiple SAPs. In addition, there were greater disparities in the adoption intensity than in the adoption rates; the awareness and recognition of SAPs did not necessarily translate into increased usage. The study recommends that the interdependence nature of agricultural innovations should be considered in designing strategies dissemination of SAPs to provide farmers with a choice among different sets of practices that possess desirable traits. Given that diverse factors influence the usage of different combinations of SAPs, it is important that policymakers should take into consideration the significant factors to ensure that farmers can maximize the benefits of SAPs through provision of training programs to enlighten farmers on the benefits of SAPs.

Keywords: Sustainable agricultural practices; rate and intensity; adoption; ordered probit model; small-scale maize growers.

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Introduction

Agriculture contributes considerably to the economies of the majority of developing nations (Addison *et al.*, 2022) and supports people's livelihoods (Pawlak & Kołodziejczak, 2020). In Sub-Saharan Africa, a substantial proportion of the population is directly dependent on the agricultural sector (Misango *et al.*, 2022). Agriculture remains a vital sector of Tanzania's economy and contributes significantly to economic expansion (Bank of Tanzania, 2021). Faced with a growing global population, there is a need to increase the agricultural production to attain food security, employment opportunities and foreign currency. Moreover, the burden on agricultural production systems to achieve global food security in the context of rising demands and depletion of natural resources necessitates a rethinking of current production systems in the direction of more sustainable models from economic and resource management perspectives (Piñeiro *et al.*, 2020).

FAO (2022) estimates that agricultural production must increase by 60% by 2050 to satisfy the global rising demand for food. In Tanzania, it is projected that by 2050 the population will exceed 129 million. The implication is that there is a need for a corresponding increase in agricultural output, notably for food crops such as maize, which is the most important cereal in Tanzania, accounting for about 70% of annual cereal production (URT, 2017).

Notwithstanding, Tanzania's agricultural sector, like in most East African countries, remains predominantly subsistent (Selejio & Lasway, 2019). Crop production is dominated by small-scale farmers who largely rely on climatic conditions for production. The use of basic farming techniques and a limited number of farming practices, on top of such challenges as declining soil fertility and drought conditions contributes to the low productivity of major staple crops like maize (Lyimo *et al.*, 2014). It is critical to note that along with paddy, maize is regarded as a staple and cash crop (USAID, 2022). In addition, maize consumption increased from 5,162 metric tons in the 2020/2021 season to 5,325 metric tons in the 2021/2022 season. This necessitates an increase in maize production (USAID, 2022).

Globally, smallholder farmers administer 85% of all farms, with 75% of this population residing in Africa (FAO, 2022). Consequently, there are approximately 33 million smallholder farmers in

Sub-Saharan Africa, who account for 80% of all farmers in the region. This signifies the contribution of smallholder farmers to the overall production of cereal commodities in the region.

In recognition of the food and commercial values of maize and its importance as a food security crop, the government and other development agencies have made concerted efforts to improve production and productivity. One of the focus areas has been testing, promoting and disseminating sustainable agricultural practices (SAPs). Available evidence shows that the use of improved maize varieties, crop rotation, manure, intercropping and crop residuals can significantly increase maize productivity (Gunton *et al.*, 2016; Kansiime *et al.*, 2022; Lyimo *et al.*, 2014; Selejio *et al.*, 2018).

Statistics show that in Tanzania, domestic maize production steadily decreased from 6,540 metric tons to 6,148 metric tons per year, while demand increased from 6,072 metric tons to 6,186 metric tons per year in the year 2020 (National Bureau of Statistics, 2020). Moreover, while domestic consumption exceeds domestic production, reported actual yield increase results from land expansion rather than from intensification, even though intensification has been branded as the best method to increase crop yields on existing croplands.

In light of diminishing availability of land caused by a burgeoning population, SAPs intensification remains pivotal in addressing inefficiencies within the food production system. Therefore, to be able to intensify domestic maize production, identifying and resolving the socio-economic policy and institutional factors that contribute to the low uptake of the relevant technologies need to be empirically done.

In this regard, several attempts have been made and some empirical research on determinants of the adoption of agricultural technologies in Tanzania and elsewhere have been done (Ghimire *et al.*, 2015; Lyimo *et al.*, 2014; Mwalupaso *et al.*, 2019; Nchinda *et al.*, 2020; Simtowe *et al.*, 2016; Selejio & Lasway, 2019). It is unfortunate that only a handful account of research (Bongole, 2021; Kassie *et al.*, 2013) focused on the extent of adoption of the same. Increasing the intensity of adopting existing practices can significantly enhance productivity. This approach often proves more beneficial than introducing complex and challenging new agricultural technologies.

Leveraging and maximizing the potential of current agricultural practices through increased usage and optimized application can bring about tangible and immediate improvements in productivity while minimizing the complexity and challenges associated with adopting entirely new agricultural technologies (Ruzzante *et al.*, 2021).

Due to a lack of rigorous research evidence, context heterogeneity and the risk of bias in the limited sample of existing research, it is difficult to formulate evidence-based policies to increase the intensity of the adoption of sustainable agricultural practices. This study seeks to address this study gap.

Furthermore, utility theory was used to establish the study's hypotheses on the association between the adoption intensity of multiple SAPs and socio economic, institutional and farm related variables. The null hypothesis (H_0) posits that there is no significant association between the adoption intensity of multiple SAPs, socio

economic, institutional and farm related variables among smallholder maize farmers in the Morogoro Region.

Literature Review

Sustainable Agriculture and Sustainable Agricultural Practice

According to FAO, 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 with equal weight. Today, most 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 (Aslihan *et al.*, 2020).

Table 1: Studies on Adoption Intensity of Sustainable Agriculture

Authors	Country	Practice	Theory/ Assumption	Statistical Model
Kiconco <i>et al.</i> (2022)	Uganda	IMP (Banana)	Utility	Ordered probit model
Pedzisa <i>et al.</i> (2015)	Zimbabwe	GAP	Utility	Poisson regression
Kolady <i>et al.</i> (2021)	USA	Precision Agriculture	Utility	Poisson regression
Wang <i>et al.</i> (2016)	Canada	Improved s irrigation technologies	Utility	Ordinary least squares (OLS)
Kabir & Ruslan (2013)	India	IPM	Utility	Linear regression
Mwaura <i>et al.</i> (2021)	Kenya	Soil management practices	Utility	Tobit regression
Arslan <i>et al.</i> (2014)	Zambia	CA	Utility	Random effects Tobit, pooled fractional Probit
Ghimire <i>et al.</i> (2015)	Taiwan	IMV	Utility	Crag's double-hurdle model
Misango <i>et al.</i> (2022)	Rwanda	IMP	Utility	Fractional Logit approach
Thompson <i>et al.</i> (2023).	USA	CA	Utility	Lognormal hurdle model
Addison <i>et al.</i> (2022)	Ghana	IPM	Utility	Univariate theory
Bongole (2021)	Tanzania	CSAPs	Utility	Ordered probit model

CA = Conservation Agriculture, IPM = Integrated pest management, IMV = Improved Maize varieties
GAP = Good Agricultural Practices. CSAPs= Climate Smart Agricultural Practices

Empirical studies on the Adoption Intensity of Sustainable Agricultural Practices

The status of the intensity of the adoption of agricultural technologies in the literature is summarized in Table 1. Most studies have focused on the adoption intensity of individual practices rather than on multiple practices. The few, which did, were either not based in Tanzania or did not focus on maize. This means there is limited empirical information on the rate and intensity of adoption of bundled SAPs among small-scale maize growers in Tanzania.

Theoretical Framework

The previous adoption studies have primarily employed correlational technique to explain adoption behavior as a function of multiple variables. Consequently, estimating a function of:

$$\text{Adoption} = f(X)$$

Where 'adoption' is the observed adoption behavior towards SAPs and $X = \{x_1, x_2, \dots, x_n\}$ represents a matrix encompassing a diverse array of socio economic, farm-related, environmental, institutional, and other pertinent factors (as described in Table 2, outlining the specific variables utilized in this study).

The fundamental foundation within this theoretical framework posits that farmers are rational agents who endeavor to optimize an unobservable expected utility function (Adesina & Zinnah, 1993). In the context of this study, utility is operationalized as enhanced maize production, leading to increased profits and subsequently amplifying the potential income derived from the application of multiple SAPs (crop rotation, intercropping, manure, improved seeds, and crop residual).

Furthermore, these SAPs may exert an indirect influence on expected utility, chiefly through their interaction with risk factors at the farm level. To illustrate, factors such as larger farm plots, increased production diversity and higher levels of education may mitigate risk aversion, thereby incentivizing more educated smallholder farmers to embrace SAPs and innovations, such as improved maize varieties, which offer the prospect of heightened income with reduced associated risks (Knight *et al.*, 2003).

Consequently, it is posited that the degree of adoption corresponds to the realized value of an unobserved latent utility function, denoted as U^* .

This estimate, U^* , is typically assumed to take the form of a linear function of X (Marenya & Barrett, 2007).

$$U^* = X\beta + \varepsilon$$

In this context, β represents a vector comprising estimated parameters while ε denotes a random error term. It is postulated that the i^{th} farmer will adopt (utilize) a greater number of practices when the anticipated utility gained from an additional practice surpasses the utility derived from not adding a practice (i.e., greater than 0).

$$y_i = \begin{cases} 1, & \text{if } U_i^* \geq 0 \\ 0, & \text{otherwise} \end{cases}$$

The observed adoption behavior of the i^{th} farmer is denoted as y_i . Various modifications of this foundational model can be found in the literature. For instance, studies conducted by Bongole (2021), Kiconco *et al.* (2022), Kolady *et al.* (2021), Mensah Bonsu *et al.*, 2017), Misango *et al.* (2022), Mwaura *et al.* (2021) and Pedsiza *et al.* (2021) employed utility theory as a framework for assessing the intensity of adoption. This is typically achieved through a descriptive approach that quantifies the total number of practices employed by a farmer during a cropping season.

In the case of assessing the adoption intensity of SAPs, the outcome is often assumed to be a censored linear function of expected utility:

$$y(\text{intensity})_i = \begin{cases} \gamma U_i^*, & \text{if } U_i^* \geq 0 \\ 0, & \text{otherwise} \end{cases}$$

Where γ is a scaling term.

Thus, despite the wide variety of dependent variable definitions and estimation techniques, all adoption studies rely on the underlying theory of utility maximization. This theoretical consistency is a necessary condition to make this study a valid exercise. Thus, the utility maximization theory provides a fundamental framework for identifying the determinants of adoption intensity of bundled SAPs among smallholder maize growers in Tanzania. It should be noted that in this study, the adoption rate is a binary decision measured by a dummy variable (1 = who has land under SAPs; 0 = who does not have land under SAPs), and the intensity of adoption as a total number of individual SAPs adopted.

Methodology

Data Source

This study utilized data from the Adoption Pathways project which was conducted during the 2017/2018 cropping season. The project worked with the Australian International Food Security Research Centre (AIFSRC) and was managed by the Australian Center for International Agricultural Research (ACIAR). The project was implemented and led by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with five African countries (Ethiopia, Kenya, Tanzania, Malawi and Mozambique), Sokoine University of Agriculture and Tanzania Agricultural Research Institute (TARI).

Population and Sampling

Two districts in the Morogoro Region, Mvomero and Kilosa, were selected in 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 to 13 wards in each district, 1 to 4 villages in each ward and 2 to 30 farm households in each village from each district. Although the sample might not be a representative of Tanzania as a whole, it is representative of the main maize-legume farming systems in the country. Thus, data was collected from 470 farming households.

Research Tools

A survey was conducted through one-on-one interviews using a well-designed and pre-tested structured questionnaire administered by enumerators familiar with the local agricultural system and language. The questionnaire was utilized to collect detailed household, plot and village information on the demographic and infrastructure, household production activities and plot-specific characteristics. For each allotment, the respondent detailed the SAPs implemented during the sample year, including intercropping, crop rotation, crop residue, improved seed varieties and manure. Observations and casual conversations provided space for probing and clarifications. This yielded additional data on farmers' concerns and experience, which helped to interpret the quantitative data.

Validity and Reliability

Similar to Hair et al. (2019), the development and validation for the measurement of rate and intensity were carried through three distinct stages. First, a literature review was conducted to gain an understanding of how to measure the rate and intensity and its operationalization in this study. Thereafter, variables were constructed. Second, face validation was performed through consultation with agriculture experts to determine the relevance of constructed items in-terms of the relationship with adoption of sustainable agriculture practices, readability, clarity, conciseness, omission and adequacy.

This procedure ruled out the possibility of measure contamination which according to Nenty (2009) occurs when items unrelated to the construct or variable are included in the instruments. The comments from the experts were evaluated and accommodated accordingly. Thereafter, semantic validation was done by conducting a pilot study which involved 20 respondents, to gauge the effectiveness of the tool. The tool's reliability was statistically validated by computing the composite reliability, which was 0.961205. The composite reliability test was preferred because, it is more reliable than the Cronbach alpha, and does not rely on the number of items on the scale. Furthermore, whereas Cronbach's alpha considers all variables to be equally weighted, composite reliability weights individual indicators. Convergent test was also conducted with results of 0.67036. The coefficient values obtained for composite reliability and convergent validity were higher than the recommended minimum value of 0.7 (for composite reliability) and 0.5 (for convergent validity), cementing satisfactory levels of reliability and validity respectively.

Statistical treatment of Data

This study used quantitative data. Distinct analytical techniques were employed for each objective. The assessment of adoption rate and intensity involved descriptive analysis to derive average scores values for the adopters of SAPs, whereas the investigation into the factors influencing adoption intensity utilized an ordered probit model.

Econometric Framework

Adoption intensity is a count variable that may be analyzed with Poisson regression or Binomial negative. The Poisson regression and binomial negative assume that the occurrence of all events

has the same probability. However, the adoption intensity of SAPs doesn't have the same chances of happening. The likelihood of adopting the first SAP may differ from the likelihood of adopting subsequent SAPs (second through fifth) because smallholder farmers acquire experience upon adopting the first SAP. Smallholder farmers could have realized a greater return by adopting the first practice, and they may be willing to adopt a combination of practices to maximize their utility. Notably, the adoption intensity of SAPs may vary based on their specific characteristics, such as labor requirements, practical knowledge requirements, initial investments and whether short-term or long-term benefits are anticipated. In addition, smallholder maize farmers are hypothesized to use multiple SAPs to achieve greater utility than those who employ none or a single practice.

Adoption intensity (number of SAPs adopted by the i^{th} farmer) was regarded as an ordinal variable that could be examined with the ordered probit model. The model permits estimation of the determinants of count variables (intensity of adoption of 1, 2, 3, 4, and 5 SAPs). The ordered outcome could be evaluated as a latent variable Y , where Y is an unobservable measure of the SAPs adoption intensity among smallholder maize farmers and is specified as follows:

The adoption intensity of bundled SAPs was determined using the ordered probit model:

$$y^* = x'\beta + \varepsilon$$

Where y^* is unobserved and is given by:

$$\begin{cases} y = 0 & \text{if } y^* \leq 0 \\ = 1 & \text{if } 0 < y^* \leq \alpha_1 \\ = 2 & \text{if } \alpha_1 < y^* \leq \alpha_2, \\ = J & \text{if } \alpha_{j-1} \leq y^* \end{cases}$$

Where values of y are observed α and are unknown parameters to be estimated. We assume that ε follows a normal distribution with zero mean and unit variance. Then the probabilities of each outcome can be expressed as:

$$\Pr(y = 0 | x) = \Phi(-x'\beta)$$

$$\Pr(y = 1 | x) = \Phi(\alpha_1 - x'\beta) - \Phi(-x'\beta)$$

$$\Pr(y = 2 | x) = \Phi(\alpha_2 - x'\beta) - \Phi(\alpha_1 - x'\beta)$$

$$\Pr(y = J | x) = 1 - \Phi(\alpha_{j-1} - x'\beta)$$

As per Greene (2007), the researchers further measured the intensity of adoption by taking the number of technologies adopted by the households as the dependent variable. It was assumed that: (i) provided a household derives greater utility from the last adopted technology, there is a limit of five practices; (ii) the adoption decision of the farming household to one agricultural technology/practice does not rule out the adoption of the another available technology since the effects of certain technologies could be complementary; and (iii) the adoption of agricultural practices/technologies elements could be independent due to the variable needs and conditions of producers. Smallholder maize farmers were categorized as follows: Those who didn't practice any SAP were referred to as non-adopters, while those who practiced 1 to 3 were referred to as partial adopters, and lastly those who used 4 to 5 practices were categorized as full adopters.

Table 2: Description of Variable used in the study

Variables	Measure	Expected Sign	Justification
Crop rotation	If a farmer practised crop rotation 1, 0 if not	N/A	Helps improve soil health, decrease the occurrence of pests and diseases, improve crop diversification and preventing soil erosion (Teixeira <i>et al.</i> , 2018).
Improved maize varieties	If a farmer used improved maize 1, 0 if not	N/A	Superior cultivars, with tolerance to disease and environmental shocks like drought and floods, can further help farmers adapt to climate change, ensure food security and improve livelihoods (Masuka <i>et al.</i> , 2017).
Intercropping	If a farmer practised intercropping 1, 0 if not	N/A	Improves productivity, hence promoting sustainable utilization of resources such as land and water; diversifies income sources (Teklewold <i>et al.</i> 2019).s
Crop residual	If a farmer practised crop residual 1, 0 if not	N/A	Enhances soil moisture and fertility and reduces soil erosion (Chalise <i>et al.</i> , 2019).
Manure	If a farmer used manure 1, 0 if not	N/A	Improves soil structure and its water-holding capacity with minimum leaching (Khativov <i>et al.</i> , 2019).
Age of the household head	Years	+/-	Older farmers with better farm experience are more likely to practise SAPs (Mazvimavi and Twomlow, 2009; Ngwira <i>et al.</i> , 2014; Ng'ombe <i>et al.</i> , 2017).
Education of the household head	Level of education attained by household head-1= primary, 2= secondary 3= university, 4=technical	+	Increases the speed with which SAPs information is processed and may likely lead to SAP adoption (Kotu <i>et al.</i> , 2017; Ng'ombe <i>et al.</i> , 2017; Khonje <i>et al.</i> , 2018).
Sex of the household head	1= Male, 0 = Female	+/-	Agricultural technologies/practices are deeply gendered, from its inception in research and development to its diffusion, access, and adoption. (Mazvimavi & Twomlow, 2009; Congress <i>et al.</i> , 2010; Ngwira <i>et al.</i> , 2014; Ng'ombe <i>et al.</i> , 2017).
Farming experience	Number of years of farming (years)	+	Useful in the early stages of adoption of a given technology when farmers are still testing its potential benefits (John & Mugisha, 2014).
Household Size	Number of members in the household	+	Household size is a quite notable proxy of labour supply that can as well influence the usage of certain technology or practice (Usman <i>et al.</i> , 2022).
Farm size	Available land for production (measured in Acre)	+/-	Allow flexibility in using SAPs alongside other GAPs to spread risks. The expected effect is mixed depending on the technology under consideration (Mazvimavi&Twomlow, 2009; Ngwira <i>et al.</i> , 2014; Ngoma <i>et al.</i> , 2021).
Soil fertility	1 (if the plot has fertile soil) ² , 0= if otherwise	+	Increases the quality and quantity of crop yields over the long term because it keeps topsoil in its place and preserves the long-term productivity of the soil (Mwaura <i>et al.</i> , 2017).

Geographical location	1= Kilosa District 0 = Mvomero District	+/-	Accounts for agro-ecological differences that may have mixed effects on the adoption of SAPs (Mazvimavi & Twomlow, 2009; Arslan et al., 2014; Pedzisa et al., 2015).
Group membership	1= Yes, 0 =No	+	Increases farmer access to key services such as credit and extension services which are critical for SAPs uptake (Kansiime et al., 2022).
Access to extension services	Number of extension contacts per agricultural season	+	Extension services increase information on SAPs awareness and subsequent uptake and application of SAPs principles (Mazvimavi & Twomlow, 2009; Wossen et al., 2017; Fisher et al., 2018; Ngoma et al., 2021).
Distance to the market place	Kilometers (Kms)	-	Increases transaction costs and thus limits access to inputs/ technologies (Kotu et al., 2017; Wossen et al., 2017).
Land ownership	1 If the farmer is the owner of the land, 0 = otherwise	+/-	Reflects tenure security status and reduces the likelihood of investing in SAPs due to the limited time horizon because of the lack of land tenure security rights (Arslan, 2014).
Access to credit	1=If the farmer has access to credit, 0= otherwise	+	Provide incentives for farmers to practice SAPs (Kansiime et al., 2022).
Livestock ownership	Total tropical Livestock Unit	-	May conflict with SAPs principles (such as mulching) uptake due to competition over crop residues for feed (Ngwira et al., 2014; Ng'ombe et al., 2017).
Occupation	Number of occupations of the household head	+	Having a job outside agriculture provides additional income and financial stability. This means the farmer may have more resources available to invest in agricultural technology. Purchasing and adopting new technologies can be costly, so having an additional source of income increases the farmer's capacity to afford and implement these innovations (Tefera et al., 2018).
Production diversity	Number of crops cultivated	+/-	Production diversity can help reduce the vulnerability of farmers to market fluctuations, pests, diseases, and climate-related risks (Bongole, 2021). Also, managing diverse production systems can be more challenging and time-consuming. Farmers may be hesitant to adopt new technologies due to the complexity of integrating them into their diverse farming operations (Gatti et al., 2023).

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

Results and Discussion

Adoption Rate of Sustainable Agriculture Practices

It is evident from Table 3 that crop rotation, manure and improved seeds were the most widely used SAPs, with adoption rates of 55%, 43% and 60% respectively. Among the five SAPs addressed by the study, crop residual and intercropping were the least popular. Table 3 illustrates that the total average of the adoption rate of SAPs by smallholder maize farmers exceeded 45%, implying a moderate usage of these practices.

Table 3: Adoption Rates of SAPs

Type of SAPs	Adoption rate (%)
Intercropping	40
Crop rotation	55
Manure	43
Crop residual	30
Improved seed varieties	60

The adoption intensity of SAPs

The findings in Table 4 reveals the intensity of SAPs adoption among smallholder maize farmers, specifically in terms of the quantity of SAPs embraced. The results underscore that the degree of SAPs adoption were notably elevated when one to three SAPs (improved seed varieties, crop rotation and manure) are implemented. These empirical findings corroborate with earlier scholarly investigations, which have consistently asserted that agricultural technologies are commonly embraced by producers in composite arrangements, as evidenced by Bongole (2021), Kassie et al. (2013) and Usman (2022).

Table 4: Adoption intensity

Number	Frequency
1	201
2	150
3	80
4	25
5	14

Note: Combination between SAPs exhibits a multitude of variations

Determinants to the Adoption Intensity of Multiple SAPs

The results in Table 5 demonstrate that a farmer with high farming experience had a probability of using three, four, and five practices by 4.12, 4.06, and 5.40 per cent points, respectively, than the inexperienced ones.

These findings corroborate with the findings of Yang et al. (2021) who argued that as farmers acquire more experience, they can evaluate the benefits of using innovation and as a result, intensity increases. This is contrary to Gatti et al. (2023) who reported that experiences had heightened farmers' perception of risks and uncertainties associated with adopting agricultural technologies. It is argued that farmers' encounters with unexpected challenges, crop failures, or negative consequences in the past may heighten their views on technology adoption as a risky endeavor. The perception of risk can discourage them from embracing new technologies such as improved seed varieties. Consequently, this perspective implies that individual coping mechanisms, technology maturity could significantly shape farmers' perceptions on the adoption of SAPs.

The results in Table 5 indicate that households headed by farmers with higher levels of formal education exhibited a high adoption intensity of multiple SAPs. The findings show that the adoption intensity increased by 3.01, 2.51, and 4.90 per cent points for the two, three, and four practices, respectively. The findings confirm those of studies by Ali et al. (2020) and Emmanuel et al. (2021) which showed that more educated farmers had higher rate of adoption of improved maize varieties. This implies that most of the respondents in the study area were capable of effectively following and using instructions or guidance for the application of SAPs. Results are consistent with those by Paltasingh (2016), Paltasingh and Goyari (2018) which reported that education helped farmers in making informed decisions including adopting modern agricultural technologies in India.

Households with higher production diversity had higher probability of using three, four and five practices by 3.12, 6.10 and 4.03 per cent points, respectively, compared to those with less production diversity. This is consistent with Teklewold et al. (2019) who found that farming household in Ethiopia diversified their production system to mitigate the risks of production shocks. Similarly, Bongole (2021) reported comparable observations in Tanzania.

Table 5: Coefficients for the ordered Probit model for the adoption intensity of bundled SAPs.

Variables	Coef.	Std. Err.	Pr (Y = 0 X)	Std. Err.	Pr (Y = 1 X)	Std. Err.	Pr (Y = 2 X)	Std. Err.	Pr (Y = 3 X)
Sex of the household head	0.1901	0.1322	0.005	0.00143	-0.02534	0.0278	0.0340*	0.00128	0.0205**
Age of the household head	0.0108	0.0021	0.001	0.00030	-0.00061	0.0011	-0.0007	0.00051	0.0017
Farm experience	-0.0310	0.0031	0.000	0.00021	0.00053	0.0007	0.0003	0.00149	0.0412**
Production Diversity	0.1127	0.0291	0.0051	0.00127	0.0201	0.0046	0.0102	0.00420	0.0312***
Occupation	0.1109	0.0454	0.0076	0.00225	0.0316	0.0084	0.0290	0.00781	0.0211***
Level of Education	0.0150	0.0101	-0.001	0.00051	-0.00262	0.0021	0.0301***	0.00171	0.0251**
Household size	0.0021	0.0236	-0.001	0.00061	-0.00308	0.0035	0.0045	0.00217	0.0398
Tropical Livestock Unit	0.0066	0.0094	0.000	0.00041	-0.001	0.0017	-0.0009	0.00156	0.0005
Farm size	0.0000	0.0022	0.000	0.00033	2.61E-06	0.0006	0.0000	0.00054	0.0302**
Geographical location	-0.1076	0.0615	0.0042	0.00260	-0.0134	0.0114	0.0215	0.01042	0.0406**
Soil fertility	-0.0099	0.0560	0.000	0.00246	0.01595	0.0102	0.0015	0.00932	-0.0008
Membership	0.2010	0.0552	0.0065	0.00165	-0.0354	0.0117	0.0291	0.01007	0.0277***
Extension services	-0.0412	0.0769	0.002	0.00359	0.007573	0.0143	0.007	0.01245	-0.0039
Access to market	-0.0001	0.0001	0.010	0.00123	1.41E-05	0.0000	0.001	0.00002	0.0000
Plot ownership	0.1489	0.0810	-0.0051	0.00367	-0.02525	0.0108	0.0201*	0.01325	0.0311**

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Variables	Pr (Y = 4 X)	Std. Err.	Pr (Y = 5 X)	Std. Err.
Sex of the head of the household	0.0125*	0.0361	0.0161	0.0081
Age of the household head	0.0011	0.004	0.0010	0.0013
Farm experience	0.0406**	0.011	0.0540**	0.0085
Production diversity	0.0610***	0.009	0.0403***	0.0040
Occupation	0.0366***	0.016	0.0191***	0.0038
Level of education	0.0490**	0.001	0.0013	0.0010
Household size	0.0233	0.003	0.0302	0.0010
Tropical Livestock Unit	0.0041	0.002	0.0005	0.0008
Farm size	0.0411***	0.003	-0.0001	0.0003
Geographical location	0.0211***	0.019	0.0206**	0.0081
Soil fertility	-0.0018	0.011	-0.0008	0.0050
Membership	0.0408***	0.020	0.0190	0.0056
Extension services	-0.0084	0.016	-0.0036	0.0065
Access to market	0.0001	0.002	0.0011	0.0001
Plot ownership	0.0275***	0.025	0.0223	0.0062
/cut1	1.498165	0.319682		
/cut2	2.509412	0.380126		
/cut3	3.406715	0.322087		
/cut4	4.339516	0.327751		
/cut5	5.308471	0.390562		

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

The findings in Table 5 further show that having multiple jobs significantly influenced the adoption intensity of multiple SAPs. It was found that the probability of using three, four and five practices were 2.11, 3.66 and 1.91 per cent points, respectively, higher among farming households with multiple jobs compared to those with fewer occupations. These findings concur with those by Bongole (2021) in Tanzania but contradict those by Tuda *et al.* (2019) who found that multiple occupations decreased the intensity of using more than two practices in Malawi.

Male-headed households were more likely to use two, three and four practices by 3.40, 2.05, and 1.25 per cent points, respectively, higher than female-headed households. The findings support previous results by Asante *et al.* (2021) who reported that males are less preoccupied with daily family management duties, giving them more time to interact with extension workers. Additionally, male-headed households tend to have a better financial status partly due to their ability to work in multiple jobs. Similarly, Kapoor (2019) reported that male-headed households had greater access to cash as an asset compared to female-headed households, which was attributed to the higher hourly earnings of males in various occupational groups in Ghana.

Membership in farmer organizations had a significant impact to the intensity of SAPs usage. The findings indicate that the likelihoods of using two, three, and four practices were 2.77 and 4.08 per cent points, respectively, higher for members of farmer's organization. This can be attributed to the knowledge sharing platform provided by such settings, which played a critical role in increasing knowledge about SAPs and sharing success testimonies. The group pressure within the organization could serve as a push factor for intensifying the adoption of SAPs. These findings are consistent with findings of previous research by Teklewold *et al.* (2019) and Bongole (2021) who reported that membership in farmer organizations increased the intensity use of Good Agricultural Practices (GAPs) and Climate Smart Agricultural Practises (CSAPs) among farming households in Ethiopia and Tanzania respectively.

The results in Table 5 show a significant positive relationship between farm size and the number of SAPs used. This implies that farmers with larger farm sizes were 3.02 and 4.11 per cent points more

likely to use three and four practices, respectively, compared to those with smaller farm sizes. This is consistent with Akter *et al.* (2021) who found that land size positively influenced the number of agriculture-based technologies used by a farmer in rice-maize systems in Bangladesh. A plausible reason for this could be that a larger farm size serves as a security against the risk of crop failure.

Agricultural households in Kilosa district showed higher probability of using three, four and five practices by 1.02, 2.11, and 2.06 per cent points, respectively, compared to agricultural households in Mvomero district. The difference in the intensity of adoption of SAPs can be attributed to varying climatic conditions such as rainfall within their respective locations. This is consistent with Arslan *et al.* (2017) Bongole (2021) and Kassie *et al.* (2013) who concluded that farming households in developing countries such as Tanzania exhibit differentiation in their agricultural output due to varying climatic conditions and soil characteristics of their locations.

The likelihoods of using two, three and four practices were 2.01, 3.11, and 2.75 per cent points, respectively, higher on farms/plots that were owned versus rented farms/plots for agricultural production. Farmers who lease or rent plots of land may be hesitant to invest in agricultural technologies, particularly if the lease term is short or uncertain. The temporary nature of their access to the land limits their willingness to invest in technologies that may not yield immediate returns or that require long-term commitments. Moreover, lack of long-term control over land can discourage the adoption of technologies that require substantial investments or alterations to the plot. The findings are corroborated by Teklewold *et al.* (2019) who found comparable results in their Ethiopian study.

The study found that tropical livestock unit, household size, soil fertility, access to market and access to extension services were not significantly related to the adoption intensity of SAPs in the study areas. These findings are consistent with the previous research by Tuda *et al.* (2019) on Tropical livestock units in Ghana, Wainaina *et al.* (2016) on household size in Kenya, Mwaura *et al.* (2021) on soil fertility in Kenya, Kotu *et al.* (2017) on market access in Ghana and Wossen *et al.* (2017) on access to extension services in Nigeria.

Conclusions and Recommendations

The study concludes that the rate of SAPs adoption among the surveyed population was average, indicative of a moderate level of uptake. Furthermore, education level, occupation, farming experience, sex of the household head, farm size, plot ownership, geographical location, membership in farmers' organization and production diversity had significant impacts on the adoption intensity of multiple SAPs. Hence, the authors failed to accept the H_0 , implying that the adoption intensity can significantly be influenced by the socio economic, institutional and farm related factors.

There were greater disparities in the adoption intensity than in the adoption rates; the awareness and recognition of SAPs did not necessarily translate into increased usage while the socio-economic factors, institutional and farm related factors had significant influences on the adoption intensity of multiple SAPs. Thus, the study recommends that the interdependence nature of agricultural innovations should be considered in designing effective strategies for the development and dissemination of agricultural SAPs. Such an intervention should provide farmers with a choice among different sets of practices that possess desirable traits such as high yields, cost effectiveness, and suitability to local climatic conditions.

Given that diverse factors influence the different combination of SAPs, it is important that in designing incentives that smallholder farmers should use multiple SAPs; policymakers should take into consideration farm managerial, socio-economic and plot-specific factors to ensure that farmers can maximize the benefits of SAPs. Examples of such incentives include provision of training programs designed to enlightening farmers on the benefits of SAPs as well as on first-hand information on weather conditions. Furthermore, shock management strength of farmers should be well examined and considered when designing and executing dissemination schemes for different SAPs. Lastly, it remains a subject for further exploration to discern the potential impacts of adopting multiple SAPs on the production outcomes and overall welfare of smallholder maize farmers such as yield, household incomes and food security. Addressing this gap in adoption is crucial to unlock the full potential of these practices.

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CHAPTER FOUR PAPER III

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

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ABSTRACT

This paper uses a multinomial endogenous switching regression and data from a sample of 470 farming households to assess the impacts of adopting sustainable agricultural practices (SAPs) on farm yields and household incomes among smallholder maize farmers in Morogoro region. Results show that the following combinations had significant impacts on the maize yields: improved maize varieties with crop residual by (46%), maize-legume rotation with crop residual (49%), intercropping with crop residual (65%), improved maize varieties with manure use (58%), maize rotation with intercropping (57%), maize-legume rotation, intercropping, improved maize varieties with manure use (60%), intercropping with improved maize varieties (53%), improved maize varieties, intercropping, manure, crop residual and crop rotation (74%). Moreover, the model estimates indicate that individual elements of SAPs significantly increased yield by the following percents; crop residual (30%), improved maize varieties (63%), intercropping (53%), and manure (43%), whereas, the application of bundled SAPs had significant impacts on household income via the following combinations; maize-legume rotation with crop residual (50%), improved maize varieties with crop residual (46%), improved maize varieties with manure (70%), maize-legumes rotation with improved maize varieties (46%), maize rotation and intercropping (68%), maize rotation, improved maize varieties, crop residual, with intercropping (41%), intercropping and improve maize (57%), improved maize varieties, intercropping, manure, crop residual, and crop rotation (55%). Individual elements of SAPs significantly increased income by the following percentages; crop rotation (43%), improved maize varieties (63%), intercropping (45%), and manure (43%). 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 yields and incomes, while simultaneously addressing issues related to the dis-adoption of SAPs, and interventions to climate change, by raising awareness and educating 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 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 by a multitude of obstacles. These include decline in farm sizes due to the escalating pressure caused by rapid population growth, the degradation of the environment resulting from adverse effects of climate change, the persistent cultivation of soil without proper restorative practices, inadequate recycling of organic matter, and

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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 persistence of poverty in the smallholder farming community (Ethiakpor *et al.*, 2021).

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 diminish.

Additionally, the shortage 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, 2021). In addition, the overall economic development of a region or country can be hindered by the physical repercussions of unsustainable agricultural practices (Gebremariam & Wünsch, 2016). 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. An 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 in 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 increase production levels.

A worldwide discourse has emerged around the mitigation of adverse externalities associated with agricultural 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.

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) have 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 with each other. 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 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 incomes and yields in a cross-regional setting. 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) extensively examined the impact of adopting specific components or individual elements of SAPs, such as improved seed, irrigation, crop varieties' resilience to drought, climate change, soil and water conservation methods on outcome measures such as income, outputs, consumption spending, and food security. Thus, 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 the 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 (Ethiakpor *et al.*, 2021; Kassie *et al.*, 2013; Manda *et al.*, 2018; 2019; Setsoafia *et al.*, 2022; Usman *et al.*, 2020).

In addition, building 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 agricultural resources

(Marenya *et al.*, 2020). The focus on modelling adoption studies as a joint decision-making process is crucial, as it highlights the need for farmers to apply composite practices.

The study was designed to offer evidence on the impact of SAPs based on farmers' 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 validity 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 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 yields and incomes 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 agricultural 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 agricultural 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 (Bongole 2021; Kassie *et al.*, 2013; Manda *et al.*, 2016; Setsofia *et al.*, 2022).

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.*, 2013). 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 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 have 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 & Wünscher 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 incomes and maize yields 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
Teklewold 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
Marenya 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 from 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 employed in 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)

Table Cont'd				
Zeweld et al. (2017)	Decomposed Theory of planned behavior	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)
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

This study notes that previous studies on adoption of SAPs 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 was assumed that a household adopts SAPs if the expected utility from adopting is higher than the utility from dis-adopting. Following Feder et al. (1985), the return from land were assumed to be a function of the SAPs used.

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 yields is expected to enhance household incomes by allowing to sell surplus maize. In addition, the increased usage of SAPs could indirectly affect household incomes in two 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. 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, (Marennya 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 bundled SAPs, income, and yield among smallholder maize farmers.

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; Czyżewski 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; and 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 :

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

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; η_{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 λ_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 incomes

Package (<i>Exogenous</i>)	Ln maize per yield	Ln household income per capital
Crop residuals	26% (0.14)	15% (0.18)
Maize-legume rotation	36% (0.14)	31% (0.18)
Improved maize varieties	38% (0.13)	26% (0.16)
Maize-legume Intercropping	58% (0.14)	62% (0.17)
Manure use	43% (0.17)	-12% (0.22)
Maize-legume rotation and crop residual	58% (0.20) **	32% (0.31) **
Improved maize varieties and crop residual	39% (0.11) **	40% (0.16) *
Intercropping and crop residual	47% (0.20) *	29% (0.33)
Manure and crop residual	40% (0.17) **	-12% (0.26)
Maize-legume rotation and Manure	10% (0.27)	29% (0.21)
Improved maize and Manure use	50% (0.12) *	51% (0.17)
Intercropping and Manure use	10% (0.22)	33% (0.11) *
Maize-legume rotation, intercropping, improved maize and manure use	72% (0.15) *	38% (0.22)
Maize rotation and improved maize	43% (0.17) ***	38% (0.25)
Maize rotation and intercropping	55% (0.20)	59% (0.13)
Maize rotation, improved maize, Crop residual and intercropping	33% (0.17)	69% (0.23)
Intercropping and improved seeds	30% (0.21)	33% (0.18)
Improved maize, intercropping, manure, crop residual, and crop rotation.	51% (0.19)	38% (0.21) *
Package (<i>Endogenous</i>)	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 (<i>Selection term</i>)	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.

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 maize yield and household income.

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.

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 varieties and manure), (crop rotation, intercropping), (improved maize varieties and manure use), (maize rotation and intercropping), and (maize rotation and improved maize varieties) 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 varieties and intercropping which surprisingly outperforms the more comprehensive SAP packages. 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, it was found that combination of improved maize varieties and crop residual significantly increased maize yield by (46%), while intercropping with crop residual (65%), improved maize varieties 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.

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 (yield). 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 70% compared to non-adopters. 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 increase in

household income by 46%. Surprisingly, adopting all five SAPs as a package had lower income impacts compared to SAP packages involving improved maize combined with either intercropping 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.

Application of bundled SAPs had significant impacts on the household income via the following combinations: maize-legume rotation and crop residual (50%), improved maize varieties and crop residual (46%), improved maize varieties and manure (70%), maize rotation and improved maize varieties (46%), maize rotation and intercropping (68%), maize rotation, improved maize varieties, crop residual, and intercropping (41%) intercropping and improved maize varieties (57%), and lastly improved maize varieties, 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. In general, 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 varieties, 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.* (2013) 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 could have a significant 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 maize seeds. The adoption of the package that includes improved maize varieties only and the bundle consisting of improved maize varieties 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 of 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 farmers about the benefits of using SAPs and implementing mitigative measures for climate change. This includes providing 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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CHAPTER FIVE

PAPER IV

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

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ABSTRACT

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

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

I. INTRODUCTION

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



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

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

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

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

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

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



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

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

II. LITERATURE REVIEW

2.1 The concept of sustainable agriculture

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

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

2.2 Sustainable agricultural practices

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

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

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



Table 1
Selected sustainable agricultural practices for the study

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

Source: Dictionary of Agriculture (2006)

2.3 Linkage between SAPs, food security, nutrition and poverty

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

2.4 Empirical framework

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

**Table 2**

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

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

2.5 Theoretical framework

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

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

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



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

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

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

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

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

III. METHODOLOGY

3.1 Data

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

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

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

3.2 Econometric Framework

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

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

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

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

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

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



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

$$E[R_{1it} | Y = 1, X_{1it}, \gamma_{1t}] = \delta_1 X_{1it} + \sigma_{1\epsilon} \gamma_{1t} \dots \dots \dots (ii)$$

Then the ATT is presented as follows:

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

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

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

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

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

3.2 Description of the outcome variables

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

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

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

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

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

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

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

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



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

IV. RESULTS & DISCUSSIONS

4.1 Weak instrument test

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

Table 3

Endogeneity Test and Weak Instrument Robust Tests for IV

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



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

Table 3:
Average treatment effect of SAPs adoption on FCS, HDDS and HFIAS

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

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

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

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

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



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

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

Table 4

Average Treatment Effect of SAPs on poverty indices

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

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

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



V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

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

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

5.2 Recommendations

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

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CHAPTER SIX

6.0 Introduction

This thesis is concluded in the final chapter. Inspired by the widespread occurrence of low rates of adoption of SAPs, this thesis sought to close the four research gaps that were found. Following this study and directly arising from it are policy ideas that offer broad implications for various situations and countries while concentrating on Tanzania's agriculture sector. Research limitations and implications also provide potential avenues for future investigation.

6.1 Summary of Major Results and Conclusions

SAPs are a mechanism for improving agricultural sustainability in terms of production, environmental health, and social wellbeing. SAPs have not been adopted by most farmers in many countries despite considerable investment and public policies being formulated. Motivated by this phenomenon, smallholder maize farmers in Morogoro regions have been chosen as a case study.

This thesis has been dedicated to generating a greater understanding of the farmer behavior under which SAPs adoptive decisions are being made by Tanzanian smallholder maize farmers along with adoption impacts on yields, incomes, and food security. This has been achieved by fulfilling the four objectives of this thesis whose results and conclusions are summarized in sub-sections 6.1.1, 6.1.2, 6.1.3, and 6.1.4.

- I. Assess the determinants of adoption of multiple SAPs among smallholder maize farmers in the study area.
- II. Assess the rate and intensity of adoption of multiple SAPs among smallholder maize farmers in the study area.
- III. Evaluate the economic impact of adopting multiple SAPs on yields and incomes of smallholder maize farmers in the study area.
- IV. Evaluate the impacts of adopting multiple SAPs on food security, nutrition, and poverty indices among smallholder maize farmers in the study area.

Thus, the adoption of multiple SAPs has been analyzed in relation to yields, incomes and food security among smallholder maize farmers in Morogoro region. The study has been motivated by the theories of utility maximizing and diffusion of innovation in light of this intricacy. Dataset from adoption pathway project was utilized, with the utility maximization framework and diffusion innovation theory serving as a guide. First, in order to produce valuable input on survey operations and questionnaire design, focus groups were held. Second, in-person interviews using interview guide and survey using questionnaires were carried out with 470 respondents who were randomly selected.

6.1.1 Rate and Intensity of Adoption of Bundled Sustainable Agricultural Practices

This study was conducted with the primary objective of assessing the adoption rate, intensity, and determinants to the adoption intensity of SAPs. It was found that the rate and intensity of SAPs adoption among the surveyed population was average, indicative of a moderate level of uptake. It is noteworthy that a substantial proportion of farmers were implementing one to three practices, either individually or in combination. However, it remains a subject for further exploration to discern the potential impacts of adopting multiple SAPs on the production outcomes and overall welfare of smallholder maize farmers. Addressing this gap in adoption is crucial to unlock the full potential of these practices. Furthermore, the findings show that education level, occupation, farming experience, sex of the household head, farm size, plot ownership, geographical location, membership in farmers' organization, and production diversity had significant impacts on the adoption intensity of multiple SAPs.

The findings offer a number of vital implications for policy. As evidenced in the results, it is concluded that agricultural innovations are interdependent. This suggests that the interdependence nature of agricultural innovations should be considered in designing effective strategies for the development and dissemination of agricultural SAPs in Tanzania, as well as in other developing countries.

Giving that diverse factors influence the different combination of SAPs, it is important that in designing incentives for smallholder farmers to use multiple SAPs, policymakers should take into consideration several farm managerial, socio-economic and plot-specific factors to ensure that farmers can maximize the benefits of SAPs. Examples include provision of training programme designed to enlightening farmers on the benefits of SAPs, as well as on first-hand information on weather conditions. Also, shock management strength of farmers should be well examined and considered when designing and executing dissemination schemes for different SAPs.

6.1.2 Determinants of the Adoption of Multiple Sustainable Agricultural Practices

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.

6.1.3 Economic Impact of Adopting Bundled SAPs on Yields and Household Incomes

The findings reveal that SAPs adopted in combination or as a package are more effective than those adopted in isolation except for the improved maize varieties. The adoption of the package that includes improved maize varieties only and the bundle consisting of improved maize varieties 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 varieties 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 conventional practices.

Intercropping, manure, crop residual, improved maize varieties are more successful in lowering input costs and raising yields, as the research has shown. However, it also highlights how sustainable agriculture supports economic sustainability. Given that the majority of farmers prioritize crop yields, this research is essential from an economic perspective, it is possible to outperform the weakest component in the bundle' relative advantages, which are economic benefits.

6.1.4 Impact of Adopting Bundled SAPs on Food Security, Nutrition, and Poverty indices

Previous research indicates that farming households in the Morogoro region continue to experience poverty, nutritional inadequacies, and food insecurity despite government measures to boost SAP adoption for enhancing food security and reducing poverty by 2030. Low SAPs adoption rates have made these problems worse by resulting in low maize yields, which has made food and nutrition insecurity in agricultural households worse. As a result, recent initiatives have centered on advancing affordable, climate-resilient SAPs.

By using an endogenous treatment effect model to analyze the effects of implementing SAPs on food security, nutrition, and poverty, this study offered a fresh viewpoint. Crop rotation, intercropping, improved maize varieties, and crop residuals considerably increased food security and nutrition. Remarkably, the only practice in the bundle that had a substantial effect on poverty indices was the use of improved maize varieties. In order to improve food security, nutrition, and poverty alleviation among farming households in various agro-ecological contexts throughout Tanzania, it is imperative that multiple SAPs be used concurrently.

6.2 General Recommendations

The adoption of SAPs is a somewhat complicated set of behaviors, and policy creation in this area should take that into consideration. It involves economic issues. Prior to legislating in this domain, a general understanding from a multidisciplinary perspective is required, as no one factor can fully explain the voluntary action. Keep in mind that a deeper knowledge of SAP adoption is frequently provided by the economic perspective. The following are recommendations based on the results provided in the study.

Policymakers should focus on variables that show a stronger impact on SAPs adoption. Tanzania, for instance, needs to concentrate especially on the availability and caliber of resources across regional boundaries. Tailored efforts are required in the promotion of sustainable agriculture to accommodate the unique requirements of individual districts or regions. Additionally, the local policy ought to highlight the role that financial systems play in facilitating SAPs investment.

Extension efforts should primarily concentrate on SAPs' relevant factors. This frequently occurs as a result of farmers' inadequate knowledge of their ability to maximize output and reduce input costs. Furthermore, local communities have been primarily engaged in the promotion of sustainable agriculture through the use of standardized information created by the Government, such as extension services. It has not been customary to consider how the regional heterogeneity of resources affects the viability of SAP's application. In actuality, a subset of SAPs may be more applicable to particular crops in particular regions.

Promoting sustainable agriculture as a one-size-fits-all approach is inappropriate. Repositioning sustainable agriculture as a relevant and commercially feasible farming system should be the aim of an enhanced strategy. This method must be multifaceted in order to do this, given the complexity of farming systems and decision-making on farms. Farmers' field schools and participatory research, for instance, are useful for demonstrating local farming practices and disseminating extension

messages where farmers can become familiar with SAPs and see their obvious financial benefits.

Furthermore, some SAPs can be marketed to prospective adopters as an affordable "starter pack". For first-time users, the "starter pack" includes a series of profitable SAPs along with the necessary guidelines for putting the suggested practices into practice. In this instance, promoting SAPs to Tanzania's agricultural sector should emphasize intercropping, improved maize varieties and manure. When suggesting certain types of improved seeds and manure and crops that are compatible for intercropping, much thought should be provided. It is crucial to make such customization efforts in order to represent the unique circumstances of different locations. Farmers will feel more confident and be able to begin investing in sustainable agriculture at a reduced risk when they see the value of the "starter pack" in relation to reality. Farmers can gradually adopt more pertinent SAPs as they prove to be successful.

6.3 Contribution of the Research

6.3.1 Contribution to Literature

Integrated Framework for Adoption Studies

The thesis introduces and applies an integrative framework that combines the utility maximization theory and the theory of diffusion of innovation. This framework provides a holistic approach to understanding the complex adoption behaviors among smallholder farmers, considering both economic and social factors. This contribution enhances the theoretical foundation for future studies on SAPs adoption.

Simultaneous Adoption Patterns

The thesis contributes to the literature by revealing that smallholder maize farmers tend to adopt SAPs concurrently, treating them as a package. These findings challenge traditional approaches that may focus on individual practices and underscores the need for policymakers to consider the interdependence of sustainable agricultural innovations.

Adoption Intensity Determinants

The study goes beyond adoption rates and investigates factors influencing adoption intensity. The findings shed light on disparities in the intensity of SAP adoption, emphasizing the importance of considering various factors beyond awareness and recognition when designing effective dissemination strategies.

Economic Impacts on Yield and Incomes

The thesis provides detailed insights into the economic impacts of specific combinations of SAPs on maize yields and household incomes. This contribution enhances the literature by offering a nuanced understanding of the synergistic effects and individual contributions of different practices to agricultural productivity and economic well-being of farming households.

Food Security and Poverty Alleviation

The study contributes to the literature by demonstrating the positive impacts of SAPs, particularly improved maize varieties, on household food security and poverty alleviation. This finding emphasizes the broader socio-economic benefits of sustainable agricultural practices beyond immediate productivity gains.

Policy Recommendations and Future Directions

The study concludes with practical policy recommendations based on the identified factors influencing SAPs adoption and their economic impacts. These recommendations provide actionable insights for policymakers, agricultural development organizations, and other stakeholders, contributing to the practical application of research findings.

6.3.2 Contribution to Methodology

Integration of Theoretical Frameworks:

The thesis introduces and applies an integrative framework that combines the utility maximization theory and the theory of diffusion of innovation. This integration provides a comprehensive and multidimensional approach to understanding the adoption process.

By combining economic utility considerations with social aspects related to innovation diffusion, the framework offers a more holistic lens for studying complex behaviors associated with SAP adoption.

The thesis contributes to the methodological landscape by employing a well-integrated, multifaceted approach. The use of advanced statistical techniques, such as multivariate regression, ordered probit analysis, multinomial switching regression, and endogenous switching regression, enhances the robustness of the study. Additionally, the incorporation of both quantitative and descriptive elements reflects a methodological richness that advances the understanding of SAP adoption among smallholder maize farmers in Tanzania.

6.3.3 Contribution to Theory

The thesis makes significant contributions to theoretical frameworks related to the adoption of SAPs among smallholder maize farmers in Tanzania. The key contributions to theory include:

Integrated Framework for Adoption Studies

The introduction and application of an integrative framework that combines the utility maximization theory and the theory of diffusion of innovation contribute to theoretical advancements. This framework recognizes the multidimensional nature of SAPs adoption, integrating economic utility considerations with social and innovation diffusion factors. This theoretical integration offers a more comprehensive understanding of the complex decision-making processes involved in adopting sustainable practices.

Complexity of Adoption as a Behavior

The thesis addresses the complexity of adoption as a behavior influenced by both economic and social aspects. By acknowledging that adoption decisions are shaped by factors beyond economic considerations, the study advances theoretical perspectives on the dynamics of agricultural innovation adoption. The incorporation of diverse factors, including age, gender, education, and access to extension

services, contributes to a nuanced understanding of the interplay between individual, social, and institutional factors.

Synergistic Adoption of SAPs as a Package

The finding that smallholder maize farmers adopt SAPs concurrently and treat them as a package contributes to theoretical frameworks on innovation adoption. This challenges traditional views that may focus on individual practices and emphasizes the interconnectedness of sustainable agricultural innovations. The theoretical insight encourages policymakers and researchers to view SAPs holistically, recognizing the synergistic effects between different practices.

Adoption Intensity and Disparities

The exploration of adoption intensity and the identification of factors influencing the degree of SAPs adoption contribute to theoretical perspectives on the heterogeneity of adoption behaviors. By recognizing that farmers may differ not only in their adoption decisions but also in the intensity of adoption, the study enriches theoretical discussions on the diverse ways in which farmers engage with and integrate sustainable practices into their agricultural systems.

Endogenous Switching Regression for Household Outcomes

The application of endogenous switching regression to assess the impact of SAPs on household food security and poverty alleviation contributes to theoretical advancements in understanding the causal relationship between adoption and outcomes. This methodological approach recognizes the endogeneity of the adoption decision and its simultaneous impact on household well-being, providing a nuanced perspective on the theoretical underpinnings of SAPs adoption and its broader socio-economic implications.

Practical Implications for Policy Design

The thesis bridges theoretical frameworks with practical implications by offering recommendations tailored to policymakers. The integration of theoretical insights into actionable policy recommendations advances the theoretical discourse on the application of research findings to real-world interventions, emphasizing the importance of considering diverse factors in policy design.

In summary, the thesis contributes to theoretical advancements by offering a more nuanced understanding of SAP adoption through the integration of diverse theoretical frameworks. The recognition of adoption as a complex behavior influenced by economic, social, and institutional factors, along with the consideration of adoption intensity and disparities, enhances theoretical perspectives on sustainable agricultural innovation adoption. The study's contributions have implications for shaping future theoretical discussions and guiding empirical research in the field of agricultural innovation and sustainability.

6.4 Proposed Areas for Future Research

Beyond this concept, given the variety of agricultural advances accessible for study, a vast array of farm issues can be studied under the umbrella of adoption. Recent research topics include inputs (hybrid seeds, genetically engineered seeds), outputs (precision technologies, organic approaches), and climate change adaptation strategies. Their objectives are concentrated on a variety of environmental and natural resource management concerns that have been recognized by a range of human institutions (such as the government and consumers) in a variety of geographical contexts (such as a nation or area). It is possible to formulate pertinent research questions/hypothesis on a specific innovation from a variety of contextual perspectives.

6.4.1 Research Approach

Before beginning research design, researchers should conduct a comprehensive review of the existing literature. In addition to the vote count approach, meta-analysis is another way to assess the results of a research strand. Both approaches result in a knowledge bank of what is known and what needs more research, despite their relative complexity. Making decisions on farms requires careful thought. Therefore, in order

to comprehend adoption from a multidisciplinary perspective, an integrative approach is required. This method provides a theoretical framework for analyzing adoptive behavior, which is a result that goes beyond economic consideration and is more in line with close observation.

6.4.2 Research Techniques

Any preliminary research should begin with a model that is applicable to everybody. The results show which attribute is most valued and which is least valued after refinement. Because adoptive behavior is so complicated, an integrated model would probably be a better fit. But such a model is limited in its ability to analyze a wider variety of parameters.

Empirical data regarding the profitability of SAPs is required. Even though SAPs that are managed well should be profitable, their short- and long-term financial returns differ. It is advised that more research be done in the future, paying close attention to the relevant time period. Which SAP is more result-effective will be demonstrated by short-term profitability, which will draw in new users. Adopters will be persuaded to continue using SAPs by information demonstrating which SAP results in long-term economic sustainability.



Kuhusu Tasnifu Hii

Utafiti huu ulifanyika katika wilaya za Kilosa na Mvomero ili kuchunguza athari za kutumia kanuni za kilimo endelevu (SAPs) kwenye mavuno, mapato na usalama wa chakula miongoni mwa wakulima wadogo wa mahindi. SAPs zilizofanyiwa utafiti ni pamoja na mzunguko wa mazao, kilimo mseto, aina bora za mahindi, samadi, na mabaki ya mazao. Mkoa wa Morogoro ulitumika kama kielelezo. Utafiti ulitumia takwimu iliyowekwa kutoka kwenye mradi wa njia ya kuasili. Takwimu za ubora na kiasi ambazo zilikusanywa kwa kutumia dodoso, mijadala ya vikundi lengwa na usaili wa kina, kisha kuchakatwa na kuchambuliwa. Utafiti uligundua kuwa kiwango cha utumiaji wa SAPs kati ya watafitiwa kilikuwa cha wastani, wakati mambo ya kiuchumi ya kijamii yalionekana kuwa muhimu kwa kupitishwa kwa SAPs kwa wakati mmoja, zaidi ya hayo, SAPs zilizopitishwa kwa pamoja au kama kifurushi zilikuwa na ufanisi zaidi kuliko zile zilizopitishwa kwa kujitegemea katika kuboresha mavuno ya mahindi na mapato ya kaya. Matumizi ya SAPs hasa mbegu bora za mahindi ziliongeza uhakika wa chakula na lishe miongoni mwa kaya za wakulima. Utafiti unapendekeza watunga sera na mashirika ya kilimo kuzingatia sifa za kijamii na kiuchumi za wakulima katika mikakati yao. Msisitizo juu ya mwingiliano wa SAPs, kutetea mchanganyiko mzuri ili kuongeza matokeo, afua lengwa, iliyoundwa mahsusi kwa kaya zisizo na chakula na zilizo katika mazingira magumu za kilimo, zinazolenga kutokomeza njaa na kushughulikia upungufu wa lishe kati ya kaya za wakulima.