The impact of the adoption of sustainable agricultural practices on farm income and household food security in Northern Ghana

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The adoption of sustainable agricultural practices (SAPs) has been recommended by many experts and international institutions to address food security and climate change issues. Global support for the Sustainable Development Goals (SDGs) has focused attention on efforts to up-scale the use of SAPs in developing countries where growth in populations and incomes is compromising the resilience of natural resources. However, little is known about the effects of these practices in West Africa. Therefore, this thesis sets out to investigate the factors that influence the adoption of SAPs by smallholders in northern Ghana and the effects of adoption on farm income and food security. The study achieved this by *(i)* Comparing food security measures and investigating the determinants of household food security (HFS); *(ii)* Investigating the factors that influence smallholder farmers' decisions to adopt multiple SAPs; *(iii)* Estimating the impacts of SAPs adoption on the gross margins and food security status of smallholder farmers; and *(iv)* Examining the heterogeneous effect of SAPs adoption and its impact on food security of smallholders in northern Ghana.

This thesis utilizes different econometric approaches to achieve the targeted objectives. Specifically, seven measures of household food security, spearman's rho correlation, percentages and a probit regression were used in achieving objective (*i)*. The multinomial endogenous switching regression and the marginal treatment effects model were used in realizing the objectives (*ii)*, (*iii)* and (i*v)*. Primary data covering 494 households were collected and used in the analysis of objectives (*i)* and (*iv)*. Secondary data from the Africa RISING project covering 1284 households and 5500 plots were used to estimate objectives (*ii*) and (*iii)*.

The thesis's results revealed strong correlations between food consumption score (FCS) and household dietary diversity(HDD), between household food insecurity access scale (HFIAS), household hunger score (HHS), coping strategy index (CSI) and reduced coping strategy index (rCSI), and between self-assessed food security (SAFS) and HFIAS. Food insecurity prevalence varied across the measures with HDD giving the least prevalence whilst FCS and HFIAS gave the highest prevalence of food insecurity. Social demographics of the households, plot characteristics, location, extension, satisfaction with extension, and membership in Africa

RISING farmer-based organisation (FBO) were the main factors influencing the adoption of multiple SAPs. Results from the treatment effect estimations indicated that adopting SAPs had a positive influence on farm income and food security, and farmers adopting improved seeds, fertilizer use and soil and water conservation practices simultaneously, appear to benefit more than their counterparts adopting individual SAPs. The results indicated positive selection on gains from adoption across both HDD and FCS, suggesting that households who are more likely to adopt SAPs usually benefit more in terms of food security from adoption. Our findings suggest that the adoption of multiple SAPs and their impacts on farm income and food security in Northern Ghana can be improved through interventions and policies that advocate the adoption of multiple SAPs, provide input subsidies, improve extension service, and encourage farmer group membership, and engagement in off-farm work

Keywords: Sustainable Agricultural Practices (SAPs); Food security; Farm income; Spearman rho; Probit regression; Impact evaluation; Northern Ghana

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List of Abbreviations

Abbreviations	Meaning
ADVANCE	Agricultural Development and Value Chain Enhancement
AfricaRISING	Africa Research in Sustainable Intensification for the Next Generation
AR	Africa RISING
CAPI	Computer Assisted Personal Interviewing
CFSVA	Comprehensive Food Security and Vulnerability Analysis
CSI	Coping Strategy Index
EBFMPS	Ecosystem-Based Farm Management Practices
FANTA	Food And Nutrition Technical Assistance Project
FAO	Food And Agriculture Organisation
FCS	Food Consumption Score
FEWS NET	Famine Early Warning Systems Network
GDP	Gross Domestic Product
GFSI	Global Food Security Index
GSS	Ghana Statistical Service
HDD	Household Dietary Diversity
HFIAS	Household Food Insecurity Access Scale
HFS	Household Food Security
HHS	Household Hunger Score
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
LEAP	Livelihood Empowerment Against Poverty
MESR	Multinomial Endogenous Switching Regression
MDG	Millennium Development Goals
MOFA	Ministry Of Food and Agriculture
MTE	Marginal Treatment Effects
MUAC	Mid-Upper Arm Circumference
NGO	Non-Governmental Organisation
OLS	Ordinary Least Squares
PSM	Propensity Score Matching
rCSI	Reduced Coping Strategy Index
SAFS	Self-Accessed Food Security
SANREM CRSP	Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program
SAPS	Sustainable Agricultural Practices
SAIPS	Sustainable Agricultural Intensification Practices
SIPS	Sustainable Intensification Practices
SDG	Sustainable Development Goals
SSA	Sub-Sahara Africa

UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
WHO	World Health Organisation
WFP	World Food Programme

Chapter 1
Introduction

1.1 Background

Food security has long been an issue of global importance. However, the increasingly negative impact of climate change on food production means there is a greater urgency in the calls for action to tackle food security challenges. According to FAO, IFAD, UNICEF, WFP, and WHO (2020), 2 billion people out of the world's population of 7.8 billion are experiencing moderate to severe food insecurity, with the majority of this number found in Asia and Africa. Out of this number, 250 million people in Africa are classified as undernourished. The report also indicates that the rate of people being undernourished is higher in Africa than in any other part of the world. The situation in sub-Sahara Africa (SSA) is worsened due to heavy reliance on rainfed agriculture, fluctuations in food supply and poor management of the region's natural resources (Adamu, Bawa, & Tukur, 2021; Erdoğan, Çakar, Ulucak, & Kassouri, 2021; Huss, Brander, Kassie, Ehlert, & Bernauer, 2021; Lamptey, 2022). The situation can also be attributed to high population growth rates, climate change, and endemic poverty in some parts of the region (Adeyeye, Ashaolu, Bolaji, Abegunde, & Omoyajowo, 2021; Akuriba, Akudugu, & Alhassan, 2021; Maja & Ayano, 2021).

According to the WFP (2021), about 1 million people in Ghana are food insecure, with northern Ghana still categorized as a high-priority area in terms of addressing food insecurity. Northern Ghana (made up of the Northern, Upper East, Upper West, Savannah and North East regions) falls within the Sudan savanna and guinea zones of Ghana's agroecological zone (Agula, Akudugu, Dittoh, & Mabe, 2018; MoFA, 2019). It is the worst-hit area in the country in terms of climate change issues. The area often experiences drought, depletion of water resources, unpredictable weather conditions and low soil fertility (Tinonin et al., 2016b). With people in the area depending almost exclusively on agriculture for their livelihood, it is no surprise that one of the major reasons for food insecurity identified by the World Food Program (WFP) is limited agricultural outputs and the increasing inflation rates due to the Covid-19 pandemic (Tinonin et al., 2016b; WFP, 2013, 2021). Apart from the governmental interventions, there have been several interventions led by nongovernmental organisations (NGOs) to enhance agriculture productivity, farmer income, and food security. Examples of such interventions from NGOs include Feed the Future Agriculture Technology Transfer project, the Africa RISING project, and the ADVANCE project.

Sustainable agricultural practices (SAPs) (or elements of SAPs) are one of the interventions introduced by the change agents (e.g., the Africa RISING project) to improve farm productivity and farm income. Evidence shows there is potential for sustainable agricultural practices (SAPs) to reduce the negative impacts of climate variability in smallholder agriculture (Yahaya, 2015). SAPs have been credited with improving yields which could translate into reducing food insecurity. These practices include different agronomic practices such as improved seeds, appropriate use of inorganic fertilizer, cereal legume rotations, mixed cropping, soil bunds, terracing, composting, and mulching. It is generally believed that improving agriculture by enhancing productivity is a key strategy for alleviating rural poverty and food insecurity (Darko, Palacios-Lopez, Kilic, & Ricker-Gilbert, 2018; Maziya, Mudhara, & Chitja, 2017).

1.2 The challenge and need for SAPs

There is considerable pressure on agriculture to meet the demands of a growing world population, which is projected to increase to 9.2 billion by 2050. This is evident in the rising demand for necessities such as food, raw materials for industries, and biofuels (Nchanji, Bellwood-Howard, Schareika, Chagomoka, & Schlesinger, 2017; Portney, 2015; Pretty & Bharucha, 2014). According to Calicioglu, Flammini, Bracco, Bellù, and Sims (2019) growth in agricultural production globally does not match this demand well especially, in parts of Africa. These pressures are made even more complex with agriculture being the major contributor to the world's greenhouse gas emissions (IPCC, 2014). Africa has been projected to be vulnerable to climate change effects because of its proximity to the equator (Abdulai, 2018). Some of the effects on Africa include rising sea levels, temperature and rainfall changes which negatively impact agricultural productivity, farm income, food security and economic development in the region. The livelihoods of the poor and food insecure in Sub-Saharan Africa (SSA) are tied to agriculture; therefore, most international institutions, recognize agriculture as a significant channel for reducing food insecurity and poverty in the region (Darko et al., 2018; Leonardo, van de Ven, Kanellopoulos, & Giller, 2018).

Sustainable agriculture management may be the solution to this challenge, according to experts (Dobermann & Nelson, 2013; FAO, 2011; Montpellier Panel, 2013; Portney, 2015; Pretty & Bharucha, 2014). Sustainable agriculture management is defined as…. "the management and conservation of the natural resource base, and the orientation of technological change in such a manner as to ensure the attainment of continued satisfaction of human needs for present and future generations. Sustainable agriculture conserves land, water, and plant and animal genetic resources, and is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO, 1988).

This approach is expected to increase agricultural production whilst reversing the negative degradation processes of the agroecosystem, particularly in smallholder farming systems (Ehiakpor, Danso-Abbeam, & Mubashiru, 2021; FAO, 2011; Gebremariam & Wünscher, 2016). This is an upgrade of the green revolution which led to a significant increase in agricultural productivity globally and is credited for jump-starting economies in Asia out of poverty but has left negative externalities such as deforestation, land degradation, salinization of water bodies, loss of biodiversity etc. in its wake. The green revolution model consisted of the introduction of higher-yielding varieties of main staples such as maize, wheat, and rice with heavy reliance on complementary inputs such as irrigation, fertilizer, and pesticides. It promoted homogeneity and focused on high-potential areas.

To reverse the negative externalities from crop intensification, farmers have been advised to adopt sustainable agricultural practices which comprise elements of the green revolution as well as an agronomic revolution. These practices have been given different typologies by different authors, which can be used interchangeably. Some authors call them sustainable intensification practices (SIPs) (Kassie, Teklewold, Jaleta, Marenya, & Erenstein, 2015; Kotu, Alene, Manyong, Hoeschle-Zeledon, & Larbi, 2017). Whilst others called them sustainable agricultural practices (SAPs). (Gebremariam & Wünscher, 2016; Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Teklewold, Kassie, Shiferaw, & Köhlin, 2013) .Still, other names can also be found in the literature. For example, Yahaya (2015) referred to them as sustainable agricultural intensification practices (SAIPs) and Agula et al. (2018) called them Ecosystem-based farm management practices (EBFMPs). This thesis follows the terminology of Gebremariam and Wünscher (2016) and self-assessed.

1.3 Adoption of SAPs in Africa

SAPs are needed everywhere but particularly in smallholder agriculture in Africa. This sector is bedevilled by a myriad of problems, including poor soils, poor infrastructure, climate change, inefficient markets, loss of agrobiodiversity and production inefficiencies, which aggravate issues of productivity, farm incomes, food, and nutrition insecurity (Armah, Al-Hassan, Kuwornu, & Osei-Owusu, 2013; Kassie et al., 2013; MoFA, 2019; Yahaya, 2015). It is not surprising that the original concept of SAPs was proposed in the African context, due to the low agricultural productivity and the degradation of natural resources recorded there at the time.

According to Pretty, Toulmin, and Williams (2011) work began in the 1990s in terms of developing SAPs in Africa through the Foresight Global Food and Farming project. This project took place in 20 countries in Africa (such as Ethiopia, South Africa, Uganda, and Zimbabwe) and there is evidence of the multiplicative benefits to farming families. According to Dalton, Yahaya, and Naab (2014) and Paul Nkegbe and Shankar (2014) farmers are aware of soil erosion, fertility and climate change issues in their production systems and often take steps such as stone bunding, terracing and grass strips ("indigenous SAPs") as possible solutions to these issues. While some of these practices are like those recommended by experts, they may vary in terms of application processes and management.

In Ghana, there is evidence of the adoption of various elements of SAPs, while some studies (Agula et al., 2018; Paul Nkegbe & Shankar, 2014) attribute the source of some knowledge of the technologies to indigenous knowledge. Other authors attribute it to the efforts of NGOs such as the International Institute of tropical agriculture's (IITA) Africa RISING project and the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP) (Kotu et al., 2017; Yahaya, 2015). Some studies have suggested that adopting the practices, particularly in Northern Ghana, is part of farmers' adaptation strategies to climate change (Abdulai & Huffman, 2014; Gebremariam & Wünscher, 2016).

1.4 Research problem

In developing countries such as Ghana, increasing food availability is vital for addressing food insecurity. Increases in agricultural productivity could mean farming households can access food for home consumption and commercialization. While increasing agricultural productivity improves food availability, Burchi and De Muro (2016) argue that food availability though crucial is not enough to solve the food insecurity issue. The food available should also meet the taste and preferences of the household. Although the NGOs and governmental institutions have made significant efforts to increase smallholder agricultural productivity, northern Ghana continues to experience high levels of poverty, food and nutrition insecurity (WFP, 2013).

The literature is filled with studies on the adoption of specific elements of SAPs such as improved seed and soil and water conservation practices and their effect on yield and net farm income (Abdulai & Huffman, 2014; Arslan, McCarthy, Lipper, Asfaw, & Cattaneo, 2014;

Becerril & Abdulai, 2010; Kassie, Jaleta, & Mattei, 2014; Kunzekweguta, Rich, & Lyne, 2017; Ng'ombe, Kalinda, & Tembo, 2017; Paul Nkegbe & Shankar, 2014). Despite the potential complementarity or substitutability of specific elements of SAPs, there is limited research on the adoption of multiple SAPs and their effect on outcome variables such as income, outputs and consumption expenditure (Agula et al., 2018; Gebremariam & Wünscher, 2016; Kassie et al., 2014; Kotu et al., 2017; Teklewold et al., 2013)

Most of the literature on multiple adoption of SAPs focuses on Southern and Eastern Africa (Kassie et al., 2014; Kassie et al., 2013; Kassie, Teklewold, et al., 2015; Kunzekweguta et al., 2017; Mutenje, Kankwamba, Mangisonib, & Kassie, 2016; Ng'ombe et al., 2017; Teklewold et al., 2013), with few studies in West Africa. Adoption of elements of SAPs has been said to be context-specific because there are no blueprints of the various combination of SAPs that work in every environment. Different mixes usually result in different agricultural outcomes. With significant differences in the agroecological, socio-political and institutional conditions across these areas, factors affecting adoption and impacts are likely to differ in the Ghanaian setting.

A growing number of studies have shown that the adoption of multiple SAPs enhances agricultural productivity (Kotu et al., 2017; Montpellier Panel, 2013; Pretty & Bharucha, 2014). Some studies have explored the effect of SAP adoption on household consumption expenditure and poverty, but focused on single elements of SAPs such as improved seed and irrigation (Kassie et al., 2014; Kunzekweguta et al., 2017). To date, very few studies have investigated whether increased productivity due to SAPs adoption does translate into food security, especially in a context considering multiple SAPs.

1.5 Objectives of the thesis

The main objectives of the thesis are to improve our understanding of the role of multiple SAPs adoption in affecting sustainable agricultural production and estimating the impacts of SAP adoption on farm income and food security of smallholder farmers in Northern Ghana. Specifically, this thesis aims to:

i. Compare food security measures and investigate the determinants of household food security (HFS).

ii. Determine the factors that influence whether or not smallholder farmers adopt multiple SAPs.

iii. Estimate the impact of SAPs adoption on the gross margins and food security status of smallholder farmers.

iv. Examine the heterogeneous effect of SAPs adoption and its impact on food security of smallholders in northern Ghana.

1.6 Relevance of study

This thesis seeks to provide empirical information on the various combinations of SAPs adopted and the factors influencing the adoption of SAPs in Northern Ghana. These findings will help government institutions and NGOs formulate programmes and policies that are best suited for enhancing the adoption of SAPs in northern Ghana. The thesis adds to the limited research on the adoption of multiple SAPs. It throws more light on the potential complementarity or substitutability of the various elements of SAPs. Addressing these inter-relationships reduces the risk of underestimating or overestimating the influence of the various factors on the adoption decision and the impacts of adoption (Abdulai & Huffman, 2014).

We also provide empirical insights into the determinants of food security, using four measures of household food security. Examining the convergence of these food security measures using Spearman's rho provides information, which will aid government agencies and NGOs in the selection of appropriate HFS measures to employ depending on the goal of the intervention. Most past studies focused on other proxies of household welfare such as net farm income, net crop income per acre and consumption expenditure rather than the food security status of farm households (Gebremariam & Wünscher, 2016; Kassie, Teklewold, et al., 2015; Kotu et al., 2017). The use of food security as a proxy measure for welfare is particularly important in the Ghanaian context, where farming is undertaken on a subsistence level, and farmers sell crops as and when they need cash. Thus, farmers may be food secure but may not have a high net farm income or high consumption expenditure. Analysis of the effect of the adoption of SAPs on food security will highlight the relationship between SAP adoption and food security. We also provide evidence as to whether adopting SAPs improves farm income and household food security.

1.7 Thesis outline

This thesis is organized into six chapters. Chapter one gives a general introduction to this thesis. In Chapter two, we give a general overview of the methodology, study area and data used. Chapters three to five are manuscripts to be submitted for journal publication (chapters 3 & 4 have been submitted and are currently under review for publication). Specifically, chapter three assesses the convergence of seven measures of household food security and the determinants of household food security. Chapter four examines SAPs adoption and its impacts on farm income and food security using a multinomial endogenous switching regression model. Chapter five examines the heterogeneous effects of SAPs adoption on the food security of smallholders using the marginal treatment effect model. Chapter six presents the summary, conclusions, and policy implications of this study. Figure 1 shows how the objectives are analysed and translated into Chapters 3,4 and 5 of this thesis.

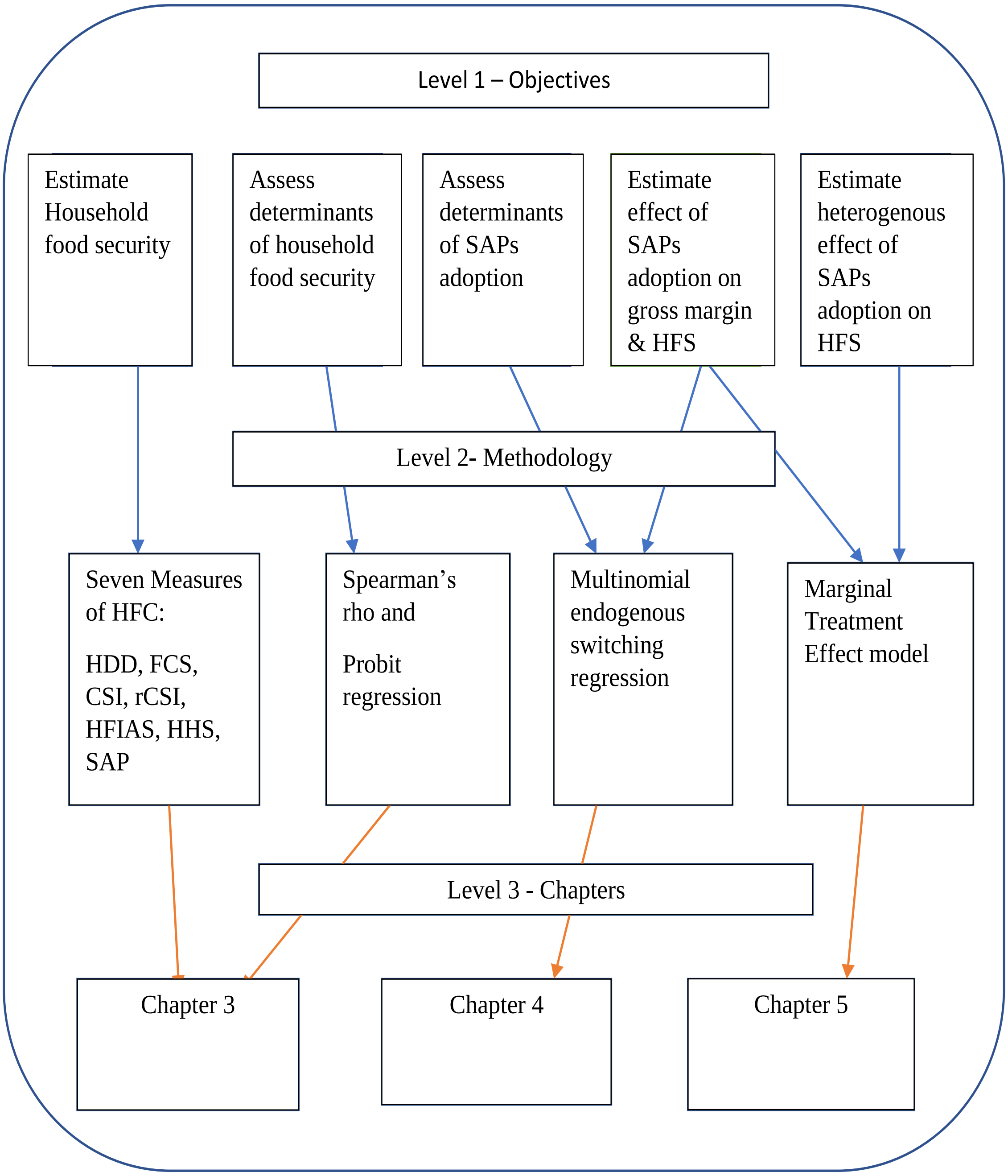

Figure 1: Analysis of Objectives Framework

Chapter 2

General Overview of Literature and Methodology

2.1 Efforts Towards Sustainable Development

According to Brundtland (1987), challenging pressures from poverty, growth, survival and economic crises worldwide pushed for the global discussion of sustainable development. After almost three years of stakeholder engagement across the five continents, the Brundtland Committee defined sustainable development as "…..the development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(Brundtland, 1987, p. 41). For example, growing food in such a way that feeds us today and preserves the land (soil) for future generations to also cultivate. The commission described sustainability in terms of equity, environment, and economy (Portney, 2015). Since then, there have been individual campaigns aimed at eliminating poverty, increasing food availability, and protecting the environment.

In September 2000, the UN General Assembly adopted the Millennium Development Goals (MDGs), which were part of the United Nations Millennium Declaration. It comprised 8 goals which included eradicating extreme poverty and hunger (MDG goal 1) and ensuring environmental sustainability (MDG goal 7). The United Nations Millennium declaration, of which the MDGs were a part, was the first-ever global strategy with measurable targets to be agreed upon by all UN member states and the world's leading development institutions. The MDGs pushed a development agenda which has been credited for an unprecedented international movement against extreme poverty and reducing it by more than 50 per cent globally (Kumar, Kumar, & Vivekadhish, 2016; Santosh & Indumati, 2020; Servaes, 2017). The MDGs ended in 2015 and were replaced with the SDGs. Although sustainable development concepts have been around for some time, they received more attention with the formulation of sustainable development goals (SDGs). The SDGs are viewed as extensions of MDGs with sustainability characteristics added to each MDG. The 17 goals of the SDGs are based on three dimensions of development, namely, economic, social and environmental (Kumar et al., 2016; Vu, 2021). For example, Goal 1 (End poverty in all its forms everywhere) covers the economics dimension whilst Goal 2 (End hunger, achieve food security and improved nutrition, and promote sustainable agriculture) covers the three dimensions. The SDGs are set to end in 2030, and there has been considerable effort to ensure the achievement of the goals at various levels of leadership globally amongst the UN's member states.

2.2 Food Security in Northern Ghana

The formulation of the SDGs emphasizes the importance of food security in the livelihoods of people and communities. Due to the heavy dependence on agriculture as a source of livelihood by most rural communities, agricultural productivity largely determines food security among farming communities. Studies have attributed the low agricultural productivity to poor agronomic practices, limited access and inappropriate use of farm inputs such as improved seeds, fertilizer, pesticides, access to markets, credit, infrastructure and lack of appropriate technologies (Bjornlund, Bjornlund, & Van Rooyen, 2020; Paul Nkegbe & Shankar, 2014; Shimeles, Verdier-Chouchane, & Boly, 2018).

Low agricultural productivity limits the farmer's ability to access markets and also limits the household's access to alternative livelihoods (Maziya et al., 2017). According to (FAO et al., 2020), when domestic production falls due to unpredictable weather patterns, it negatively affects the pricing of food i.e. it raises food prices, subsequently limiting an individual's purchasing power. When there is crop failure households that are dependent on agriculture are at a higher risk of becoming food insecure. Households are described as food insecure when access to adequate uantities of food, and the right quality of food to satisfy the nutritional and dietary needs of all its members is limited (Dodo, 2020).

According to the (WFP, 2013, 2021), about 16 per cent of households in Northern Ghana are food insecure. This is because of the high poverty rate in northern Ghana. The poorer households had small harvests and spent a larger share of their incomes on food (usually buying staples when market prices are higher). In the 2013 report, they further explained that the figures recorded in 2012 were due to a poor harvest from the previous cropping season due to poor rainfall, which subsequently affected the households' food reserves. According to Kansanga, Mkandawire, Kuuire, and Luginaah (2020) and Balana, Sanfo, Barbier, Williams, and Kolavalli (2019) food reserves last for seven months on average. The WFP 2013 report indicated that the food insecurity figures may be transitory because they were captured during the lean season (April – May), thus the figures may be lowered during the harvest season.

2.3 Usage of SAPs and Intensity of adoption

According to Blake et al. (2021); Dalton et al. (2014); Naab, Mahama, Yahaya, and Prasad (2017) farmers are aware of soil erosion, fertility and climate change issues in their production systems and often implement practices such as stone bunding, terracing and use of grass strips (referred to as "indigenous SAPs") as possible solutions to these issues. While some of these practices are similar to those recommended by experts, they may vary in terms of application processes and management. Balana et al. (2019); Blake et al. (2021) argued that often adoption theories and change agents understate the fact that producers may not adopt new technologies or adopt the technology package at varying intensities due to sound reasons. For instance, mulching which is highly recommended by change agents was found not to be adopted widely because it fosters a breeding environment for crop pests such as ants, which infest and destroys crops if not managed properly. Dessart, Barreiro-Hurlé, and van Bavel (2019); Rodriguez, Molnar, Fazio, Sydnor, and Lowe (2009) also found that though experts recommend a set of SAPs, farmers may adopt these packages at varying intensities because the change agents are not well prepared to attend to specific needs of the farmers regarding SAPs.

While SAPs have been recommended by change agents for minimizing the rate of declining soil fertility, enhancing soil structure, averting soil erosion and promoting sustained soil fertility, Pretty et al. (2011) acknowledge the challenge of effectively spreading the processes and lessons to smallholder farmers on the African continent. According to Dalton et al. (2014), the Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP) adopted a participatory approach to induce learning by changing farmers' perceptions in their bid to introduce SAPs to farmers in the Upper West region. They found that the approach effectively raised the knowledge of farmers on the SAPs during their impact evaluation.

In Zimbabwe, NGOs actively promoted the use of conservation agriculture (CA), a component of SAPs, which entails minimum soil disturbance or no-till, permanent soil cover using crop residues and crop rotation. The NGOs provided free inputs to motivate the adoption of the practice; adoption rates increased by 5% as reported by Sepo Marongwe, Nyagumbo, Kwazira, Kassam, and Friedrich (2012) though the rates declined after the NGOs stopped providing inputs due to project maturity. Kunzekweguta et al. (2017), in their work determining factors that influenced the adoption and intensity of adoption of conservation agriculture practices in Zimbabwe, found that gender, experience with CA practices, farm size, and advice from social network were some of the factors that influenced the adoption of CA practices. To address the issue of the intensity of adoption they created an index, the conservation agriculture index (CAI), and found the distance to the market and ownership of an ox-drawn plough influenced the intensity of adoption.

Paul Nkegbe and Shankar (2014) analysed the determinants of the intensity of adoption of soil and water conservation practices in northern Ghana. Using count models, they found access to information, wealth, per capita landholding and social capital influenced the intensity of adoption of the soil and water conservation practices. Agula et al. (2018) in their work on promoting sustainable agriculture in Ghana found that the intensity of adoption of SAPs (defined in their work as ecosystem-based farming management practices, EBFMPs) was influenced by the age of farmers, perception of soil fertility, knowledge of EBFMPs, type of irrigation used, distance to farms, and the number of extension visits. The factors that influenced the intensity of adoption were examined using Poisson and negative binomial models. The count models used by the authors did not look at combinations of SAPs adopted and whether the impact of adoption is the same across the various combinations of SAPs. Studies on the simultaneous adoption of SAPs (Gebremariam & Wünscher, 2016; Kassie, Teklewold, et al., 2015; Kotu et al., 2017; Teklewold et al., 2013) used multinomial probit which enables factors influencing the adoption of interrelated practices to be determined.

2.4 Effects of SAPs

With the strong advocacy for a paradigm shift from crop intensification to sustainable agriculture intensification, it is expected that the adoption of SAPS will enable farmers to achieve their productivity and welfare objectives whilst addressing the adverse effects of crop intensification. There have been various studies to evaluate the effects of SAPS in different dimensions such as welfare, productivity, adaptation/mitigation strategies, and nutrition.

The Foresight Project, according to Pretty et al. (2011), looked in greater detail at how 40 projects in Africa where sustainable agricultural practices such as agroforestry, crop improvements, conservation agriculture, integrated pest management etc, were practiced and found that there were significant economic benefits (increases in yields) for adopting farmers as well as environmental improvements. The Montpellier Panel (2013) report also discusses how sustainable agriculture practices in Africa – such as small-scale water harvesting, intercropping, home gardens, integrated pest management, conservation farming, and forms of crop and livestock breeding – raised yields and farmers' incomes while bringing myriad environmental benefits. Kassie, Teklewold, et al. (2015) explored the decision to adopt multiple Sustainable Intensification Practices (SIPs) in eastern and southern Africa and found that some of the practices in maize farming are substitutable whilst others were complimentary. Teklewold et al. (2013) also looked at adoption of SAPs and the effect on productivity, labour and agrochemical use in Ethiopia. They found that though the practices increased maize income for farmers, it also increased dependency on pesticides and increased workload for women.

Gebremariam and Wünscher (2016) investigated the adoption of SAPs and its effect on the welfare (net crop income per acre and consumption expenditure per capita) of farmers in Ghana. They found that adopting different combinations of SAPs had higher positive effects on welfare than adopting just a single SAP. This finding was similar to Kotu et al. (2017) who assessed the adoption of sustainable intensification practices (SIPs) on productivity in northern Ghana. They found that adopting multiple SIPs increased productivity significantly.

Most of these works (Gebremariam & Wünscher, 2016; Kotu et al., 2017; Teklewold et al., 2013) show different combinations of SAPs in a different environment, this highlights the fact that the type of SAPs adopted must be context specific as suggested by Hansen et al. (2019); Mills et al. (2020). With the evidence that the simultaneous adoption of SAPs enhances agricultural productivity, it is important to establish whether this translates to improvements in the level of food security of adopting farmers.

2.5 Measuring household food security (HFS)

To estimate the food security status of households objectively, food security indicators are used; however, the multidimensional nature of food security makes it difficult to measure using just one indicator (Maxwell, Vaitla, & Coates, 2014; Nkomoki, Bavorová, & Banout, 2019; Sandoval, Carpio, & Garcia, 2020; Vaitla et al., 2020). Often indicators used to measure household food insecurity measure aspects of food security such as availability, access, utilization, and stability. The measures can be classified either as quantitative measures or qualitative measures (Jones, Ngure, Pelto, & Young, 2013; G. Kennedy et al., 2010; Leroy, Ruel, Frongillo, Harris, & Ballard, 2015). Quantitative measures such as the FAO index, household income, and expenditure surveys, and anthropometric indicators (Jones et al., 2013; Leroy et al., 2015; Napoli, De Muro, & Mazziotta, 2011) used at the household levels have been found to be difficult to implement, expensive and time-consuming to collect (particularly in developing countries). Qualitative measures such as the Household Hunger Scale (HHS); the Household Dietary Diversity Scale (HDDS); Food Consumption Score (FCS) are now commonly used at the household level because of the ease of data collection (Jones et al., 2013).

It has been recognised that a suite of measures/indicators is needed to be able to measure all the aspects of food security i.e., availability, access, utilization and stability. Therefore, to determine the food security status of smallholder farmers, which is the first objective of the thesis, seven household-level indicators were used to assess food security. These include the Household Food Insecurity and Access Scale (HFIAS); the Coping Strategies Index (CSI), the Reduced Coping Strategies Index (rCSI); the Household Hunger Scale (HHS); the Household Dietary Diversity Scale (HDDS); Food Consumption Score (FCS); and a self-assessed measure of food security (SAFS). The convergence of these measures was assessed using Spearman's rho and percentages. We probed further by assessing the determinants of household food security using probit regression.

2.5.1 Household food insecurity and access scale (HFIAS)

The HFIAS was developed by Food and Nutrition Technical Assistance Project (FANTA) to provide a valid tool for measuring food insecurity in a developing country context that allows for comparison cross-culturally (Coates et al. 2007). It is made up of 9 questions on the occurrence of a condition associated with the experience of food insecurity and 9 questions on the frequency of occurrence during the past 30 days. These questions cover anxiety about food supply, inadequate quality and inadequate food supply and physical consequences. An HFIAS (a continuous variable) is computed by summing the appropriate codes of the responses to the frequency of occurrence questions. Where 0 is the code for a response such as “no” and 3 is the code for the response “often”. The maximum score of a household is 27 and the minimum score is 0. The higher the score is, the worse the severity of food insecurity (access) experienced by the household.

2.5.2 Household hunger scale (HHS)

The HHS also developed by FANTA is used to measure food security across countries and has a consistent meaning. The HHS has been authenticated for cross-cultural use, though it reflects the more severe range of household food insecurity (actual hunger and food deprivation). It uses three questions on the occurrence of a condition in the most severe food-insecure experiences and three questions on the frequency of occurrence in the last 30 days. The HHS is computed by summing the appropriate codes of the responses to the frequency of occurrence questions. Where 0 is the code for a response such as “no” and 3 is the code for the response “often”. The maximum score of a household is 6 and the minimum score is 0. The higher the score is, the worse the severity of food insecurity (access) experienced by the household.

2.5.3 Coping strategies index (CSI)

The CSI is a behavioural measure based on the actions people undertake when they have limited access to food. People use several regular behavioural responses when faced with household food shortages. A list of coping strategies will be made context-specific by adjusting it to suit local circumstances. The measure is based on the use of these strategies and the frequency of use, within the past 30 days. Weights are assigned to each strategy depending on the perceived severity of each strategy by community-level focus groups. The weighted scores are combined in an index to reflect the current food security status of the household. The CSI scores can be standardized for a given location, by using a computerized linear normalization process. The higher the CSI score is, the worse the severity of the food insecurity situation and vice versa.

2.5.4 Reduced coping strategies index (rCSI)

The rCSI is a shorter version of the CSI based on 5 food-related coping strategies applied in the past 7 days. It is used cross-culturally because it focuses on a similar set of behaviours. Households will be asked about the frequency of use of a set of five short-term coping strategies in food shortage situations during the 7 days prior to the interview. The rCSI is computed based on the information gathered. The rCSI score shows the frequency and severity of the coping strategies employed by the household. Household rCSI scores are determined by multiplying the number of days in the past week each strategy was employed by its corresponding severity weight and then summing together the totals. The rCSI will be categorized as no or low coping (rCSI= 0-3), medium coping (rCSI = 4-9), high coping (rCSI ≥10).

2.5.5 Food consumption score (FSC)

The FCS is a proxy indicator of current food security, which is based on dietary frequency, food frequency (in the past seven days) and the relative nutrition importance of nine different food groups. Household food consumption is the consumption pattern (*frequency * diversity*) of households over the past seven days. A 7-day food frequency data are collected on all 9 specific food groups. The consumption frequencies of the food items of the same group are summed and recorded. The food groups are assigned weights which will be used to generate the weighted food group scores (by multiplying the value obtained for each food group by its weight). The sum of the weighted food groups score is the food consumption score. The maximum FCS is 112 which means all the food groups were consumed in the 7 days. The FCS is a continuous variable, which can be classified into three categories: poor consumption (FCS = 1.0 to 28); borderline (FCS = 28.1 to 42); and acceptable consumption (FCS = >42.0).

2.5.6 Household dietary diversity (HDD)

The Household Diet Diversity Score measures how many food groups (out of 8) are consumed over the past 7 days. The HDD is used as a measure of a proxy measure of the socioeconomic level of the household. Household food consumption is collected using the previous 24 hours as a reference period (24-hour recall). The number of different food groups prepared and consumed by the household is used to reflect a quality diet. A series of yes or no questions are asked to collect data for the HDD indicator. The HDD is a continuous variable generated by summing the responses of each household, and its value will range from 0 to 9.

2.5.7 Self-assessed food security (SAF)

SAF is a highly subjective measure that may be easy to manipulate in programmatic contexts. It includes self-assessments of current food security status in a recent recall period and the change in livelihood status over a longer period. Though subjective, SAF is used to gauge the household's awareness of food security (Maxwell et al., 2014). Following Tinonin et al. (2016b), the self-assessed food security measure used in this study was constructed by asking households how long they were able to store their produce from the last production season.

While using a suite of indicators helps with advocacy and the programming of interventions, it is important to understand how these indicators converge in various settings (Maxwell et al. 2014). There is limited work in this regard in West Africa, with the few works focusing on at most three measures, including HDD, FCS and SAFS (Butaumocho & Chitiyo, 2017; De Cock et al., 2013; Faber, Schwabe, & Drimie, 2009; Gandure, Drimie, & Faber, 2010). Some of the measures capture one dimension of food security more than the others. For example, HDD and FCS have been described as capturing more of the quality aspect of the access dimension of food security, whilst SAFS also captures the stability dimension (Maxwell et al., 2014). Thus, it is important to investigate whether the factors determining food security are the same for these measures.

2.6 Summary of Literature Review and Research Gaps

So far, the challenges necessitating the study of sustainable agriculture practices in the smallholder context have been discussed. There is enough evidence to suggest that SAPs adoption enhances agricultural productivity; however, the clear linkage to the food security of farmers has not been established. The following research gaps were identified:

i. There is limited evidence on the convergence of the measures of household food security.

ii. Little is known about the effects of the simultaneous adoption of SAPs in West Africa.

iii. Past studies have focused on other proxy measures of welfare such as net farm income, net crop income per acre and consumption expenditure rather than the food security status of farmers. (Gebremariam & Wünscher, 2016; Kotu et al., 2017)

iv. The ideal combination of SAPs and whether the gains from adoption are heterogenous have received little attention in past studies.

2.7 Estimating farm income (gross margins)

The study estimates the farm income of smallholder farmers as gross margins from crop production. This is calculated by subtracting the total variable cost of production from total revenue. Total revenue is the cash value realized during a production cycle. To arrive at the total revenue in cash, the total quantity of crop production is multiplied by the unit price of the crop. The variable costs covered the cost of all the variable inputs such as seeds, fertilizer, and herbicides, used in the production cycle. Since most farmers engaged in mixed cropping, the estimation of farm income was undertaken in a mixed crop setting. This reduces the risk of underestimating the effects of the SAPs on crop productivity.

2.8 Conceptual Framework

This study uses the theory of the agricultural household model which combines the two fundamental units of microeconomic analysis, i.e. the household and the firm. Agricultural households in developing countries are both producers and consumers of the products they cultivate. This is largely due to the scale of operation, the motivation for farming, access to land, lack of infrastructure and poorly functioning output and factor market systems. The interactions between the consumption and production behaviour of smallholders in developing countries are aptly captured in the agricultural household model (Sadoulet & De Janvry, 1995; Singh, Squire, & Strauss, 1986). In a single framework, the household model integrates decisions about resource allocations (i.e. land, labour, and capital), SAPs to use and crop combinations to grow (Sadoulet & De Janvry, 1995). Rural household operates to maximize the expected utility due to the interactions between the production and consumption of goods and services (Gebremariam & Wünscher, 2016).

Farm households that do not have access to the market, usually produce for home consumption and rely mainly on family labour, in such subsistence conditions production and consumption decisions are made simultaneously. However, most farm households are semi-commercial, i.e. they sell some of the produce and purchase some inputs from ill-functioning markets. Poor functioning markets affect the type of strategies farmers adopt in terms of labour and capital allocations. For instance, (Teklewold et al., 2013) found that conservation tillage increased labour demand, this assertion may limit the use of this technology if the farmer has limited family labour and is unable to access hired labour. Poor access to credit is a major constraint for farmers (Setsoafia, Aboah, & Gideon, 2015) and most farmers rely heavily on their savings and borrowing from relations, this is likely to limit the use of capital-intensive strategies. Poorly functioning markets increase transaction costs for semi-commercial rural households, thus affecting decisions about SAPS.

The duality of roles played by the household means they are affected by policies on prices of goods both produced and consumed; such policies usually have complex implications for household production and welfare. The household is a price taker in all the markets it participates in, whilst optimal household production is determined independently of leisure and consumption choices (Singh et al., 1986). When the maximum income level is derived from profit-maximizing production, labour supply, and consumption decisions can be made. Due to the interaction between production and consumption for the rural household, a non-separable household model (made up of profit and utility maximizing components) which incorporates the market imperfections can be used for modelling decisions and resource allocations (Gebremariam & Wünscher, 2016).

This work follows (Fernandez-Cornejo, Hendricks, & Mishra, 2005; Gebremariam & Wünscher, 2016) where utility(U), is based on the consumption of purchased goods (G) and leisure (l), subject to human capital and other household characteristics (Z_h). Therefore utility (U) is maximized

$$MaxU(G, L; H, Z_h) \quad (1)$$

subject to time constraints:

$$T = L_f\left(d_j\right) + L_e + L, L_e \geq 0 \quad (2)$$

Technology constraint:

$$Q = Q\left\lfloor X(d_j), L_f(d_j), H, d_jR, eI_i)\right\rfloor, d_j, eI_i \geq 0 \quad (3)$$

Income constraint:

$$P_gG = P_qQ - W_xX + W_eL_e + A \quad (4)$$

The household's utility is constrained by time, production and income. The time constraint deals with the labour decisions of households regarding leisure (L), time allocated for farm work (L_f), time allocated for off-farm work (L_e), which is equal to the household's time endowment (T). The production constraint is a convex continuous production function, where

Q is the quantity of output (crops) produced, X is farm inputs, L_f is time allocated for farm work, H is human capital, R is a vector of exogenous variables that shift the production function and d_j is the type of SAP adopted. The type of SAP used directly affects farm inputs and labour demanded from households. For instance, contouring or grass stripping may require more labour..

The type of SAP adopted or used is determined by the household's experience with shock (S), social capital (S_C), household assets (w), plot level characteristics P_l, risk preference (RP), human capital (H) and household characteristics (Z_h). This is shown as:

$$d_j = (S, S_C, w, P_l, RP, H, Z_h) \qquad (5)$$

The extent of SAP adoption will be captured using an adoption extent index eI, computed as:

$$eI_i = \sum_r W_{ir} P_{ir} \qquad (6)$$

where eI denotes the SAP adoption extent index score computed for the ith household. This ranges between 0 and 1, with 0 meaning no adoption and no extent of adoption; and 1 means full adoption and the highest extent of adoption.

W_{ir} is weight generated as a ratio of number of SAPS adopted to number of total SAPs under consideration. P_{ir} is the area of the plot on which the SAPs have been adopted relative to the total area planted by the farmer.

The income constraint depicted in equation (4), shows the household's budget constraint such that expenditure (price of purchased goods (P_g) times quantity of purchased goods (G)) is less than net farm income (Price of output (P_q) time output quantity (Q) minus price of inputs (W_x) times input quantity (X)), off-farm income (wage rate (W_e) times off-farm work (L_e)) and other sources of income such as remittances and pension (A) .

Substituting equation (3) into equation (4) gives a farm technology-constrained measure of household income:

$$P_g G = P_q Q\lfloor X(d_j), L_f(d_j), H, d_j, eI_i, R\rfloor - W_x X + W_e L_e + A \quad (7)$$

The Kuhn-Tucker first-order conditions can be obtained by maximizing the Lagrangian expression l over (G, L) and minimizing it over (λ, ɳ):

$$l = U(G, L; H, X_h) + \lambda\{P_q Q\lfloor X(d_j), L_f(d_j), H, d_j, R, eI_i\rfloor - W_x X + W_e L_e + A - P_g G\} + \eta[T - L_f(d_j) - L_e - L] \quad (8)$$

where λ and ɳ represent the Lagrange multipliers for the marginal utility of income and time, respectively. The first order conditions are shown as:

$$\partial l/\partial X = \lambda P_q \partial Q/\partial X - W_x = 0 \quad (9)$$

$$\partial l/\partial L_f = \lambda P_q \partial Q/\partial L_f + \eta = 0 \quad (10)$$

$$\partial l/\partial d_j = \lambda\{P_q[(\partial Q/\partial X)(\mathrm{d}X/\mathrm{d}\,d_j) + (\partial Q/\partial L_f)\,\mathrm{d}L_f/\mathrm{d}\,d_j + \mathrm{d}Q/\mathrm{d}\,d_j] - W_x(\mathrm{d}X/\mathrm{d}\,d_j - \eta(\mathrm{d}L_f/\mathrm{d}\,d_j) = 0 \quad (11)$$

$$\partial l/\partial L_e = \lambda W_e - \eta \leq 0, L_e \geq 0, L_e(\lambda W_e - \eta) = 0 \quad (12)$$

$$\partial l/\partial G = U_G - \lambda P_g = 0 \quad (13)$$

$$\partial l/\partial L = U_L - \eta = 0 \quad (14)$$

Where $U_G = \partial U/\partial G$ and $U_L = \partial U/\partial L$ are partial derivatives of the function U

The optimal time allocation conditions for the households' farm work, off farm work and leisure can be obtained from the optimality conditions equation (10), together with equations (12), (13) and (14):

$$\eta/\lambda = P_q \partial Q/\partial L_f \geq W_e \quad (15)$$

where ɳ/λ represents the marginal rate of substitution between leisure and consumption goods equations (13) and (14)); $P_q \partial Q/\partial L_f$ is equal to the value of the marginal product of farm labour.

The optimal SAPs adoption decision can be attained from the optimality conditions, equations (11), (13) and (14):

$$P_q \mathrm{d}Q/\mathrm{d}d_t - P_g(U_L/U_G)(\mathrm{d}L_e/\mathrm{d}\,d_j) = 0 \tag{16}$$

where the total derivative of $\mathrm{d}Q/\mathrm{d}d_t$ is equal to $(\partial Q/\partial X)\big(\mathrm{dX}/\mathrm{d}\,d_j\big) + \big(\partial Q/\partial L_f\big)\,\mathrm{d}L_f/\mathrm{d}\,d_j + \mathrm{d}Q/\mathrm{d}\,d_j$; $\eta/\lambda = Pg(UL/UG)$, which represents the marginal rate of substitution between leisure and consumption goods, can be derived based on equations (13) and (14).

Following (Fernandez-Cornejo et al., 2005; Gebremariam & Wünscher, 2016), the Kuhn-Tucker conditions are solved, the reduced-form expression of the optimal level of household income (Y*) can be obtained by:

$$Y^* = Y(d_j, W_x, P_q, P_g, A, H, eI_i, T, R, Z_h) \tag{17}$$

and household food security status (FS) can be expressed as:

$$FS^* = G(d_j, W_e, P_g, Y^*, H, eI_i, T, Z_h) \tag{18}$$

Therefore, the reduced forms of Y* and FS^* are influenced by a set of explanatory variables, including the type of SAP, d_j. Equation (17) and (18) leads to the econometrics procedure outlined in the next section since SAP used is a result of optimal household decision making strategy.

2.8.1 Determinants of SAPs adoption and its effect

The decision to adopt or use a particular combination of SAPs on a plot is made by the farmer in response to drought, erosion, perceived decline in soil fertility, weeds, pests, and diseases. Studies in Southern and Eastern Africa (Kassie et al., 2014; Kassie et al., 2013; Kassie, Teklewold, et al., 2015; Kunzekweguta et al., 2017; Mutenje et al., 2016; Ng'ombe et al., 2017; Teklewold et al., 2013) have found that household characteristics (size, age, wealth, education), plot-level characteristics (incidence of pest or disease, soil fertility, distance to market) community demographics (social capital, market access, extension service) influence adoption of different combinations of SAPs. We used these probable factors in drawing the conceptual framework for SAP adoption and its effect as shown in Figure 2.

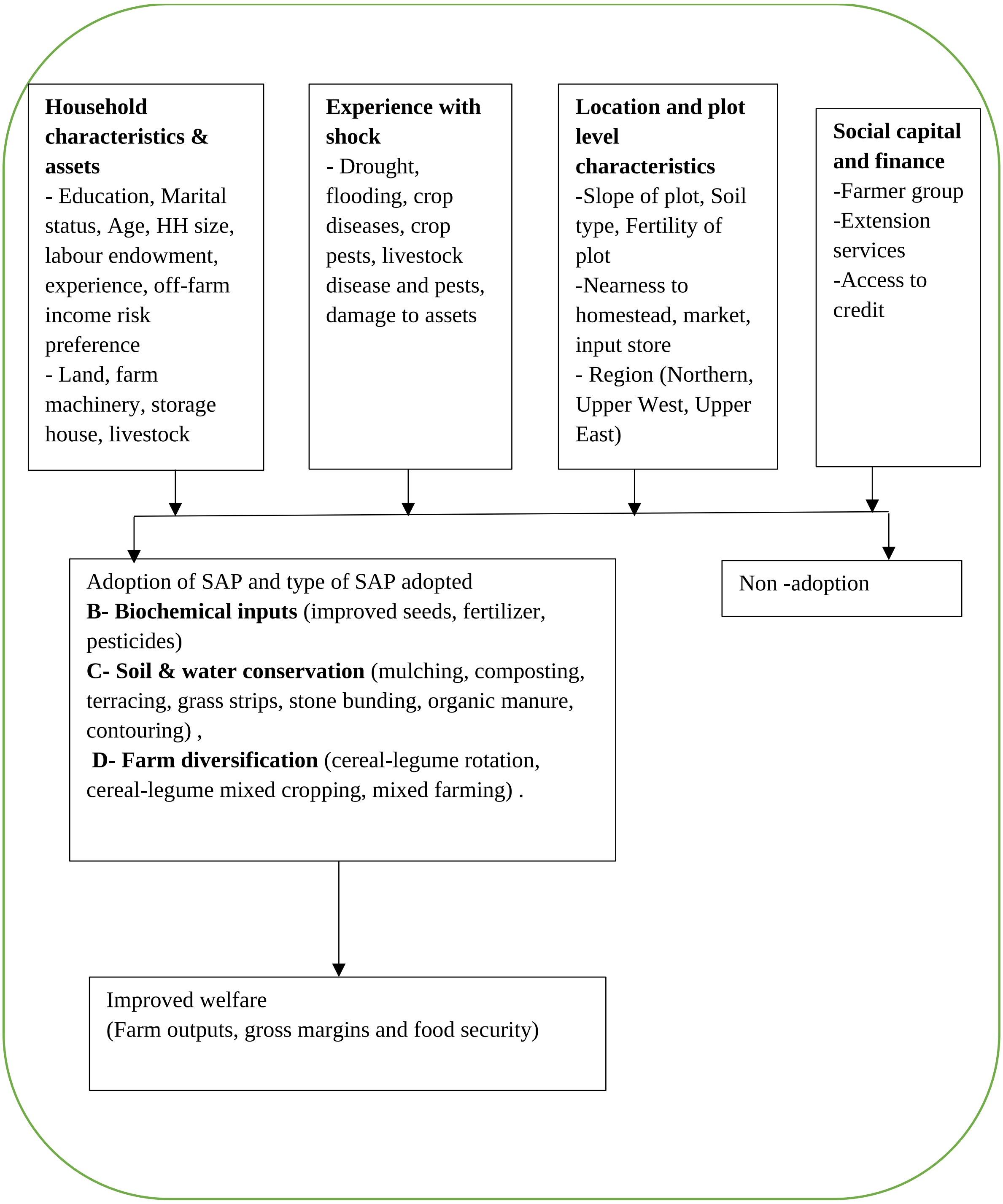

Figure 2: Framework of SAPs adoption and impact of SAP adoption

2.9 Multinomial endogenous switching regression

In recent years, there has been an increase in studies that estimate determinants of adoption and impact analysis of agricultural technologies simultaneously (Abid, Schneider, & Scheffran, 2016; Issahaku & Abdulai, 2020; Salim, Hassan, & Rahman, 2020; Wordofa et al., 2021). These studies have employed methods like Propensity score matching (PSM), Heckman's treatment effect model or endogenous switching regression. The main issue with PSM is its no confoundedness assumption, which implies that once observable characteristics are controlled for, the technology assumption is random and uncorrelated with outcome variables (Abdulai & Huffman, 2014). According to Smith and Todd (2005) there is the potential for systematic differences between adopters and non-adopters outcomes even after conditioning since selection is based on unmeasured characteristics.

Heckman's treatment effect model is a two-step estimation procedure, which has been mainly criticized because it generates heteroskedastic residuals that cannot be used to obtain consistent standard errors without adjustments (Lokshin & Sajaia, 2004). The endogenous switching regression was developed as a generalization of Heckman's selection correction approach (Abdulai & Huffman, 2014; Heckman, 1979; Lee, 1982). Its main advantages over the Heckman model are that outcome variables such as yields, and food security can be observed for adopters and non-adopters.

We used a multinomial endogenous switching regression in this study, to assess the determinants of SAPs adoption and its effect on gross margins and food security. These SAPs are interrelated according to Teklewold et al. (2013) and Gebremariam and Wünscher (2016), and could either be substitutes or complements. The choice to adopt a single SAP or the full package is based on the household's observed and unobserved characteristics. This may be because of a systematic difference in the characteristics of the adopter from non-adopters. A self-selection model would be apt to analyze this difference since the study is an observational one.

The MESR evaluates the various alternative combinations of SAP practices as well as individual SAP practices. It is known for capturing self-selection bias and interactions amongst choices of alternative practices (Teklewold et al., 2013; Wu & Babcock, 1998). The model is in two stages; the first stage involves modelling the decision to adopt/or use specific SAPs combinations in a multinomial logit selection model. The second stage uses ordinary least squares (OLS) regression model with selectivity correction terms from the first stage to estimate the impact of adoption on the outcome variables.

2.10 Marginal treatment effect model

The multinomial endogenous switching regression addresses selection bias arising from both observable and unobservable factors; however, its limitation is that it accounts for selection bias by aggregating unobservable heterogeneity and aggregate parameter estimates, though this heterogeneity varies across individuals (Cornelissen, Dustmann, Raute, & Schönberg, 2016). We use the marginal treatment effects approach (MTE) to estimate the treatment effect heterogeneities of adopting SAPs on food security to address these issues. This approach allows us to identify, to some extent, a range of individual treatment effects which subsequently characterise the magnitude and pattern of treatment effect heterogeneity (Cornelissen et al., 2016; Cornelissen, Dustmann, Raute, & Schönberg, 2018).

2.11 Study area

Agriculture in Ghana is mainly undertaken by smallholder farmers. Most farm holdings in the country are usually less than two hectares, with very few large-scale commercialized farms (MoFA, 2019). The agricultural sector employs as much as 38.3 per cent of the population and contributes about 18.24 per cent to the country's gross domestic product (GDP) (GSS, 2019). This study focuses on the Upper East, Upper West and Northern regions, which make up three-fifths of Northern Ghana. These regions are the most vulnerable in terms of climate change issues in Ghana, with prolonged drought and erratic rainfall being the most problematic climate concerns. These regions also record a high level of food insecurity and poverty even though there is overall economic growth in the country (WFP, 2013, 2021). They fall within the Guinea Savannah agro-ecological zone, which makes up 40% of the total land area of the country (MoFA, 2013, 2019). The Guinea Savannah is characterised by a unimodal and erratic rainfall distribution with an average annual amount of 1,000mm.

According to Amanor-Boadu et al. (2015), the production systems of northern Ghana are characterized by small landholdings and low input - low output, which impacts negatively on food security. The growing season usually starts in May and ends in October. Cereals and legumes (i.e., maize, millet, sorghum groundnuts, cowpeas, and soybeans) are dominant crops, while root crops (i.e., yam, cassava, potatoes), vegetables, and fruits are cultivated to a lesser extent. Farmers produce most crops for home consumption and market sales (Amanor-Boadu et al., 2015; Kotu et al., 2017). In general, soils in these regions are steadily depleting, causing the yields per unit area to fall to very low levels; this is due to the continuous monoculture of growing crops in the area (Amanor-Boadu et al., 2015). Livestock (i.e., goat, sheep, and poultry) is a main component of the farming system; the mode of livestock rearing is free ranching. According to Houssou, Kolavalli, Bobobee, and Owusu (2013), oxen are often used as draught power for land preparation in all of the three regions and for weeding in some parts of the Upper East Region. Manure from livestock is used on plots close to homesteads.

The Africa RISING project which is being implemented by IITA has been training smallholder farmers on SAPs to sustainably move smallholder farmers beyond poverty and hunger that is endemic within northern Ghana. This thesis focuses on Africa RISING intervention communities as shown in Figure 3.

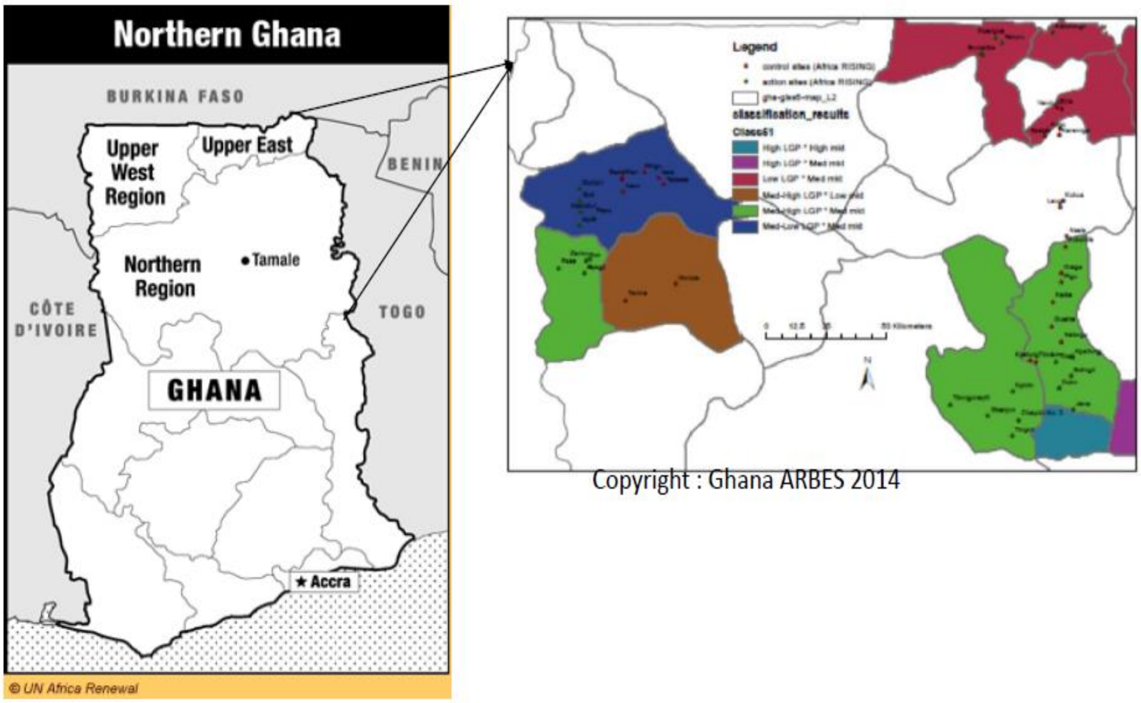

Figure 3: Map Showing Northern Ghana and Africa RISING Project Location

2.12 Sampling and data collection

We used baseline survey data collected in 2014 for the project 'Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) from 50 rural communities in the regions of northern Ghana, namely, Upper East, Upper West, and the Northern region. The data was collected from 1284 households operating approximately 5,500 plots. The baseline survey used a stratified two-stage sampling technique. Data was collected using Computer Assisted Personal Interviewing (CAPI) supported by Survey CTO software on tablets (Tinonin et al., 2016a). A structured questionnaire was used to conduct the household interviews.

We also collected primary data from the households in the AR project location in 2019. A multi-stage sampling technique, made of stratified sampling, random and cluster sampling was used to select the respondents. The project took place in 9 districts in Northern Ghana, in 25 intervention communities and 25 counterfactual communities. We stratified the project locations into 25 AR intervention communities and 25 counterfactual (no intervention) communities. Ten communities of the intervention communities and five communities of the counterfactual communities were randomly selected. A total of 494 households were sampled, made up of 345 households participating in AR intervention and 149 counterfactual households.

The breakdown of the sampling is shown in Table 1. This thesis also used baseline survey data collected in 2014 for the project 'Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) from 50 rural communities in the regions of northern Ghana, namely, Upper East, Upper West, and the Northern region. The data was collected from 1284 households operating approximately 5,500 plots. The baseline survey used a stratified two-stage sampling technique. Data was collected using Computer Assisted Personal Interviewing (CAPI) supported by Survey CTO software on tablets (Tinonin et al., 2016a). A structured questionnaire was used to conduct the household interviews.

Table 1: Sample size for the study

Region - district	AR* intervention communities (Number selected)			Counterfactual communities (Number selected)		
Regions		Communities selected	Households sampled	Communities selected		HH sampled
Northern: (Tolon/ Kumbungu, Savelugu-Nanton, West Maprusi)	10 (3)	Cheyohi No Tingoli Tuko	45 45 45	15 (2)	Tibali Kadia	30 30
Northern Total			**135**			**60**
Upper East: (Kassena-Nankana, Bongo, Talensi- Nabdam)	7 (4)	Bonia Sabungo Nyangua Gia	30 30 30 30	2 (1)	Shia	30
Upper East Total			**120**			**30**
Upper West: (Wa West, Nadowli, Wa East)	8(3)	Zanko Guo Goli	30 30 30	8 (2)	Tania Goriyi	29 30
Upper West Total			90			59
Total	**25 (10)**		**345**	**25 (5)**		**149**

* Africa RISING is an agricultural research and development programme being implemented in northern Ghana by IITA with funding from USAID. The programme trains and encourages farmers to adopt SAPs

The data covers the various SAPs, demographic characteristics, agricultural land holdings, crop outputs and sales, livestock production, farmers' access to agricultural information and knowledge, access to credit and markets, household assets, and income. Primary data was collected from a sample drawn from the Africa RISING sampling frame to establish the effect of the project on SAP adoption and their impact on welfare outcomes. A structured questionnaire presented in Appendix A (A.1), was used for interviewing the household, and relevant information was collected for the other objectives of the thesis. As part of Lincoln University Policies and Procedures, the questionnaire went through the process for human ethics clearance from Human Ethics Committee before it was administered to the respondents.

Chapter 3

Measuring food security in northern Ghana: An assessment of food security indicators and their determinants

Abstract

Since the subject of food insecurity reared its head in the 1970s, there have been multiple attempts to define the phenomenon. Apart from the problem of changing definitions, there is also the issue of measurement. There is no gold standard for measuring food security. In recent years, seven measures have been used as a suite of indicators increasingly because of their ease of use for measuring food security. However, there is limited work on the convergence of these measures in West Africa. Using Spearman's rho and probit regression, we assess the correlations and determinants of these measures of static household food security, specifically, Household Food Insecurity and Access Scale (HFIAS), Coping Strategies Index (CSI), Reduced Coping Strategies Index (rCSI), Household Hunger Scale (HHS), Household Dietary Diversity Scale (HDDS), Food Consumption Score (FCS), and a Self-assessed measure of food security (SAFS). Particularly, we investigate the factors influencing the FCS, HHS, CSI, and SFA measures, using primary data were collected from 494 smallholder households in three northern regions of Ghana. The results show strong correlations between FCS and HDD, between HFIAS, HHS, CSI and rCSI, and between SAFS and HFIAS. The level of food insecurity prevalence varied across the measures with HDD giving the least prevalence whilst FCS and HFIAS gave the highest prevalence of food insecurity. Food security amongst smallholders in northern Ghana is mainly determined by socio-demographics of household head, farm size, drought, membership in farmer group, duration of storage, ownership of animals, and geographic locations.

Keywords: Food security measures; Correlation; Spearman rho; Probit regression; northern Ghana

JEL Codes: Q12; R20; O2; I32

3.1 Introduction

The issue of food security started gaining prominence in the 1970s. Since then, various development organizations such as FAO have defined food security in different ways. Most of the definitions capture the four dimensions of food security, including availability, accessibility, utilization, and stability. The most widely accepted definition is from the world food summit in 1996, which states that "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (Shaw, 2007).

Like the numerous definitions of food security, there are just as many measures for food security. These measures include Global Food Security Index (GFSI), Mid-upper arm circumference (MUAC), Famine Early Warning Systems Network (FEWS NET), and Comprehensive Food Security and Vulnerability Analysis (CFSVA), and they are found at the global, national, household, and individual levels (Haysom & Tawodzera, 2018; Jones et al., 2013; Leroy et al., 2015). While some measures, such as GFSI and MUAC, can be used on one level, others, such as FEWS NET and CFSVA, can be used on multiple levels. These metrics usually capture mainly one or two dimensions of food security. The multidisciplinary nature of the food security concept has hindered efforts to formulate one metric that captures all the dimensions of food security. Therefore, multiple measures have been used to indicate levels of food security in an area.

From FAO's Scientific Symposium on Measurement and Assessment of Food Deprivation and Undernutrition held in 2002, it was recognized that "no individual measure suffices to all aspects of food insecurity" and a "suite of indicators was needed to cover the different dimensions of food security: availability, access, utilization and stability of access" (Cafiero, Melgar-Quiñonez, Ballard, & Kepple, 2014; Danso-Abbeam, Baiyegunhi, Laing, & Shimelis, 2021; Maxwell et al., 2014). Seven commonly used indicators of food security include Household Food Insecurity and Access Scale (HFIAS), Coping Strategies Index (CSI), Reduced Coping Strategies Index (rCSI), Household Hunger Scale (HHS), Household Dietary Diversity Scale (HDD), Food Consumption Score (FCS), and a self-assessed measure of food security (SAFS). The use of these seven measures has been increasing in recent years primarily because of the ease of use for measuring food security (Jones et al., 2013; Maxwell, Parker, & Stobaugh, 2013).

Among the seven food security measures, the CSI correlates with other complex food security measures such as caloric intake, dietary diversity and food frequency indicators (Carletto, Zezza, & Banerjee, 2013). However, it is has been criticized for being context-specific and not universally applicable (Maxwell, Coates, & Vaitla, 2013). For this reason, the rCSI was developed to overcome the shortfalls associated with CSI. HHS was designed to be used together with a suite of food security indicators. Although the HHS can be used in cross-cultural settings, it has been criticized for measuring only the "most severe forms" of food insecurity (Carletto et al., 2013; Kerren Hedlund, Maxwell, & Nicholson, 2013; Maxwell, Coates, et al., 2013). The HFIAS, which measures a broader range of food security, was developed to overcome the drawbacks of the HHS.

The FCS and HDD are dietary measures for food security. In particular, the FCS considers weighted food groups consumed in a week, while the HDD considers unweighted food groups consumed during the last 24 hours. Several studies have validated FCS as an indicator that effectively correlates with other measures for calories consumption, though to different degrees across contexts (Coates et al., 2007a; Maxwell, Parker, et al., 2013; Wiesmann, Bassett, Benson, & Hoddinott, 2009). The SAFS involve the perception of current food security status as assessed by respondents and the changes in livelihood status over a longer period of time by respondents (Maxwell et al., 2014). According to Maxwell et al. (2014), SAFS should be used together with other indicators since it provides a self-perception about food insecurity that the other indicators do not provide, making it useful for crosschecking.

While using a suite of indicators helps with advocacy and the programming of interventions, it is important to understand how these indicators converge under various settings (Maxwell et al. 2014). There is limited work in this regard in West Africa, with the few works focusing on at most three measures, including HDD, FCS and SAFS (Butaumocho & Chitiyo, 2017; De Cock et al., 2013; Faber et al., 2009; Gandure et al., 2010). Some of the measures capture one dimension of food security more than the others. For example, HDD and FCS have been described as capturing more of the quality aspect of the access dimension of food security, whilst SAFS also captures the stability dimension (Maxwell et al., 2014). Thus, it is important to investigate whether the factors determining food security are the same for these measures.

The purpose of this study is to assess the convergence and validity of the seven food security measures above. Moreover, we investigate the factors influencing food security measured by FCS, HHS, CSI, and SAFS. This study contributes to the literature from two aspects. First, this study illustrates how these food security measures are correlated by using Spearman's rho, helping identify the appropriate measure depending on the goal of intervention by both government agencies and NGOs. Second, it provides empirical insights into the determinants of food security as measured by four of the seven measures, using first-hand data collected from Ghana. Although some studies have investigated the determinants of food security (Kuwornu, Suleyman, & Amegashie, 2013; Paul Nkegbe, Abu, & Issahaku, 2017; Quaye, 2008; Tuholske, Andam, Blekking, Evans, & Caylor, 2020), the work focusing on Ghana is limited. Findings from the study will aid in the formulation of specific policies targeted at improving the food security status of farm households.

The next section covers the analytical procedure and data used in this paper. The results are presented and discussed in Section 3, and Section 4 highlights the conclusions and policy implications of the findings.

3.2 Methodology

The study assesses the strength of the correlations amongst the seven measures (i.e. FCS, HDD, HFIAS, HHS, CSI, rCSI, and SAFS) using Spearman's rho. The approach helps examine non-parametric bivariate relationships of both the scale values of the measures and the categorical values obtained using commonly used cutoffs. Then, we use the probit model to examine the determinants of food security as measured by four of the seven measures. The probit regression is used in the comparison rather than the multivariate probit because different sets of variables may account for food security as measured by the measures (Bruce, 2013; Butaumocho & Chitiyo, 2017; Habyarimana, 2015; Hendriks et al., 2016; Maziya et al., 2017; Paul Nkegbe et al., 2017)

3.3 Food security measures

According to Maxwell et al. (2014), these seven measures can be classified into four categories, namely behavioural measures (rCSI and CSI), experiential measures (HFIAS and HHS), dietary diversity and frequency measures(HDD and FCS), and self-assessed measure (SAFS). Table 2 summarizes how these measures are computed following their field manuals.

Table 2: Food security Measures Computation

Measurements	How it is computed
Food Consumption Score (FCS)	9 Weighted food groups consumed by HH in the last 7 days and frequency of consumption
Household Dietary Diversity (HDD)	12 Unweighted Food groups consumed by HH in the last 24hr
Household Food Insecurity Access Scale (HFIAS)	9 Behaviours towards hunger and frequency of use, in the last 30 days
Household Hunger Score (HHS)	3 Behaviours towards hunger occurrence and frequency of occurrence in the last 30 days
Coping Strategy Index (CSI)	13 Coping strategies to hunger used in the last 30days
Reduced Coping Strategy Index (rCSI)	5 Coping strategies to hunger used in the last 30 days
Self-Assessed Food Security (SAFS)	Number of months HH experienced food shortage in the last 18 months

The indexes of these seven measures are formulated by answering a series of questions as specified in the fieldwork manual guides (Ballard, Coates, Swindale, & Deitchler, 2011; Coates, Swindale, & Bilinsky, 2007b; G. Kennedy, Ballard, & Dop, 2011; Maxwell & Caldwell, 2008 ; Vaitla, Coates, & Maxwell, 2015; Wiesmann et al., 2009). The study computed food security as measured by these seven measures. The raw scores and the original category as specified in Table 3 were assessed, using Spearman's rho to examine non-parametric bivariate relationships of both the scale values of the measures and the categorical values.

Table 3: Classification systems of food security measure

Indicator	Raw score range	Original category	Original qualitative label	Converted binary classification
CSI/rCSI*	0-4	1	Food secure	Food Secure
	5-10	2	Moderately food insecure	Food Insecure
	>11	3	Severely food insecure	
HFIAS⁺		1	Food secure	Food Secure
		2	Mildly food insecure	
		3	Moderately food insecure	Food insecure
		4	Severely food insecure	
HHS	0-1	1	Little to no hunger	Food secure
	2-3	2	Moderate hunger	Food insecure
	4-6	3	Severe hunger	
FCS	35.5 -112	1	Acceptable	Food secure
	21.5 -35	2	Borderline	Food insecure
	0 -21	3	Poor	
HDD	6-12	1	Food secure	Food secure
	4-5	2	Moderately food insecure	Food insecure
	0-3	3	Severely food insecure	
SAFS	0-1	1	Food secure	Food secure
	2-3	2	Moderately food insecure	Food insecure
	>3	3	Extremely food insecure	

*The guidance manual for CSI/rCSI does not include thresholds for the various categories of food security and insecurity. The study developed adapted the thresholds from Maxwell, Coates, et al. (2013); Vaitla et al. (2015).
⁺The guidance manual for HFIAS shows answering specific questions in the index determines the original category for the respondent. The raw score of HFIAS ranges from 0 to 27.

3.4 Empirical specification

To identify the factors that determine the food security status of smallholder farmers in northern Ghana, the study uses a probit regression. The probit regression is used to model binary choices, in this case, food secure or food insecure. The probit model assumes a latent, unobservable continuous variable denoted as Y^*, which could take all values between (-∞, +∞), and that defines the value of Y and includes an error term distribution along with realistic probabilities. The underlying latent model can be specified as follows (Bruce, 2013; Chris, 2008; Ndakaza et al., 2016)

$$Y = (1, Y_i^* > 0;\ 0, Y_i^* \leq 0) \quad and \quad Y^* = X'\beta + \varepsilon \tag{1}$$

where Y^* is a latent variable capturing the probability that a household is secure or insecure in food, which is observed by a binary variable Y .In particular, this study specifies our dependent variable Y as 1= food secure and 0 = food insecure. X denotes a vector of explanatory variables (e.g., gender, marital status, farming experience, and location dummies) expected to affect food security status. β denotes parameters to be estimated. ε denotes the random errors. Marginal effect of "i" variable as the effect of a unit change of this "i" variable on the probability $P(Y = 1|X = x)$, given that all other variables are constant and can be specified as follow:

$$\partial P(y_i|x_i)/\partial x_i = \partial E(y_i|x_i)/\partial x_i = \varphi(x_i'\beta)\beta \tag{2}$$

When the independent variables have different nature, the ways to calculate the average marginal effects of the independent variable on the dependent variable are different. Specifically, the average marginal effect of the continuous independent variable is computed as follows:

$$AME = \frac{1}{n}\sum_i^n = 1\varphi(x_i'\,\beta)\beta \tag{3}$$

When the independent variable is binary, we can calculate the average marginal effect in the following ways:

$$AME = \frac{1}{n}\sum_{i=1}^{n}[\vartheta(x_i'\beta|x_i^k = 1) - \vartheta(x_i'\beta|x_i^k = 0)] \quad (4)$$

3.5 Study area and data

The study focuses on three regions in Northern Ghana namely Upper East, Upper West, Northern regions. These regions are the most vulnerable in terms of climate change issues in Ghana, with prolonged drought and erratic rainfall being the most problematic climate concerns. These regions are also recorded high levels of food insecurity and poverty even though there is overall economic growth in the country (MoFA, 2019; WFP, 2013, 2021). They fall within the Guinea Savannah agro-ecological zone, which makes up 40 % of the total land area of the country (MoFA, 2013, 2019). According to (Amanor-Boadu et al., 2015) production system of northern Ghana is characterized by small landholdings and low input - low output, which negatively impacts food security. Farmers produce most crops for both consumption and sale (Amanor-Boadu et al., 2015; Kotu et al., 2017). The soil natural resources are steadily depleting and causing the yields per unit area to fall to very low levels; this is due to the continuous monoculture of growing crops in the area (Amanor-Boadu et al., 2015)

Primary data was collected from 494 smallholder farmer households in the study area. A multi-stage sampling technique, comprising stratified, random and cluster sampling, was used. The basis for the sampling frame is the Africa RISING (AR) project location. Based on the sampling frame, we stratified the project locations into 25 AR intervention communities and 25 counterfactual (no intervention) communities. In this study, ten communities of the intervention communities and five communities of the counterfactual communities were randomly selected. A total of 494 households was sampled, made up of 345 households participating in AR intervention and 149 counterfactual households A semi-structured questionnaire was used to collect data on the socio-demographics of households, coping behaviours, as well as 24 hour and weekly recall of food consumed by the household and the consumption frequencies. These data were used to estimate the food security status of households.

3.6 Results and discussion

3.6.1 Descriptive statistics

The descriptive statistics of the selected variables are presented in Table 4. It shows that the sample consisted of 51% male and 49% female, with 92% of the respondents practising farming as their primary occupation. In terms of alternative sources of income, 58.7% of the respondents engaged in off-farm work; 27.3% and 6.1% of the sample received remittances and welfare payments, i.e., LEAP, respectively. The mean land size of a household is 4.16 hectares; the main crops cultivated by the respondents were maize, rice, millet, and yam.

The mean gross income of the household from crop farming is 180 USD per hectare, which is very low. This is mainly due to farmers' overreliance on rainfall as the main source of irrigation in the area. Farmers experience drought during the 2018/2019 cropping season, with over 36% of the households saying it significantly impacted their production. We found that 83.2% of the households were members of a farmer group. Also, 54% of respondents were credit constrained in the cropping year. When compared to the other crops grown in the area, maize has the longest mean duration of storage of 6 months.

Table 4: Descriptive Statistics of Sample

Variable	*Mean*	*Std. Dev.*	*Min*	*Max*
Gender+	0.510	0.500	0	1
Marital status+	0.860	0.348	0	1
Age	44.741	12.391	19	85
Household size	10.060	6.110	2	70
Household members under 15 years	3.524	2.382	0	16
Education in years	1.923	3.739	0	19
Primary Occupation (farming) +	0.927	0.261	0	1
Off farm activity+	0.587	0.493	0	1
Remittance+	0.273	0.446	0	1
Welfare payment (LEAP)+	0.061	0.240	0	1
Perceived effect of drought	1.441	0.637	1	3
Perceived effect of crop diseases and pests	2.083	0.810	1	3
Total Farm size	4.463	3.518	0.5	48
Maize output	8.047	17.043	0	200
Rice output	4.342	9.075	0	90
Millet output	2.700	16.848	0	240
Yam output	1.158	13.660	0	200
Net income	925.515	2015.795	-9240	9420
Credit Constrained	0.549	0.498	0	1
Membership in Agricultural group	0.832	0.374	0	1
Satisfied with extension service+	0.741	0.439	0	1
Duration of maize storage	6.387	3.050	0	12
Duration of storage millet	0.089	0.584	0	6
Duration of storage yam	0.024	0.540	0	12
Duration of rice storage	1.540	3.300	0	12
Own animals (livestock and poultry)	1.656	1.152	0	6
Northern region +	0.389	0.488	0	1
Upper East region+	0.310	0.463	0	1
Upper West Region (used as base)	0.302	0.459	0	1
HHS+	0.721	0.449	0	1
SAFS+	0.623	0.485	0	1
CSI+	0.419	0.493	0	1
FCS+	0.401	0.491	0	1

+, it indicates a dummy variable.

The seven food security measures are presented as percentages in Table 5. It shows that the FCS recorded the highest number of food-insecure households. The HHS was expected to give the least number of food-insecure households since it measures the severest forms of hunger, but HDD recorded the least number of food-insecure households.

Table 5: Food Security measures in Percentages

	HHS	*SAFS*	*CSI*	*rCSI*	*HDD*	*FCS*	*HFIAS*
Food Secure	72.1	62.5	42.5	50.1	79.2	40.1	40.7
Food Insecure	27.9	37.5	57.5	49.9	20.8	59.9	59.3

This could be because the threshold used in the study records households that consume five or fewer food groups as food insecure, i.e., the moderately food insecure and the severely food insecure categories were combined as food insecure.

3.6.2 Correlations between food security measures

The results estimating the relationships amongst the seven measures using the scale values (i.e., raw scores), which are estimated by spearman rho, are reported in Table 6. Our estimates show that HDD and FCS had a strong positive relationship and a negative relationship with all the other measures. This finding, which is similar to Maxwell et al. (2014); Moroda, Tolossa, and Semie (2018), is to be expected because FCS and HDD are scored in such a way that, the higher their score, the more food secure the household is, whilst with the other five measures, the higher the score, the less food secure the household is (or the more food insecure the household is).

Table 6: Correlations Amongst Food Security Measures- Scale Values

	SAFS	HDD	FCS	HHS	HFIAS	CSI	rCSI
SAFS	1.000	0.055	-0.078	0.267**	0.467**	0.373**	0.408**
HDD	0.055	1.000	0.492**	-0.175**	-0.101*	-0.007	-0.085
FCS	-0.078	0.492**	1.000	-0.190**	-0.205**	-0.216**	-0.251**
HHS	0.267**	-0.175**	-0.190**	1.000	0.708**	0.601**	0.632**
HFIAS	0.467**	-0.101*	-0.205**	0.708**	1.000	0.713**	0.767**
CSI	0.373**	-0.007	-0.216**	0.601**	0.713**	1.000	0.902**
rCSI	0.408**	-0.085	-0.251**	0.632**	0.767**	0.902**	1.000

** , * correlation is significant at the 0.01 level, and 0.05 level (2-tailed)

We also found that HHS had a very strong positive relationship with HFIAS, CSI and rCSI. As shown in Table 6, the study found a similar relation amongst the measures when the raw scores were transformed into categorical values using standardized thresholds, as shown in Table 7.

Table 7: Correlations amongst food security measures - categorical values

	HHS	SAFS	CSI	rCSI	HDD	FCS	HFIAS
HHS	1.000	0.193**	0.416**	0.471**	0.143**	0.198**	0.515**
SAFS	0.193**	1.000	0.339**	0.287**	-0.041	0.050	0.422**
CSI	0.416**	0.339**	1.000	0.858**	0.032	0.191**	0.716**
rCSI	0.471**	0.287**	0.858**	1.000	0.100*	0.236**	0.729**
HDD	0.143**	-.041	0.032	0.100*	1.000	0.420**	0.063
FCS	0.198**	0.050	0.191**	0.236**	0.420**	1.000	0.288**
HFIAS	0.515**	0.422**	0.716**	0.729**	0.063	0.288**	1.000

** , * correlation is significant at the 0.01 level, and 0.05 level (2-tailed) respectively

SAFS was found to have a moderately strong positive relationship with HFIAS and CSI. Upon further investigation, we found that most measures that had strong relationships captured the same households either as food secure or food insecure, albeit they had varied percentages of food secured to food-insecure households because of the thresholds used. This indicates that there is convergence amongst the measures though the width is determined by the thresholds of the various measures.

3.6.3 Determinants of food security in Northern Ghana

To further assess the food security measures, we investigate the determinants of food security using four of the seven measures, namely FCS, HHS, CSI and SAFS. These four measures were selected because they had a high positive correlation with the other three. Specifically, the FCS is correlated with HDD, HHS is correlated with HFIAS, and CSI is correlated with rCSI. The SAFS was added because it is a self-assessed measure of food security and had a weak correlation with all the other measures except HFIAS. It is also important to note that HHS and rCSI are subsets of HFIAS and CSI respectively thus the selection of just one of each pair for further analysis. As discussed earlier, a probit regression was used to determine the factors that affect the food security status of a household. The results, as shown in Table 8, indicate that the probit regression was well suited for the model.

A male-headed household increased the probability of a household being food secure by 9% and 11.9% using CSI and SAFS measures, respectively. This means female-headed households are more likely to be food insecure which is consistent with past findings such as (FAO et al., 2020; Horrell & Krishnan, 2007; Tibesigwa & Visser, 2016). This is partially explained by the fact that women usually have limited access to the factors of production such as land, labour, and credit in northern Ghana. According to the HHS measure, a household has a 14.1% probability of being food insecure if the household head is not married. Engagement in off-farm activity had a positive effect on food security, i.e., households increased their probability of being food secure by 9.8% and 13.1% according to FCS and SAFS measures, respectively. Additional income from off-farm activities helps the farm household in two main ways, which also contributes to the achievement of particular Sustainable Development Goals. First, it can help relieve credit constraints, allowing farmers to invest in innovative technologies such as SAPs to enhance production and protect the environment. This can be seen to contribute to the achievement of SDG Goal 2. Second, it also boosts the disposable income of the household, which may increase their access to food especially during the lean season, thereby contributiig to the achievement of both SDG Goal 1 and 2. This is consistent with the finding of (Rahman & Mishra, 2020; Setsoafia, Ma, & Renwick, 2022). Households that received remittance also increased their probability of being food secure by 29.2% and 8.6%, according to FCS and SAFS, respectively. Remittances boost a household’s disposable income and allow them to increase the quantity and quality (diversity) of meals consumed (Tuholske et al., 2020).

Households that were negatively impacted by drought were more likely to experience food insecurity by all the measures except HHS, with a higher probability of food insecurity when measured by FCS. Experiencing drought is most likely to affect the yields of the farmer and, subsequently, the household's food security status (Kotu et al., 2017). Households that were credit constrained within the 2018/2019 cropping year were more likely to be food insecure with all the measures with the highest probability of food insecurity from CSI, i.e., 13.6%. This means according to CSI; such households have a higher probability of using coping strategies to food insecurity such as borrowing food from a friend or skipping meals throughout the day or limiting the portion size of food. Being a member of a farmer group positively affects the household's probability of being food secure across all the measures, with the highest probability, i.e., 16.4% being from SAFS.

Table 8: Determinants of Household Food Security

	FCS	HHS	CSI	SAFS
Variables	dy/dx (Robust Std. Err.)	dy/dx (Robust Std. Err.)	dy/dx (Robust Std. Err.)	dy/dx (Robust Std. Err.)
Gender	-0.086(0.056)	-0.040(0.051)	0.091*(0.054)	0.119**(0.052)
Marital status	-0.068 (0.071)	-0.141*(0.051)	N/I	N/I
Farming Experience	0.002 (0.002)	0.001(0.002)	-0.002(0.002)	N/I
Off farm activity	0.098 **(0.489)	N/I	N/I	0.131**(0.050)
Remittance	0.292*** (0.545)	-0.043(0.049)	0.042(0.053)	0.086*(0.051)
Welfare payment Leap	-0.088(0.108)	-0.096(0.095)	0.149(0.105)	N/I
Perceived effect of drought	-0.197*** (0.040)	N/I	-0.105**(0.038)	-0.078*(0.038)
Credit Constrained	-0.131**(0.049)	-0.089**(0.045)	-0.136**(0.048)	-0.070(0.048)
Membership in Farmer Group	0.127 **(0.059)	0.159**(0.067)	0.110*(0.059)	0.164**(0.065)
Maize storage duration	-0.009 (0.009)	0.025**(0.008)	0.009(0.009)	0.021**(0.008)
Rice storage duration	-0.012 (0.009)	-0.012 (0.008)	-0.006(0.009)	0.008(0.009)
Millet Storage duration	0.180***(0.054)	N/I	N/I	-0.098**(0.041)
Millet output	-0.016** (0.005)	0.002**(0.001)	-0.004**(0.002)	0.001(0.002)
Yam Output	N/I	-0.003**(0.001)	-0.004**(0.002)	-0.001(0.002)
Net income	0.000** (0.000)	-0.000 (0.000)	0.000(0.000)	0.000(0.000)
Own animals	-0.185 (0.062)	N/I	-0.041*(0.022)	0.141**(0.064)
Northern	0.049 (0.076)	0.102*(0.062)	-0.086(0.074)	-0.214**(0.078)
Upper East	0.145** (0.063)	N/I	-0.071(0.063)	-0.264***(0.061)
Household size	N/I	0.008(0.005)	0.004(0.005)	0.006(0.004)
Household members less than 15 years	N/I	-0.024*(0.013)	N/I	N/I
Primary Occupation	N/I	-0.178*(0.096)	N/I	N/I

Education(years)	N/I	0.007(0.006)	-0.006(0.007)	0.010(0.007)
Perceived effect of crop pest and disease	N/I	0.016(0.026)	N/I	N/I
Total Farm size	N/I	0.012*(0.006)	N/I	N/I
Satisfied with extension	N/I	0.023(0.056)	N/I	N/I
Wald chi^2	92.78	47.79	44.28	80.08
Prob>chi^2	0.000	0.001	0.001	0.000
Pseudo R^2	0.162	0.079	0.064	0.125

***, **, * indicates 1%, 5%, 10% significance level, respectively. "N/I" means not "not included in the model".

Farmers who are members of a farmer group probably participated in the farmer training, input support etc. provide by the Africa RISING project and other NGOs, thus were more likely to implement innovations that improved their yields and subsequently their food security status (Abebaw & Haile, 2013; Ma & Abdulai, 2016; Mutenje et al., 2016). According to HHS and SAFS, the longer the duration households stored maize, the higher the probability of being food secure.

There were mixed results with the duration of millet storage, with FCS giving an 18% probability a household will be food secure if they stored millet a month longer and SAFS giving a 9.8% probability a household will be food insecure if they stored millet a month longer. The results were also mixed on the effect of millet output, whilst FCS and CSI showed that higher millet output would increase the chances of a household being food insecure. HHS showed that a higher millet output would make the household more food secure. This could be because most farmers cultivate millet on a smaller scale compared to maize and mostly retain it for household consumption; hence a higher yield may not necessarily lead to an increase in food diversity for the household but maybe enough to reduce severe hunger which is what HHS measures. According to HHS and CSI, a higher yam output has a 3% and a 4% probability of reducing households' food security. According to FCS, net income has a positive effect on a household being food secure, even though the effect is very small. An increase in net income affords the household the opportunity of having diverse meals, i.e., improving the food quality of the household (Tuholske et al., 2020).

Households owning multiple types of livestock are more likely to be food secure according to SAFS; but less likely to be food secure according to CSI. Households located in the Northern region and Upper East are more likely to be food secure according to HHS and FCS, respectively, but less likely to be food secure according to SAFS. This could be because households in Upper East do a lot more mixed cropping, thus having more opportunities for more diverse meals; hence FCS classifies them as food secure. Results from the model show that households that have a greater number of children (under 15 years old) are more likely to be food insecure as measured by HHS. Households whose primary occupation is not farming were more likely to be food insecure in the study area, according to the HHS. Farm size had a positive effect on food security according to HHS; meaning, as farm size used by the household increases by a hectare, the probability of the household being food secure increases by 12%. This is contrary to the findings of (Gebremariam & Wünscher, 2016; Teklewold et al., 2013), who found farm size has a negative relationship with food security and argue that smaller holder farmers tend to achieve food security by sustainably intensifying production in their small lands.

3.7 Conclusions and policy implications

The study set out to assess seven of the commonly used food security measures in northern Ghana and examine the determining factors of food security among smallholder farmers. The study found strong correlations among FCS and HDD; HFIAS and HHS; CSI and rCSI; and SAFS and HFIAS. We found huge variations in the level of food insecurity prevalence, with FCS and HFIAS given the highest percentage of food-insecure households whilst HDD gave the least percentage. The study also found HDD giving the least percentage of food-insecure households, which is contrary to the expectation that HHS usually gave the least number of food-insecure households because it measures the most severe form of hunger. The determining factors of food security amongst smallholders in northern Ghana include socio-demographics of household head, farm size, drought, membership in a farmer group, duration of storage of maize and millet, ownership of animals and location.

The study concludes that because of the huge variations in the prevalence of food-insecure households amongst the seven measures, one must be cautious about which measure to use, especially when measuring acute food insecurity for better targeting during an intervention. Interventions that seek to target a wider range of food-insecure households can use FCS or HFIAS as an indicator, whilst interventions that seek to target severely food-insecure households can use either HDD or HHS as indicators. Also, researchers should use at least two measures of food security, i.e., a dietary diversity measure (HDD and, FCS) and a behavioural (rCSI and CSI) or experiential measure (HFIAS and, HHS), to get a wholesome view of the food security situation amongst smallholder farmers in northern Ghana. Membership in a farmer group had a positive effect on the food security status of households across all the measures. Policies to improve food security amongst smallholders should encourage membership in farmer groups to assess farmer training, input support etc., organized by extension agencies, Africa RISING and other stakeholders. Other policies that encourage the storage of food for longer periods should also be pursued to improve food security in northern Ghana and contribute to the achievement of SDG Goal 2. These include supporting well managed community warehousesand improving credit access through microfinance institutions such as village savings and loans schemes.

Chapter 4

Effects of sustainable agriculture practices (SAPs) on farm income and food security of smallholder farmers in northern Ghana

Abstract

The adoption of sustainable agricultural practices (SAPs) has been recommended by many experts and international institutions to address food security and climate change problems. Global support for the Sustainable Development Goals (SDGs) has focused attention on efforts to up-scale the adoption of SAPs in developing countries where growth in populations and incomes compromises the resilience of natural resources. This study investigates the factors affecting smallholder farmers' decisions to adopt SAPs (improved seed, fertilizer, and soil and water conservation) and the impacts of the adoption on farm income and food security, using data collected from Ghana. Food security is captured by the reduced coping strategy index and household dietary diversity. The multinomial endogenous switching regression model is utilized to address selection bias issues. Results show that farmers' decisions to adopt SAPs are influenced by the social demographics of the households, plot-level characteristics, extension services and locations. Adopting all three SAPs has larger positive impacts on farm income and food security than adopting single or two SAPs. Our findings advocate for policies that enhance the quality of extension service and strengthen farmer-based organizations for the wider dissemination of adequate SAP information. Farmers should be encouraged to adopt SAPs as a comprehensive package for increasing farm income and ensuring food security.

Keywords: Sustainable agriculture practices; MESR model; Farm income; Food security; Ghana

JEL Codes: C34; O12; Q16; Q18

4.1 Introduction

There is considerable pressure on agriculture to meet the demands of a growing world population. This is heightened with rising demand for necessities such as food, raw materials for industries, and biofuels. However, growth in agricultural production globally does not match this demand well, especially in parts of Africa. Africa has been projected to be vulnerable to climate change because of its proximity to the equator (Ahmed, 2022; Ojo, Ogundeji, & Belle, 2021; Onyeneke, 2021; Sarr, Ayele, Kimani, & Ruhinduka, 2021; Thinda, Ogundeji, Belle, & Ojo, 2021). Some of the physical impacts of climate change in Africa are rising sea levels, temperature, and rainfall changes (Abdulai, 2018), which will harm agricultural productivity, farm income, food security, and economic development. This will negatively affect the poor, whose livelihoods are tired of agriculture in Sub-Saharan Africa.

There has been a global discussion on overcoming the negative externalities of climate change. Most experts believe that sustainable agricultural management could be a solution to the challenge associated with climate change (Adenle, Wedig, & Azadi, 2019; Bekele, Mirzabaev, & Mekonnen, 2021; Ehiakpor et al., 2021; Kassie et al., 2013; Ma & Wang, 2020; Ndiritu, Kassie, & Shiferaw, 2014; Ogemah, 2017; Rose et al., 2019; Zeweld, Van Huylenbroeck, Tesfay, Azadi, & Speelman, 2020; Zhou, Ma, & Li, 2018). This approach is expected to improve agricultural production performance whilst reversing the negative degradation processes on the agroecosystem, particularly in smallholder farming systems. It is an upgrade of the green revolution, which led to a significant increase in agricultural productivity globally and is credited for jump-starting economies in Asia out of poverty but has left negative externalities such as deforestation, land degradation, salinization of water bodies, and loss of biodiversity in its wake.

To reverse the negative externalities from crop intensification, farmers have been advised to adopt sustainable agricultural practices (SAPs), which are made up of elements of the green revolution and an agronomic revolution. The literature is filled with studies on the adoption of specific or single elements of SAPs, such as improved seed, irrigation, drought-tolerant crop varieties, climate-resilient crop variety, organic soil amendments, and soil and water conservation practices, and their effects on crop yield and net farm income (Abdulai & Huffman, 2014; Adegbeye et al., 2020; Adenle et al., 2019; Agula et al., 2018; Ahmed, 2022; Kimathi, Ayuya, & Mutai, 2021; Yang, Zhu, Liu, & Wang, 2022; Zheng, Ma, & Li, 2021). Despite the potential complementarity or substitutability of specific elements of SAPs, the research on the adoption of multiple SAPs and their effects on outcome variables such as income, outputs, consumption expenditure and food security remain limited (Bopp, Engler, Poortvliet, & Jara-Rojas, 2019; Ehiakpor et al., 2021; Kassie et al., 2013; Manda, Alene, Gardebroek, Kassie, & Tembo, 2016; Oyetunde-Usman, Olagunju, & Ogunpaimo, 2021; Teklewold et al., 2013).

This paper seeks to investigate the determinants of multiple SAPs adoption and the adoption effects on farm income and food security, using second-hand data collected from Ghana. This study contributes to the literature in twofold. First, it provides empirical insights into the importance of SAPs on welfare indicators, specifically food security. The use of food security as a proxy measure for welfare is particularly important in the Ghanaian context, where farming is done mostly on a subsistence level, and farmers sell crops as and when they need cash. Thus, farmers may be food secure but not have a high net farm income or high consumption expenditure. Our analysis extends previous studies that have focused on other proxies of household welfare such as net farm income, net crop income and consumption expenditure (Bopp et al., 2019; Ehiakpor et al., 2021; Kassie et al., 2013; Manda et al., 2016; Oyetunde-Usman et al., 2021; Teklewold et al., 2013) Secondly, we employ a multinomial endogenous switching regression model to mitigate selection bias. In particular, this model helps address the selection bias issues arising from observed factors (e.g., age, gender and education) and unobserved factors (farmers' innate ability in innovation adoption and motivations to address external shocks). Findings from the study will aid in formulating specific policies targeted at improving SAP adoption and enhancing the food security status of farm households in developing countries.

The remaining sections of the paper are as follows; Section 2 covers a review of relevant literature. The methodology is presented in Section 3. The descriptive and empirical results are presented and discussed in Section 4. The final section highlights the conclusions and policy implications of the findings.

4.2 Literature review

A growing number of studies have explored the factors that determine the adoption of SAPs in Africa. In the past, most of the works have focused on single components of SAPs (Abdulai & Huffman, 2014; Adenle et al., 2019; Carrión Yaguana, Alwang, Norton, & Barrera, 2016; Fisher et al., 2015; Kimathi et al., 2021; Lamptey, 2022; Manda, Alene, et al., 2020; Martey, Etwire, & Kuwornu, 2020). For example, Abdulai and Huffman (2014) reported that rice farmers' decisions to adopt soil and water conservation are influenced by their education, capital and labour constraints, social networks, extension contacts, and farm soil conditions. Manda et al. (2016) found that farmers' decisions to adopt improved maize varieties are mainly influenced by education, household size, livestock holdings, land per capita, market information, and locations in Zambia. The study by Martey et al. (2020) reveals that farmers' adoption of drought-tolerant maize varieties is mainly determined by access to seed, gender, access to extension, labour availability and location of the farmer in Ghana. Kimathi et al. (2021) investigated farmers' decisions to adopt climate-resilient potato varieties and found that the main factors affecting adoption were access to information, quality seeds, training, group membership and variations in agro-ecological zones.

Some studies have also explored the factors affecting smallholder farmers' decisions to adopt multiple SAPs. Most of the past works have been focused on Eastern and Southern Africa (Bese, Zwane, & Cheteni, 2021; Kassie et al., 2014; Nonvide, 2021; Teklewold et al., 2013), though a growing number of studies seek to bridge the research gap in the adoption of multiple SAPs in West Africa (Ehiakpor et al., 2021; Faye, Hopple, & Bridgham, 2021; Paul Nkegbe & Shankar, 2014; Struik, Klerkx, van Huis, & Röling, 2014). The multiple SAPs considered by Teklewold et al. (2013a) include maize–legume rotation, conservation tillage, animal manure use, improved seed, and inorganic fertiliser use. They showed that a household's trust in government support, credit constraints, spouse education, rainfall and plot-level disturbances, household wealth, social capital and networks, labour availability, plot and market access are the main factors determining both the probability and the extent of adoption of SAPs in rural Ethiopia. In their investigation for Ghana, the multiple SAPs considered by Ehiakpor et al. (2021) include improved maize seeds, maize-legume rotation, animal manure, legume intercropping, crop residue retention, zero/minimum tillage, integrated pest management, and chemical fertilizer. Non-farm income, livestock ownership, pest and disease prevalence, farmers' experience of erosion, farmers' perception of poor soil fertility, participation in field demonstration, membership of saving groups, access to agricultural credit, plot ownership, and distance to the agricultural input market are found to be important determinants of adoption of SAPs (Ehiakpor et al. 2021).

Studies estimating the impacts of SAP have utilized various outcome variables, such as household income, agrochemical use, demand for labour, crop yields, food security (Abdulai & Huffman, 2014; Amondo, Simtowe, & Erenstein, 2019; Gebremariam & Wünscher, 2016; Manda et al., 2016; Marenya, Gebremariam, Jaleta, & Rahut, 2020; Oduniyi & Chagwiza, 2021; Teklewold et al., 2013). Gebremariam and Wünscher (2016) found that higher combinations of SAPs led to higher payoff measured by net crop income and consumption expenditure in Ghana. Khonje et al. (2018) showed that joint adoption of multiple SAPs had higher impacts on yields, household income and poverty than the adoption of components of the technology package in Zambia. Amondo et al. (2019) found that adopting drought-tolerant maize varieties increases maize yield by 15% in Zambia. Marenya et al. (2020) concluded that a higher number of SAPs adopted resulted in higher maize grain yield and maize income in Ethiopia. The adoption of elements of SAPs has been said to be context-specific because there are no blueprints of the various combination of SAPs that work in every environment. Therefore, this study explores how SAP adoption affects farm income and food security, using Ghana as a case study.

4.3 Methodology

Smallholder farmers make decisions to adopt SAPs in response to external shocks such as drought, erosion, perceived decline in soil fertility, weeds, pests, and diseases. 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 (Kassie et al. 2013; Teklewold et al. 2013; Manda et al. 2016; Ehiakpor et al. 2021). Due to the self-selection nature of technology adoption, farmers without adopting any SAPs and those adopting a single SAP or package may be systematically different. The fact 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; Czyżewski, Polcyn, & Brelik, 2022; Ma, Zhu, & Zhou, 2021) or the multinomial endogenous switching regression (MESR) model (Ahmed, 2022; Kassie, Bekele, & Ndiritu, 2015; Oparinde, 2021) to address the selection bias issues. For example, Czyżewski et al. (2022) estimated the long-term impacts of political orientation (economic views and individual value systems) on the environment using the MVT model. They confirmed that local orientation is conducive to long-term environmental care. Using the MESR model, Ahmed (2022) evaluated the impact of improved maize varieties and inorganic fertilizer on productivity and wellbeing. He found that combining the two technologies significantly boosts maize yield and consumption expenditure than adopting the technologies in isolation. 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 is employed in this study.

4.3.1 Multinomial endogenous switching regression

The MESR model estimate three stages. The first stage model factors affecting smallholder farmers' decisions to adopt a specific SAP technology or a package. Following Teklewold et al. (2013a), this study focuses on three main SAP technologies, namely improved seeds (I), fertilizer (F), and soil and water conservation (cereal-legume rotation/cereal – legume intercropping, manure use, organic input use) (S). The three categories result in eight possible choices of SAPs. It bears an emphasis here that because of the small number of observations in the group that captures the combination of improved seed and fertilizer (26 samples) and the group that captures the combination of improved seed and soil and water conservation (9 samples), we combined them in empirical estimations. Also, it is worth noting here that no household has only adopted improved seed. These facts indicate that there are six mutually exclusive choices of SAP technology, including (1) non-adoption ($I_0F_0S_0$); (2) fertilizer only ($I_0F_1S_0$); (3) soil and water conservation only ($I_0F_0S_1$); (4) combination of improved seed and fertilizer and combination of improved seed and soil and water conservation ($I_1F_1S_0$); (5) combination of fertilizer and soil and water conservation ($I_0F_1S_1$); (6) combination of improved seed, fertilizer, and soil and water conservation ($I_1F_1S_1$). Farmers choose one of the six possible choices to maximize the expected benefit.

The study assumes that the error terms are identical and independently Gumbel distributed, the probability that farmer *i*, with *X* characteristics will choose package *j*, is specified using a multinomial logit model (Ma, Zheng, & Gong, 2022; McFadden, 1973; Teklewold et al., 2013;

Zhou, Ma, Renwick, & Li, 2020). It is specified as follows:

$$P_{ij} = \Pr(\eta_{ij} < 0 | X_i) = \frac{\exp(X_i\beta_j)}{\sum_{m=1}^{J}\exp(X_i\beta_m)} \tag{1}$$

where P_{ij} represents the probability that a farmer i chooses to adopt SAP technology *j*. X_i is a vector of observed exogenous variables that capture household, plot, and location-level characteristics. β_j is a vector of parameters to be estimated. The maximum likelihood estimation is used to estimate the parameters of the latent variable model.

In the second stage, the ordinary least square (OLS) model is used to establish the relationship between the outcome variables (farm income and food security) and a set of exogenous variables denoted by Z for the chosen SAP technology. Non-adoption of SAPs (i.e., base category, $I_0F_0S_0$) is denoted as *j*=1, with the other combinations denoted as (*j*= 2…,6). The possible equations for each regime is specified as:

$$\begin{cases} Regime\ 1: Q_{i1} = Z_i\alpha_1 + u_{i1}\ if\ \ I = 1 & (2a) \\ \vdots \qquad\qquad \vdots & \\ Regime\ J: Q_{iJ} = Z_i\alpha_J + u_{iJ}\ \ if\ I = 1 & (2b) \end{cases}$$

where *I* is an index that denotes farmer *i*'s choice of adopting a type of SAP technology; Q_i is the outcome variables for the i-th farmer; Z_i is a vector of exogenous variables; α_1 and α_J are parameters to be estimated; u_{i1} and u_{iJ} are the error terms.

Relying on a vector of observed covariates, captured by Z_i, Equations (2a) and (2b) can help address the observed selection bias issue. However, if the same unobserved factors (e.g., farmers' motivations to adopt SAPs) simultaneously influence farmers' decisions to adopt SAPs and outcome variables, the error terms in Equations (2a) and (2b) and the error term in Equation (1) would be correlated. In this case, unobserved selection bias occurs. Failing to address such type of selection bias would generate biased estimates. Within the MESR framework, the selectivity correction terms are calculated after estimating Equation (1) and then included into Equations (2a) and (2b) to mitigate unobserved selection bias. Formally, Equations (2a) and (2b) can be rewritten as follows:

$$\begin{cases} Regime\ 1: Q_{i1} = Z_i\alpha_1 + \lambda_1\sigma_1 + \omega_{i1}\ if\ \ I = 1 \\ \quad \vdots \qquad\qquad \vdots \\ Regime\ J: Q_{iJ} = Z_i\alpha_J + \lambda_J\sigma_J + \omega_{iJ}\ \ if\ I = J \end{cases} \qquad \begin{matrix} (3a) \\ \\ (3b) \end{matrix}$$

where Q_i and Z_i are defined earlier; λ_1 and λ_J are selectivity correction terms used to address unobserved selection bias issues; σ_1 and σ_J are covariance between error terms in Equations (1), (2a) and (2b). In the multinomial choice setting, there are $J-1$ selectivity-correction terms, one for each alternative SAP combination.

For consistently estimating the MESR model, at least one instrumental variable (IV) should be included in X_i in the MNL model but not in the Z_i in the outcome equations. In this study, two distance variables, distance to weekly market and minutes 30 to the plot, are employed as IVs for model identification purposes. Distance to the weekly market is measured as a continuous variable, measured in minutes. The variable representing minutes 30 to plot is a dummy variable, which equals 1 if the plot is within 30 minutes from the homestead and 0 otherwise. The two IVs are not expected to affect farm income and food security directly. We checked the validity of the IVs by running the Falsification test and conducting the correlation coefficient analysis (Liu, Min, Ma, & Liu, 2021; Ma, Vatsa, Zhou, & Zheng, 2021; Pizer, 2016). For the sake of simplicity, we did not report the results.

The average treatment effect on the treated (ATT) is calculated at the third step. This involves comparing the expected outcomes (farm income and food security) of SAP adopters and non-adopters, with and without adoption. Using experimental data, it is easier to establish impacts; however, this study is based on observational cross-sectional data, thus making impact evaluation a bit challenging. The challenge is mainly estimating the counterfactual outcome, i.e., the outcome of SAP adopters if they had not adopted the SAP technology. Following previous studies (Kassie et al. 2015; Oparinde 2021; Ahmed 2022), the study estimates ATT in the actual and the counterfactual scenarios using the following equations:

The outcome variables for SAP adopters with adoption (observed):

$$\begin{cases} E(Q_{i2}|I=2) = Z_i\alpha_2 + \sigma_2\lambda_2 & \text{(4a)} \\ \vdots \qquad\qquad \vdots \\ E(Q_{iJ}|I=J) = Z_i\alpha_J + \sigma_J\lambda_J & \text{(4b)} \end{cases}$$

The outcome variables for SAP adopters had they decided not to adopt (Counterfactual):

$$\begin{cases} E(Q_{i1}|I=2) = Z_i\alpha_1 + \sigma_1\lambda_2 & \text{(5a)} \\ \vdots \qquad\qquad \vdots \\ E(Q_{i1}|I=J) = Z_i\alpha_1 + \sigma_1\lambda_J & \text{(5b)} \end{cases}$$

The difference between Equations (4a) and (5a) or Equations (4b) and (5b) is the ATT. For example, the difference between Equations (4a) and (5a) is given as:

$$ATT = E[Q_{i2}|I=2] - E[Q_{i1}|\ I=2] = Z_i(\alpha_2 - \alpha_1) + \lambda_2(\sigma_2 - \sigma_1) \qquad (6)$$

4.3.2 Variables and data

The study used data collected by IITA for their Africa RISING project in the three northern regions, namely, Northern, Upper East, and Upper West regions. The data was collected in 2014 from 1,284 households operating approximately 5,500 plots in 50 rural communities in northern Ghana. The baseline survey used a stratified two-stage sampling technique, and data was collected using Computer Assisted Personal Interviewing (CAPI) supported by Survey CTO software on tablets (Tinonin et al. 2016). A structured questionnaire was used to conduct the household interviews. The data covers the various SAP technologies, demographic characteristics, agricultural land holdings, crop outputs and sales, livestock production, farmers’ access to agricultural information and knowledge, access to credit and markets, household assets, and income.

The outcome variables for this study are farm income and food security. The farm income of crops cultivated is obtained by valuing the yield of crops at market price and deducting the costs of all variable inputs. Two variables capture food security, including reduced coping strategy index (rCSI) and household dietary diversity (HDD). Specifically, the rCSI is an index that is measured by scoring coping strategies households use (and frequency of use) when they experience food insecurity. rCSI is an index with five standardized questions on the coping strategies used when faced with food insecurity, the more strategies used, and food insecure the household is. The rCSI score ranges from 0-63. A higher level of rCSI score means a higher level of food insecurity. The HDD variable is based on the diverse food groups a household consumes. The higher the score, the more diverse the diet of a household, and the more food secure the household is. Drawing upon previous empirical studies on the adoption of SAPs and related agricultural innovations (Bopp et al., 2019; Ehiakpor et al., 2021; Kassie et al., 2013; Khonje, Manda, Mkandawire, Tufa, & Alene, 2018; Oyetunde-Usman et al., 2021; Pham, Chuah, & Feeny, 2021; Teklewold et al., 2013), we have identified and selected a range of control variables that may influence the adoption of SAPs.

4.4 Results and discussion

4.4.1 Descriptive statistics

Table 1 shows the frequency of respondents that used the different categories of SAPs. Of the eight possible categories of SAPs initially specified, 6.78% of farmers in our sample did not adopt any SAPs ($I_0F_0S_0$). No farmers adopted imported seed only ($I_1F_0S_0$), while only 9 farmers combined improved seed and soil and water conversation as SAPs ($I_1F_0S_1$). Only 26 farmers combined improved seed and fertilizers as SAPs ($I_1F_1S_0$). Therefore, as discussed earlier, we merged $I_1F_1S_0$ and $I_1F_0S_1$ into one group (coded as $I_1F_1S_0$), and the empirical analysis includes six groups in total. Table 9 also shows that more than half of the farmers in our sample (51.17%) combined fertilizer and soil and water conservation as SAPs. Around 7% of farmers adopted all the three identified SAPs.

Table 9: Different SAP categories

SAPs	Category details	Frequency	Percentage	Cumulative percentage
$I_0F_0S_0$	None of the SAPs (base category)	87	6.78	6.78
$I_1F_0S_0$	Improved seed only	0	0	6.78
$I_0F_1S_0$	Fertilizer only	215	16.74	23.52
$I_0F_0S_1$	Soil and water conservation only	198	15.42	38.94
$I_1F_1S_0$	Improved seed and fertilizer	26	2.02	40.96
$I_1F_0S_1$	Improved seed and soil and water conservation	9	0.70	41.66
$I_0F_1S_1$	Fertilizer and Soil and water conservation	657	51.17	92.83
$I_1F_1S_1$	All the SAPs categories (Improved seed, fertilizer, and soil and water conservation)	92	7.17	100
Total		1,284	100	

Note: We merged $I_1F_1S_0$ and $I_1F_0S_1$ into one group (coded as $I_1F_1S_0$) in the empirical analysis due to small sample sizes.

Table 10 presents the variables and statistical descriptions. It shows that the average farm income is 2,561 GHS (roughly 400 USD). The average means of rCSI and HDD, which capture food security, are 5.576 and 7.799, respectively. Table 10 also shows that the average age of respondents was about 48 years. Around 84% of respondents are male, and almost 90% of respondents are married. The surveyed households averagely have around 9 persons. About 61% of respondents received advice from extension officers, and 45.6% were satisfied with the extension services. Approximately 70% of respondents had accessed the markets.

Table 10: Variables and statistical descriptions

Variables	Description	Mean	Std. Dev.
Dependent variables			
Farm income	Gross margin of farm production in Ghana Cedis (1,000 GHS)	2.561	12.378
rCSI	Reduced Coping strategy index	5.576	10.516
HDD	Household dietary diversity	7.799	2.094
Control variables			
Age	Age of household head (HH) in years	47.759	14.493
Gender	1 if HH is male and 0 otherwise	0.842	0.365
Education	Number of years of education	2.178	4.429
Marital status	1 if HH is married and 0 otherwise	0.893	0.309
Household size	Number of people in a household	8.529	5.064
Farm size	Hectares of land that household cultivated	3.330	3.522
Off-farm income	Income acquired from off-farm work in Ghana Cedis (100 GHS)	1.103	2.266
Africa RISING member	1 if member in AfricaRISING farmer group and 0 otherwise	0.611	0.489
Extension	1 if a farmer receives advice from an extension officer and 0 otherwise	0.609	0.488
Extension satisfaction	1 if household is satisfied with the extension agent and 0 otherwise	0.456	0.498
Number of crops	Number of crops cultivated in the cropping season	4.040	1.871
Drought and floods	1 if household experienced drought in the previous season and 0 otherwise	0.621	0.485
Market access	1 if farmer has access to market and 0 otherwise	0.704	0.457
Sandy soil	1 if farmer perceives soil as sandy and 0 otherwise	0.137	0.344
Clay soil	1 if farmer perceives soil as clay and 0 otherwise	0.238	0.426
Flat slope	1 if farmer perceives plots as having a flat slope and 0 otherwise	0.910	0.286
Moderate to steep	1 if farmer perceives plot as having a moderate slope and 0 otherwise	0.077	0.267
Northern	1 if household is in the Northern region and 0 otherwise	0.478	0.500
Upper East	1 if household is in the Upper East region and 0 otherwise	0.173	0.378
Upper West	1 if household is in the Upper West region and 0 otherwise	0.349	0.480
Instrumental variables			
Distance to weekly market	minutes	31.277	25.736
Minutes 30 to plot	1 if the distance between plot and homestead is within 30 minutes and 0 otherwise	0.547	0.498

4.4.2 Determinants of adoption of SAP categories

Table 11 presents the results estimated by the MNL model, demonstrating the factors that influence smallholder farmers' decisions to adopt different SAPs categories. Farmers who did not adopt any type of SAPs (i.e. $I_0F_0S_0$) was used as the reference group in empirical estimations. Because the primary objective of the MNL model estimations is to calculate the selectivity correction terms rather than explain the determinants of SAP adoption perfectly, we explain the results of Table 11 briefly.

The results show gender variable has significant coefficients in columns 2, 4 and 5. Our results appear to suggest that women are more likely to combine improved seeds and fertilizer ($I_1F_1S_0$) as SAPs to increase farm productivity. In comparison, men are more likely to rely on fertilizer ($I_0F_1S_0$) or combine fertilizer and soil and water conservation technology ($I_0F_1S_1$) as SAPs to improve farm performance. Our findings are largely supported by the previous studies (Paudel, Gartaula, & Craufurd, 2020; Smale, Assima, Kergna, Thériault, & Weltzien, 2018; Tambo, Matimelo, Ndhlovu, Mbugua, & Phiri, 2021), reporting gendered differences in agricultural technology adoption. For example, Smale et al. (2018) found that women are more likely to adopt improved seeds on the plots they manage in Sudan.

Education has positive impacts in all estimated specifications but is only statistically significant in the specification of adopting improved seed and fertilizer ($I_1F_1S_0$). Better education enables farmers to be aware of the benefits of SAPs and motivate them to adopt them, especially productivity-enhancing technologies such as improved seed and fertilizer. This finding is consistent with the findings of Kassie et al. (2014) for Tanzania and Gebremariam and Wünscher (2016) for Ghana. The significant coefficients of household size in columns 2 and 6 suggest that larger households are more likely to adopt multiple SAPs ($I_1F_1S_1$) but are less likely to adopt single SAP such as fertilizer ($I_0F_1S_0$). Larger households usually mean better labour endowments, allowing them to adopt multiple SAPs more easily than small ones. This is consistent with the findings of Kassie et al. (2014).

Table 11: MNL estimates of SAP adoption

Variables	$I_0F_1S_0$	$I_0F_0S_1$	$I_1F_1S_0$	$I_0F_1S_1$	$I_1F_1S_1$
Age	0.004	0.012	0.011	0.010	0.005
	(0.009)	(0.010)	(0.015)	(0.009)	(0.011)
Gender	0.174*	0.601	-0.541**	0.804***	0.422
	(0.358)	(0.361)	(0.507)	(0.338)	(0.456)
Education	0.239	0.127	0.567**	0.153	0.200
	(0.138)	(0.141)	(0.210)	(0.130)	(0.172)
Marital status	-0.543	-1.258***	-0.722	-0.661	-0.705
	(0.454)	(0.428)	(0.647)	(0.422)	(0.567)
Household size	-0.019*	0.323	0.227	0.381	0.919**
	(0.334)	(0.338)	(0.479)	(0.309)	(0.402)
Farm size	0.896	0.365	0.822	0.662	0.786
	(0.391)	(0.407)	(0.505)	(0.374)	(0.460)
Off-farm income	0.101	0.053**	0.057	0.143*	0.240**
	(0.057)	(0.058)	(0.089)	(0.055)	(0.074)
Africa RISING member	0.816*	0.748**	0.656	1.443***	1.363
	(0.300)	(0.308)	(0.459)	(0.284)	(0.400)
Extension	0.868*	0.075***	1.057	0.664	1.237**
	(0.289)	(0.292)	(0.462)	(0.268)	(0.367)
Extension satisfaction	0.033	-0.025	0.433	0.185	0.749***
	(0.299)	(0.299)	(0.442)	(0.282)	(0.357)
Number of crops	-0.488***	0.337	-0.024	0.834***	1.576***
	(0.461)	(0.454)	(0.732)	(0.422)	(0.564)
Drought and floods	0.326	0.078	0.933	0.368	0.247
	(0.289)	(0.286)	(0.475)	(0.261)	(0.373)
Market access	0.661**	-0.244***	0.217	0.424	0.455
	(0.308)	(0.292)	(0.480)	(0.274)	(0.378)
Sandy soil	0.206**	1.082	0.158	1.191***	0.715
	(0.614)	(0.583)	(0.905)	(0.572)	(0.659)
Clay soil	0.623	0.524	0.951	0.569	1.298***
	(0.415)	(0.408)	(0.542)	(0.389)	(0.442)
Flat slope	0.159**	-0.441	-0.629	-0.711**	-0.599
	(0.540)	(0.490)	(0.840)	(0.454)	(0.621)
Moderate to steep	-0.989*	0.009	-0.451	-0.034	0.090
	(0.729)	(0.637)	(1.280)	(0.604)	(0.707)
Northern	0.124***	0.572	-0.691***	1.235***	0.584
	(0.382)	(0.360)	(0.558)	(0.345)	(0.447)
Upper East	0.805**	1.494	-0.647**	1.722***	1.134
	(0.470)	(0.466)	(0.941)	(0.431)	(0.590)
Distance to weekly market	0.149***	-0.183*	-0.028	-0.093	-0.236**
	(0.143)	(0.140)	(0.195)	(0.132)	(0.152)
Minutes 30 to plot	0.146***	-0.299	0.177	-0.374**	-0.414
	(0.268)	(0.267)	(0.451)	(0.247)	(0.320)
Constant	-1.970	-0.625	-3.274*	-3.359***	-7.725***
	(1.234)	(1.207)	(1.812)	(1.147)	(1.435)

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; Upper West is used as the reference region. We checked the Independence of Irrelevant Alternatives (IIA) assumption using the Stata command "*mlogtest, iia*" after estimating the MNL model. The results show that adding or deleting alternative outcome categories does not affect the odds among the remaining outcomes, confirming the validity of our MNL model estimates.

Off-farm income has positive and significant coefficients in columns 3, 5 and 6. The findings suggest that farmers receiving a higher level of off-farm income are more likely to adopt fertilizer only ($I_0F_1S_0$), combine fertilizer and soil and water conservation as SAPs ($I_0F_1S_1$), and adopt all three SAPs ($I_1F_1S_1$). Additional income from off-farm activities can help release credit constraint issues, allowing farmers to invest in innovative technologies such as SAPs to improve farm performance. In their study for Pakistan, Kousar and Abdulai (2016) found that participation in off-farm work increases farmers' adoption of soil conservation measures.

The African RISING member variable has a positive and statistically significant impact on farmers' fertiliser adoption only ($I_0F_1S_0$), the combination of improved seed and fertilizer ($I_1F_1S_0$), and the combination of fertilizer and soil and water conservation ($I_0F_1S_1$). The importance of farmer-based organisations in promoting the adoption of innovative technologies has been widely discussed in the literature (Manda, Khonje, et al., 2020; Yu et al., 2021; Zhang, Sun, Ma, & Valentinov, 2020). For example, Manda et al. (2020) reported that membership in agricultural cooperatives increases the adoption speed of improved maize between 1.6 and 4.3 years. We show that farmers having access to extension services are more likely to adopt SAPs, including fertilizer only ($I_0F_1S_0$), soil and water conservation only ($I_0F_0S_1$), and all three SAPs ($I_1F_1S_1$). In their studies in Nepal, Suvedi, Ghimire, and Kaplowitz (2017) found that farmers' participation in extension programs increases their adoption of improved crop varieties. This finding is further confirmed by Nakano, Tsusaka, Aida, and Pede (2018), who found that farmer-to-farmer training through extension programs enhance farmers' adoption of technologies (e.g., fertilizer and improved bund) in Tanzania.

The location dummies were statistically significant in columns 2, 4 and 5. Our findings suggest that relative to farmers living in Upper West (reference group), those residing in Northern and Upper East are more likely to adopt fertilizer only ($I_0F_1S_0$) and a combination of fertilizer and soil and water conservation ($I_0F_1S_1$), but less likely to adopt the combination of improved seeds and fertilizer ($I_1F_1S_0$). Our findings confirm spatial-fixed characteristics (e.g., social-economic conditions, resource endowments, climate conditions, and institutional arrangements) may also affect smallholder farmers' decisions to adopt SAPs and highlight the importance of including them in estimations.

4.4.3 Average treatment effects of SAPs

Table 12 presents the results estimating the treatment effects of SAP adoption on farm income and food security. For the sake of brevity, we do not present and discuss the results estimated by the OLS regression model but are available upon reasonable requests. Our ATT estimate results in Table 12 record differentiated findings regarding the impacts of adopting only one SAP technology on farm income and food security, measured by rCSI score and HDD score. Specifically, adopting only fertilizer ($I_0F_1S_0$) significantly reduces rCSI score and improves HDD score. The ATT estimates indicate that fertilizer adoption only ($I_0F_1S_0$) decreases rCSI score by 42% and increases the HDD score by 6.5%. We find that fertilizer adoption only ($I_0F_1S_0$) decreases farm income. A possible reason could be the improper use of fertilizer by smallholder farmers, such as using lower than recommended amounts of fertilizer; hence they do not achieve the maximum potential output expected.

Adoption of SAP package that combines improved seed and fertilizer ($I_1F_1S_0$) improves food security significantly. The ATT estimates show that $I_1F_1S_0$ adoption reduces rCSI score by 45% and increases HDD score by 4%. However, $I_1F_1S_0$ adoption decreases farm income, a finding that is largely consistent with the finding of Ma and Wang (2020), showing that SAP adoption significantly decreases farm income in China. Adoption of SAP package that combines fertilizer and soil and water conservation ($I_0F_1S_1$) increases farm income and improves food security. We show that $I_0F_1S_1$ adoption increases farm income by 12%, reduces rCSI score by 23%, and improves HDD score by 5%.

Table 12: Treatment effects of SAP adoption on farm Income and food security

Outcome variables	SAP categories	Adopting (1)	Non -Adopting (2)	ATT (3) = (1) – (2)
Farm income (ln)	$I_0F_1S_0$	4.015 (0.119)	4.760 (0.167)	-0.744 (0.163)***
	$I_0F_0S_1$	4.672 (0.124)	4.611 (0.228)	0.613 (0.215)
	$I_1F_1S_0$	4.593 (0.531)	5.505 (0.367)	-0.912 (0.504)*
	$I_0F_1S_1$	4.733 (0.062)	4.216 (0.114)	0.517 (0.108)***
	$I_1F_1S_1$	4.522 (0.227)	3.698 (0.351)	0.824 (0.386)**
rCSI	$I_0F_1S_0$	3.247(0.242)	5.604 (0.536)	-2.357 (0.533)***
	$I_0F_0S_1$	8.984 (0.468)	9.331 (1.097)	-0.346 (0.973)
	$I_1F_1S_0$	6.086 (2.267)	4.184 (1.301)	1.901 (2.632)
	$I_0F_1S_1$	5.247 (0.121)	6.859 (0.434)	-1.596 (0.389)***
	$I_1F_1S_1$	4.217 (0.575)	8.891 (1.786)	-4.674 (1.543)***
HDD	$I_0F_1S_0$	8.381 (0.065)	7.870 (0.086)	0.512 (0.109)***
	$I_0F_0S_1$	6.787 (0.087)	7.466 (0.113)	-0.678 (0.121)***
	$I_1F_1S_0$	8.200 (0.284)	7.893 (0.211)	0.307 (0.316)
	$I_0F_1S_1$	7.885 (0.035)	7.477 (0.062)	0.408 (0.074)***
	$I_1F_1S_1$	7.804 (0.130)	6.871 (0.231)	0.933 (0.219)***

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The ATT estimates show that adopting all the three SAPs ($I_1F_1S_1$) positively and statistically impacts farm income and food security. The impact magnitudes of adopting all the three SAPs are larger than that of adopting single or two SAPs. Specifically, the $I_1F_1S_1$ adoption increases farm income by 23%, reduces rCSI score by 53%, and improves HDD score by 14%. Our results are largely supported by the previous studies (Teklewold et al. 2013; Manda et al. 2016; Oduniyi and Chagwiza 2021), pointing out that adopting multiple SAPs has larger impacts on welfare measures than adopting only one or two SAPs. For example, Teklewold et al. (2013) showed that multiple SAP adoption significantly increases household income in Ethiopia. Oduniyi and Chagwiza (2021) found that adopting sustainable land management practices increases the food security of smallholder farmers in South Africa.

4.5 Conclusions and policy implications

Many institutions have credited sustainable agricultural practices (SAPs) as a viable solution that helps tackle the worlds' feeding problems and worsening environmental issues. This study used a multinomial endogenous switching regression (MESR) to investigate factors that affect smallholder farmers' decisions to adopt different categories of SAPs and estimate the effects of the adoption on farm income and food security. In particular, we used two measures, including rCSI score and HDD score, to capture food security. We estimated the data collected by IITA for their Africa RISING project in Ghana.

The MNL results showed that farmers' decisions to adopt SAPs are influenced by the social demographics of the households (e.g., gender, education, marital status, and household size), plot-level characteristics (e.g., number of crops, soil types, and topography), extension services, and locations. The study also recorded differentiated findings regarding the impacts of adopting only one or two SAPs on farm income and food security. For example, adopting only fertilizer significantly reduces rCSI score and improves HDD score, but it unexpectedly decreases farm income. Adoption of SAP package that combines improved seed and fertilizer significantly improves food security measures, but it also decreases farm income. Nevertheless, we found that adopting all the three SAPs positively and statistically impacts farm income and food security. The impact magnitudes of adopting all the three SAPs are larger than that of adopting single or two SAPs.

The study highlights that policy, which improves the extension agents to farmer ratio should be pursued since access to extension positively influenced the adoption of SAPs. The satisfaction with the extension agent variable positively influenced the adoption of all the SAPs. This highlights the need to improve the quality of extension service to minimize the risk of adoption due to inadequate information transfer. Membership in farmer-based organizations (FBOs) such as Africa RISING positively influenced the adoption of different packages of SAPs. Therefore, farmers should be encouraged to join FBOs, and similar organizations should be established or strengthened to enhance the dissemination of information regarding SAPs. Policies to improve farmer income and food security should advocate for the comprehensive adoption of all the SAPs packages and provide incentives to motivate the adoption of all SAPs packages.

Chapter 5

Adoption of sustainable agricultural practices and its heterogeneous effects on food security in northern Ghana

Abstract

Global support for the Sustainable Development Goals (SDGs) has focused attention on efforts to up-scale the adoption of sustainable agricultural practices (SAPs) in developing countries where growth in populations and incomes compromises the resilience of natural resources. However, little is known about the effects of SAP adoption in West Africa. Therefore, this study investigates the factors that influence smallholders' decisions to adopt SAPs and examines the effects of the adoption on food security, measured by household dietary diversity (HDD) and food consumption score (FCS). We use the marginal treatment effect model to analyse survey data collected from northern Ghana in 2019. Findings reveal that there is heterogeneity in gains from SAPs adoption with respect to both observed and unobserved characteristics. The results show positive selection on gains across both HDD and FCS. Households who are more likely to adopt SAPs due to innate ability or changes in production quality usually benefit more from adoption in terms of food security.

Keywords: Sustainable Agricultural Practices; Household Dietary Diversity; Food Consumption Score; Marginal Treatment Effects model; Northern Ghana

JEL Codes: C34, O33, Q16, Q12

5.1 Introduction

There is a challenge globally to enhance agricultural productivity whilst protecting the environment. Under this context, sustainable agriculture intensification practices (SAPs/SAIPs), have been developed and promoted to help address the global issue. Previous studies have shown that SAP adoption increases yields, decrease the negative externalities from agricultural production, and improves environmental performance (Adegbeye et al., 2020; Harwood, 2020; Kotu et al., 2017). The concept promotes the stewardship of natural resources in all farming systems, whether intensive or extensive (Adegbeye et al., 2020; Harwood, 2020; Ma & Wang, 2020; Portney, 2015). In other words, sustainable agriculture has three main objectives, i.e. promoting environmental health, economic profitability, and social equity. This concept was brought to the fore with the formulation of the sustainable development goals by the United Nations (UN) member countries in 2015.

Different sustainable agricultural practices have been adopted by farmers in African countries to support their production. These include reducing the use of pesticides; the use of integrated crop protection; optimizing nutrient balance; crop rotation; improved fallows; agroforestry; mixed farming systems; efficient use of water in irrigation systems; “no-till” or direct seeding systems and; precision farming techniques (Agula et al., 2018; Ehiakpor et al., 2021; Gebremariam & Wünscher, 2016; Kassie, Teklewold, et al., 2015; Yahaya, 2015). The onus to adopt sustainable agriculture practices rests heavily on smallholders, whose numbers have been increasing nominally and are estimated to feed about 70 per cent of the world’s population (Lowder, Skoet, & Raney, 2016)

In Ghana, there is evidence of the adoption of various elements of SAPs. Whilst some studies attribute indigenous knowledge as the source of at least some of the approaches adopted (Agula et al., 2018; Paul Nkegbe & Shankar, 2014), others attribute it to the efforts of NGOs such as AFRICA RISING-IITA and SANREM (Kotu et al., 2017; Yahaya, 2015). It has been argued that adopting SAP practices, particularly in Northern Ghana, is part of farmers' adaptation strategies to climate change (Abdulai & Huffman, 2014; Gebremariam & Wünscher, 2016). The literature is filled with studies on the adoption of specific elements of SAPs such as improved seed and soil and water conservation practices and their effect on yield and net farm income (Abdulai & Huffman, 2014; Arslan et al., 2014; Becerril & Abdulai, 2010; Kassie et al., 2014; Kunzekweguta et al., 2017; Ng'ombe et al., 2017; Paul Nkegbe & Shankar, 2014). However, there is limited work on the adoption of multiple SAPs and their effects, particularly in West Africa.

On the impact of the adoption of multiple SAPs adoption (Gebremariam & Wünscher, 2016), found that increasing combinations of SAPS led to higher payoff in terms of the welfare variables considered, i.e., net crop income per acre and consumption expenditure per capita. Khonje et al. (2018) found that joint adoption of multiple SAPs had a higher impact on yields, household income and poverty than the adoption of components of the technology package. (Marenya et al., 2020)looked at combinations of SAPs adopted and concluded that a higher number of SAPs adopted resulted in higher maize grain yield and maize income. Though these studies contribute to understanding the factors driving the adoption of SAPs and their impacts on productivity, there is a gap in the literature about whether it translates into food security.

This study sets out to investigate the impact of SAPs adoption on food security of smallholders in northern Ghana in a mixed cropping setting. Household dietary diversity (HDD) and food consumption score (FCS) are utilized to measure food security variables (Maxwell, Coates, et al., 2013). We employ the marginal treatment effects model to estimate the effects of SAPs adoption on farm households' food security. The study uses recent survey data on 494 farm households in northern Ghana, specifically, the Upper East, Upper West, and North regions. Findings from the study will aid in formulating specific policies targeted at improving SAP adoption and enhancing the food security status of farm households.

This study contributes to the literature in two main ways. First, it provides empirical insights into the importance of SAPs on welfare indicators, specifically food security. Most past studies have focused on other proxies of household welfare such as net farm income, net crop income per acre and consumption expenditure (Gebremariam & Wünscher, 2016; Kotu et al., 2017; Teklewold et al., 2013). However, the effects of SAP adoption on food security of farm households have been overlooked in the literature. The use of food security as a proxy measure for welfare is particularly important in the Ghanaian context, where farming is undertaken mostly on a subsistence level, and farmers sometimes sell crops as and when they need cash. Thus, farmers may be food secure but may not have a high net farm income or high consumption expenditure. Second, this study highlights the heterogeneity in returns to adoption in observed and unobserved characteristics.

The next section outlines the conceptual framework used in the analysis. The analytical procedure and data used in this paper are presented in Section 3. The results are presented and discussed in Section 4, and Section 5 highlights the conclusions and policy implications of the findings.

5.2 Conceptual framework

The study assumes that a farmer weighs the net benefits of adopting SAPs in making the adoption decision. If the potential net benefit of adopting SAPs outweighs the benefits of non-adoption, farmers will likely adopt SAPs. Let y_i represent the outcome variables, including household dietary diversity (HDD) and food consumption score (FCS), and A_i is one if the farmers adopt SAPs and zero otherwise. The empirical relationship between the variables is specified as:

$$y_{1i} = \beta_1 X_i + \theta L_{1i} + u_{1i}$$

$$y_{0i} = \beta_0 X_i + \theta L_{0i} + u_{0i} \qquad (1)$$

where X_i is a vector of household and farm level controls such as household characteristics (age education, dependency ratio, household size), the ownership of assets (such as ownership of animals, land, machinery), off-farm income, experience with production shocks (extreme weather conditions such as floods and drought; pest and/or diseases infestation), access to extension services, credit constraints and soil characteristics (soil types, colour, slope). L_i captures location fixed effects, β and θ are the parameters to be estimated, and u_{ij} represents deviations from the mean, assumed to have zero mean and constant variance. For simplicity, the study drops L_i from the further derivation of equations.

Farmer i will adopt SAPs if the net gains expected from adoption y_{1i} outweighs the net gains from non-adoption y_{0i}. Let A_i^* be the net gains expected from adoption, then $A_i = 1$, if $A_i^* = y_{1i} - y_{0i} \geq 0$, otherwise $A_i = 0$. A_i^* is the latent propensity to adopt. The decision to adopt SAPs is endogenous because farmers self-select into adoption based on both observable and unobservable characteristics, the latent variable A_i^* cannot be directly measured but is specified as a function of observable characteristics. Therefore, a farmers adoption decision as modelled as:

$$A_i^* = f_a(X_i, Z_i) - V_i \quad (2)$$

Where A_i^* is the latent variable that captures the gains expected from adoption, Z_i represents excluded instruments for identification of the model, and V_i measures the unobserved heterogeneity in the propensity to adopt. Equation (2) shows that unobserved resistance limits farmers from adopting SAPs using a negative sign. Following (Cornelissen et al., 2018; Shahzad & Abdulai, 2021) the selection rule in Equation (2) is transformed and specified as:

$$f_a(x_i, z_i) - V_i \geq 0 \Leftrightarrow f_a(X_i, Z) \geq V_i \quad (3)$$
$$\Leftrightarrow g_v[f_a(X_i, Z)] \geq g_v(V_i)$$

where g_v denotes the cumulative distribution function of V_i (in the case of this study, standard normal distribution). The term $g_v[f_a(X_i, Z_i)]$, also denoted by $g_v[f_a(X_i, Z_i)] \equiv P(X_i, Z_i)$ is the propensity score (i.e., the probability that farmer *i* with observed characteristics X_i and excluded instrument Z_i will adopt SAPs), $g_v(V_i)$and denoted by $g_v(V_i) \equiv U_{Ai}$ represents the quantiles of the distribution of unobserved resistance to adoption V_i. Given the potential outcome specification in Equation (1), and the adoption decisions in Equation (2), heterogenous gains expected conditional on observed and unobserved characteristics of farmers can be specified as follows:

$$y_i = A_i y_{1i} + (1 - A_i) y_{0i}$$
$$= y_{0i} + A_i(y_{1i} - y_{0i})$$
$$X_i\beta_0 + A_i \underbrace{[X_i(\beta_1 - \beta_0) + U_{1i} - U_{0i}]}_{y_{1i}-y_{0i}\equiv\Delta_i} + U_{0i} \quad (4)$$

where $\Delta_i \equiv y_{1i} - y_{0i} = X_i(\beta_1 - \beta_0) + U_{1i} - U_{0i}$

The standard instrumental variable (IV) assumptions should be satisfied to identify the parameters of the model in Equations (2) and (4). Specifically, the conditional independence (exclusion restriction) assumption that ($U_{0i,}$ U_{1i} , U_{Ai}) is statistically independent of Z_i, given X_i, needs to be satisfied.

In this study, the distance to market is used as an excluded instrument. To check the internal validity of the selected instrumental variable, we conducted 3 statistical tests, namely the Wald test at the first stage probit estimation, OLS regression for outcome variables for non-adopters (shown in Table B.3 and B.4 in appendix B), and a correlation test of the outcome variables (shown in Table B.5 in appendix B) and the selected instrument. All the tests indicated the validity of the excluded instrument. Following Equation (4), the marginal treatment effects can be defined as a function of the quantiles, or the treatment effect at a particular value of U_{Ai} (Cornelissen et al., 2016; Shahzad & Abdulai, 2021)

$$MTE = (X_i = x, U_{Ai} = u_a)$$

$$E = [\Delta_i | X_i = x, U_{Ai} = u_a] \quad (5a)$$

The treatment effect for an individual with observed characteristics $X_i = x$ who are at u_a-th quantile of the V_i distribution will have a propensity score $P(X_i, Z_i) = u_a$. This implies that such a farmer is indifferent to adoption. Invoking the assumption that MTE is additively separable into observable and unobservable components, it can be expressed as:

$$MTE(x, u_a) = [\Delta_i | X_i = x, U_{Ai} = u_a] \quad (5b)$$

$$= \underbrace{x(\beta_1 - \beta_0)}_{observed\ component} + \underbrace{E(U_1 - U_0 | U_{Ai} = u_a)}_{unobserved\ component}$$

Given Equation (4) and the propensity score, the outcome equation can be estimated as a function of the observed characteristics as defined above, and the propensity score as:

$$E(Y_i | X_i) = x, P(X_i, Z_i) = p)$$

$$= X_i\beta_0 + X_i(\beta_1 - \beta_0)p + k(p) \quad (6)$$

where Y_i measures the returns to adoption for households with different levels of observable characteristics, $X_i = x$, the propensity score p and $k(p)$ is a nonlinear function of the propensity score. Taking the derivative of Equation (5) with respect to p delivers the MTE (Carneiro, Lokshin, & Umapathi, 2017; Cornelissen et al., 2016; Shahzad & Abdulai, 2021)

$$MTE = (X_i = x, U_{Ai} = p)$$

$$\frac{\partial E(Y_i | X_i = x, P(X_i, Z_i) = p)}{\partial P} \quad (7)$$

$$x(\beta_1 - \beta_0) + \frac{\partial K(p)}{\partial p}$$

The study estimates the treatment effects by first estimating the selection Equation (2) as a probit model to obtain estimates of $P(X_i, Z_i)$ as $\hat{p}$, and in the second stage, we estimate the outcome equations as:

$$Y_i = X_i\beta_0 + X_i(\beta_1 - \beta_0)\hat{p} + \sum_{k=1}^{k} \alpha_k \hat{p}^k + \varepsilon_i \quad (7)$$

The MTE curve was derived from Equation (7) by taking the derivative with respect to $\hat{p}$. The study assumes a second-order polynomial in $\hat{p}$ (i.e., k = 2) in its baseline specification. To determine the sensitivity of the MTE curve to the functional form assumed, the study also estimates MTE curves as robustness checks by using k = 1, k = 3, k = 4. According to Shahzad and Abdulai (2021), MTE is aggregated over U_{Ai} in different ways to obtain average treatment effects (ATE), average treatment effects on the treated (ATT), average treatment effects on the untreated (ATU), and local average treatment effects (LATE); as shown in the equations (8a), (8b), (8c), (8d):

$$ATE = E(y_{1i} - y_{0i}) = E[\beta_i(X_i) - \beta_0(X_i) \quad (8a)$$

$$ATT = E[y_{1i} - y_{0i}|A_i = 1] + E[U_1 - U_0|A_i = 1] = E[\beta_i(X_i) - \beta_0(X_i)|A_i = 1] + E[U_1 - U_0|A_i = 1] \quad (8b)$$

$$ATU = E[y_{1i} - y_{0i}|A_i = 0] + E[U_1 - U_0|A_i = 0] = E[\beta_i(X_i) - \beta_0(X_i)|A_i = 0] + E[U_1 - U_0|A_i = 0] \quad (8c)$$

$$LATE = E[y_{1i} - y_{0i}|A_{1i} > A_{0i}, X_i = x|\beta_i(X_i) - \beta_0(X_i)] + E[U_1 - U_0|A_{1i} > A_{0i}, X_i = x] \quad (8d)$$

5.3 Study area and data description

The study focuses on three regions in Northern Ghana: Upper East, Upper West, and Northern. These regions are the most vulnerable in terms of climate change issues in Ghana, with prolonged drought and erratic rainfall being the most problematic climate concerns. These regions also record high levels of food insecurity and poverty even though there is overall economic growth in the country (WFP, 2013, 2021). A multi-stage sampling technique, comprising stratified, random and cluster sampling, was used to collect primary data from 494 smallholder farmer households in the study area in 2019. We used Africa RISING (AR) project's location as our sampling frame. Africa RISING is an agricultural research and development programme being implemented in northern Ghana by IITA with funding from USAID. The programme trains and encourages farmers to adopt SAPs. Based on the sampling frame, we stratified the project locations into 25 AR intervention communities and 25 counterfactual (no intervention) communities. Ten communities of the intervention communities and five communities of the counterfactual communities were randomly selected. A total of 494 households was sampled, made up of 345 households participating in AR intervention and 149 counterfactual households. Trained enumerators, using structured questionnaires; collected data through face-to-face interviews from respondents.

Data collected include household characteristics, landholding, plot characteristics, production shocks, cost of production, SAP practices, output, off-farm income sources, access to extension and credit. We used HDD and FCS as measures of food security in this study. The HDD is used to monitor changes in access to adequate quantity and quality of food at the household level and to assess the impact of programmes. FCS was developed to measure food security in different cultural settings. It has been validated with other metrics of foods security such as energy consumption per capita in different countries. HDD and FCS are robust indicators of the access component of food security(Leroy et al., 2015; Maxwell et al., 2014; Vaitla et al., 2020). We used FCS as a robustness check for food security as measured by HDD.

To compute HDD, following Swindale and Bilinsky (2006), data was collected on the 12 food groups consumed by the household in the last 24 hours. The food groups are unweighted, and the frequency of consumption is not used in the computation. Thus, the HDD score of a household range from 1-12, where 1 represents the least diversified diet (severely food insecure) and 12 represent the most diversified diet. The raw HDD score was used in the analysis. The FCS is like HDD, except that the food groups are weighted and the frequency of consumption in 7 days is used in the computation of FCS. The FCS score ranges from 0-112, where 0 represent being least food secure and 112 represent being most food secure (Maxwell, Coates, et al., 2013; Maxwell et al., 2014).

The main SAPs practices used in the study area include the use of the improved seed, cereal-legume crop rotation, cereal legume mixed cropping, use of organic fertilizer, and the appropriate use of inorganic fertilizers. Soil bunds, terracing, composting, land rotation and mulching are other soil and water conservation practices used in the area to control soil erosion, conserve soil moisture, and improve soil fertility. For this study, respondents that used at least 3 SAPs were classified as adopters, and those that used less than 3 SAPs were classified as non-adopters. This is because the average number of SAPs adopted is 3, which represent three-quarters of the sample. The mean crop revenue per hectare is GHS 2278 (414 USD), which is very low because of the climate-related shocks experienced in the 2018/2019 crop season and the over-reliance on the weather for irrigation. About 36 per cent of the respondents perceived that drought had a significant negative impact on their production during the cropping season. On average, during the 2018 cropping season, households in the sample received two lots of training on SAPs. The mean distance to market is 2.593 kilometres, with the maximum distance being 15 kilometres. The definition of variables and the mean differences between adopters and non-adopters are shown in Table B.1 and Table B.2 in appendix B.

5.4 Results and discussions

We present the results for the empirical analysis in this section. The estimates of the selection equation (probit), which shows the determinants of SAPs adoption, are discussed first. This is followed by the results of the second stage estimation. All the standard errors in the results are bootstrapped with 150 replications.

5.4.1 Selection equation results

The probit selection equation results are shown in the first column of Tables 13 and 14. As discussed earlier distance to market was identified as an instrument for the estimation. The Wald test was used to test the joint significance of the excluded variable in the second stage estimations. The result from the Wald test is 179.65 and is significant at the one per cent level, indicating that the instrumental variable highly influenced adoption decisions. The *F*-test was also used to test the validity of the excluded instrument in the second stage estimation, which showed that the instrument did not influence the outcome variables. It is important to explain the results shown in Figure 4, which plots the frequency distribution of the propensity score by adoption status here. The propensity scores used in Figure 4 are predicted from the first stage probit regression.

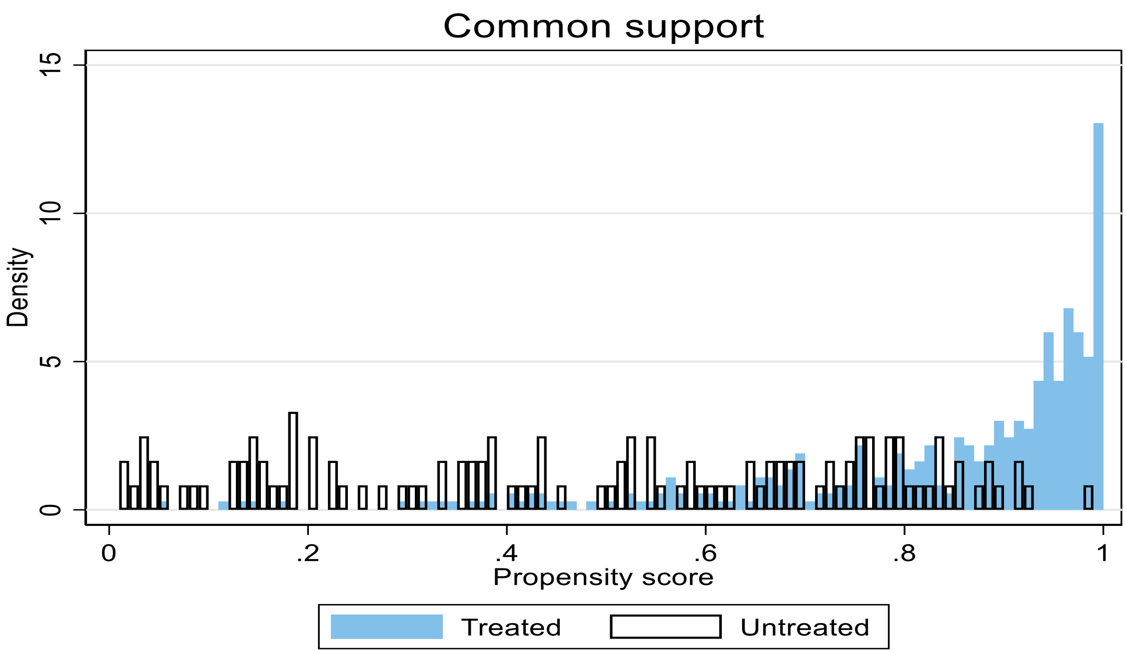

Figure 4: Common support for HDD and FCS (frequency distribution of propensity score by adoption status)

From Figure 4, it is apparent that the first stage regression produces common support in the range of 0.05 to 0.99. This shows the unconditional common support generated by variations in the instrument and the covariates in the second stage. This satisfies the assumption usually made in MTE applications that the shape of the MTE curve does not vary with control variables (Cornelissen et al., 2018; Shahzad & Abdulai, 2021).

The same variables were used to estimate all the food security outcome variables (HDD and FCS), hence similar results were obtained for the probit selection equations of all the outcome variables. We will therefore proceed to discuss the results in the first column of Tables 13 and 14 together. In column one of Tables 13 and 14, the distance to market, which serves as the instrumental variable, is a strong predictor of the adoption of SAPs. The coefficient of distance to market is positive (0.181) and significant at 10 per cent for the first stage probit selection model for all the outcome variables (HDD and FCS). This indicates that farmers who are further away from the local market are more likely to adopt SAPs. While this is contrary to expectation, it is, however, logical if one considers, that the study considers multiple SAPs which include soil and water conservation practices such as land rotations, crop rotations, terracing and soil bunds; which may be challenging to adopt on the smaller land sizes farmers typically access when closer to market due to the prime nature of such lands. Also, farmers located further away may need to be more self-reliant when it comes to technology adoption, so they may adopt the use of organic fertilizer/ manure, mulching, composting, crop rotations etc., which are not necessarily sourced from markets. This is in line with the following studies on the adoption of soil and water conservation practices (N. Kennedy, Amacher, & Alexandre, 2016; Mengstie, 2009).

The study found that female-headed households are more likely to adopt SAPs than male-headed households. Our findings are largely supported by the previous studies (Paudel et al., 2020; Smale et al., 2018; Tambo et al., 2021), reporting gendered differences in agricultural technology adoption. For example, Smale et al. (2018) found that women are more likely to adopt improved seeds on the plots they manage in Sudan.

Table 13: Selection equation and outcome equations results for HDD

	Selection		Outcome			
	(1)		(2) β_0		(3) $\beta_0 - \beta_1$	
Variables	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err
Gender	-6.870***	0.811	4.102***	1.513	-3.891**	1.671
Education	-0.044*	0.024	0.061***	0.023	-0.055**	0.026
Experience	-0.029***	0.009	0.019*	0.010	-0.014	0.011
Shocks impact	0.851***	0.128	-0.423**	0.174	0.376*	0.200
Loamy soil	1.107***	0.218	-1.036***	0.310	0.934***	0.344
Red soil	-0.648***	0.242	0.328	0.202	-0.119	0.267
Soil Fertility perception	0.886	0.578	-0.162	0.142	0.249	0.158
Organic Fertilizer Cost	1.155***	0.215	-1.050***	0.308	1.079***	0.343
Inorganic fertilizer cost	-4.201***	0.535	2.606***	0.962	-2.407**	1.073
Seed cost	-1.575***	0.260	0.888**	0.374	-0.842**	0.414
Off Farm Activity	1.379***	0.234	-0.625**	0.301	0.517	0.349
Remittance	0.016	0.284	0.073	0.123	-0.112	0.157
Farm size	-0.332	0.242	0.252	0.161	-0.102	0.194
Output_Hat1	11.684***	1.392	-7.370***	2.632	6.858**	2.917
Upper West	1.665***	0.594	-0.705***	0.278	0.491	0.338
Upper East	-2.848***	0.450	1.500**	0.760	-1.361	0.852
Hh_Size	-0.109***	0.020	0.089***	0.031	-0.095***	0.034
Hh_Above_65	-0.090	0.064	0.093	0.061	-0.090	0.082
Input credit	-0.311	0.203	-0.116	0.162	0.229	0.185
SAPs training	-0.079	0.094	0.015	0.081	-0.026	0.102
Farmgate	-0.590***	0.207	0.591***	0.198	-0.485**	0.244
Extension	-3.236	1.995	2.251***	0.777	-2.189***	0.870
Accessed credit	-0.069	0.257	-0.051	0.140	-0.044	0.167
Farmer group	-0.060	0.183	0.362**	0.155	-0.526***	0.188
_Cons	-77.353***	9.192				
Dismarketkm	0.181*	0.108				
resid_extension	-0.952	0.775				
resid_credit	0.433	0.973				
resid_farmgroup	0.833	0.891				
X^2 test for excluded instrument						179.6 50
p-value for test of excluded instruments						0.000
p-value for test of observable heterogeneity						0.003

Note: bootstrapped standard errors are reported with 150 replications.
***Significant at 1% level, ** significant at 5% level, * significant at 10% level

Household size had a negative effect on the adoption of SAPs, this is contrary to the expectation that household size translates to labour for farm work in rural areas. This may be because households sampled had more dependents, who were not part of the active labour force for farm work. The variable for household members over age 65 had a negative albeit insignificant effect on adoption, meaning household with more members above 65 were less likely to adopt SAPs. The coefficient of farming experience is negative and statistically significant at 1 per cent, indicating that the more experienced the farmer is, the lesser the likelihood of adopting SAPs. It may be because young farmers are more likely to try new technology, as opposed to older farmers who may be unwilling to disrupt their routines for new technology. This is contrary to (Shahzad & Abdulai, 2021)findings, who found that farming experience enhanced the adoption of climate-smart practices.

The positive and statistically significant coefficient of off-farm work suggests that households participating in off-farm activity are more likely to adopt SAPs, which is in line with the studies by Oseni and Winters (2009); Zereyesus, Embaye, Tsiboe, and Amanor-Boadu (2017) who found that income from off-farm activity increases the technology adoption due to the income effect. The education of household heads had a negative effect on the adoption of SAPs, and it is significant at 10 per cent. This is consistent with the work of Uematsu and Mishra (2010) who found formal education could be a barrier for technology adoption, particularly for small scale farmers with the tendency to engage in off-farm work. There have been other studies such as (Ansah, Eib, & Amoako, 2015; Mwangi, Kihurani, Wesonga, Ariga, & Kanampiu, 2015; Samiee, Rezvanfar, & Faham, 2009; Tesfaye, Bedada, & Mesay, 2016) who also found education to be a barrier to technology adoption.

Households that experience negative impacts from shocks such as drought, flood, pests and diseases, were more likely to adopt SAPs. In line with our expectation, the cost of inputs, specifically chemical fertilizers and seed, negatively influenced the adoption of SAPs, and they were significant at 1 per cent. The predicted values of crop revenue were used to deal with endogeneity, and the coefficient was positive and significant at 1 per cent.

Table 14: Selection equation and outcome equations results for FCS

	Selection		Outcome			
	(1)		(2) β_0		(3) $\beta_0 - \beta_1$	
Variables	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err
Gender	-6.870***	0.811	2.047	2.161	-0.475	2.304
Education	-0.044*	0.024	0.098***	0.035	-0.090**	0.039
Experience	-0.029***	0.009	0.017	0.013	-0.005	0.015
Shock impact	0.851***	0.128	-0.259	0.212	0.039	0.233
Loamy soil	1.107***	0.218	-0.523	0.462	0.021	0.513
Red soil	-0.648***	0.242	0.049	0.299	-0.033	0.410
Soil Fertility perception	0.886	0.578	0.109	0.222	0.020	0.246
Organic Fertilizer Cost	1.155***	0.215	-0.718*	0.422	0.490	0.448
Inorganic fertilizer cost	-4.201***	0.535	1.290	1.332	-0.110	1.431
Seed cost	-1.575***	0.260	0.333	0.555	0.042	0.604
Off Farm Activity	1.379***	0.234	-0.205	0.399	-0.199	0.422
Remittance	0.016	0.284	0.364*	0.206	-0.278	0.236
Farm size	-0.332	0.242	0.270	0.256	-0.074	0.303
Output_Hat1	11.684***	1.392	-4.156	3.691	1.114	3.947
Upper West	1.665***	0.594	-0.503	0.401	0.037	0.471
Upper East	-2.848***	0.450	0.015	0.998	0.791	1.082
Hh_Size	-0.109***	0.020	0.076*	0.043	-0.054	0.048
Hh_Above_65	-0.090	0.064	0.089	0.081	-0.112	0.110
Input credit	-0.311	0.203	-0.386	0.241	0.596**	0.277
Sap training	-0.079	0.094	0.083	0.122	-0.120	0.148
Farmgate	-0.590***	0.207	0.119	0.259	-0.300	0.299
Extension	-3.236	1.995	1.286	1.095	-0.394	1.199
Accessed credit	-0.069	0.257	-0.190	0.184	-0.005	0.222
Farm group	-0.060	0.183	0.338*	0.200	-0.491**	0.239
_Cons	-77.353***	9.192				
Dismarketkm	0.181*	0.108				
resid_extension	-0.952	0.775				
resid_credit	0.433	0.973				
resid_farmgroup	0.833	0.891				
X^2 test for excluded instrument						179.65
p-value for test of excluded instruments						0.000
p-value for test of observable heterogeneity						0.000

Note: bootstrapped standard errors are reported with 150 replications.
***Significant at 1% level, ** significant at 5% level, * significant at 10% level

The location dummies also influenced adoption, with farmers in the Upper West region more likely to adopt SAPs, whilst farmers in the Upper East region were less likely to adopt SAPs. Our findings confirm spatial-fixed characteristics (e.g., social-economic conditions, resource endowments, climate conditions, and institutional arrangements) may also affect smallholder farmers' decisions to adopt SAPs and highlight the importance of including them in estimations. Using the control function approach, the residuals of extension access, credit access and farmer group membership were added to the first stage estimation to deal with potential endogeneity issues.

5.4.2 Second stage estimation

In this subsection, we discuss the results of the second stage estimation for the food security outcome variables HDD and FCS. The results are displayed in columns 2 and 3 of Tables 13 and 14. The untreated state (β_0) is shown in column 2, and the treated state ($\beta_0 - \beta_1$) which is referred to as gains from SAPs adoption is displayed in column 3 of each table. In the next subsection, we explain the MTE curves shown in Figures 5 and 6, which shows the MTE curves at the means of the observed characteristics (X_i), the unobserved components of outcomes ($U_1 - U_0$), and the unobserved components of adoption (U_{Ai}). For robustness checks, we specify different functional forms of the MTE curves to check the sensitivity of the curve.

(a) Household Dietary Diversity

The second stage estimations of household dietary diversity (HDD) are presented in columns 2 (non-adoption state) and 3 (gains from adoption) of Table 13. HDD is a food security measure based on the diversity of food groups a household consumes in 24 hours. The higher the score, the more diverse the diet of a household, and the more food secure the household is. The gender coefficient is positive in column 2 and negative in column 3, this indicates that male-headed households have more diverse meals in the non-adoption state. However, female-headed households make gains in dietary diversity due to adoption, thus becoming more food secure. Households that experienced shocks (e.g., drought floods) made positive gains in dietary diversity due to adoption, whilst the shocks more negatively influenced households in the non-adoption state in terms of HDD.

There were mixed results regarding the cost of inputs, specifically organic fertilizer, chemical fertilizer and improved seeds. The cost of organic fertilizer increased the HDD score for adopters by 1.079 points, whilst the cost of chemical fertilizer and improved seed reduced their HDD score by 2.407 and 0.842 points, respectively. Engaging in off-farm activity had a negative effect on the HDD score for non-adopters. This could be because the lost labour effect of engaging in an off-farm activity dominates the income effect, which is in line with the work of Kousar and Abdulai (2016), who found that the use of inorganic fertilizer declined with participation in off-farm work. Thus, more labour is used in off-farm activity than farm work. Also, the extra income from the off-farm income does not improve the household food security as expected in the non-adoption state.

Output from the past season positively influenced the HDD score in the adopted state whilst it had a negative influence in the non-adoption state. This means the output of SAPs adopters positively influence their food security. The larger the household size for non-adopters, the more food secure they are in terms of HDD score. However, the opposite was found for adopters of SAPs. Farmer group membership and extension contacts positively influenced the HDD scores in the non-adoption state. However, they had a negative influence on the gains from adoption for adopters. This could be because the extension contacts were not an effective means of information dissemination in this case; which is similar to the work of Kwapong, Ankrah, Boateng-Gyambiby, Asenso-Agyemang, and Fening (2020), who found that farmer to farmer engagement more effective in promoting information assimilation than extension agents.

(b) Food Consumption Score

The second stage estimations of Food Consumption Score (FCS) are presented in columns 2 (non-adoption state) and 3 (gains from adoption) of Table 14. FCS is a food security measure, which is based on the weighted score of food groups a household consumes in 7 days. The higher the score, the more food secure the household is. Education positively influenced the food consumption score for households in the non-adoption state whilst it had the opposite effect on the gains from adoption in terms of food consumption score. The cost of organic fertilizer negatively impacted the food security of households in the non-adoption state. The coefficient of remittance is positive and statistically significant in the non-adoption state. As in the case of the HDD score, the household size positively influenced food security in the non-adoption state. Households that received input credit made gains in the FCS scores as a result of adopting SAPs. Farmer group membership had a positive effect on the FCS score of households in the non-adoption state, whilst it negatively affected the gains from adopters' adoption.

5.4.3 Marginal treatment effect of SAPs adoption

This section reports the summary treatment effect of SAPs adoption on the outcome variables (HDD and FCS). The summary of treatment effect indicates the possibility of treatment effect heterogeneity among farm households in northern Ghana. The estimates in Table 15 show that ATT is greater than ATE and ATU, which indicates a positive selection on gains.

Table 15: Impact of SAPs on food security

	HDD+			FCS+		
	Coef.	Std. Err.	% Change	Coef.	Std. Err.	% Change
ATE	2.151***	0.620	0.273	1.790**	0.896	0.049
ATT	2.680***	0.822	0.341	1.917*	1.172	0.052
ATUT	0.536*	0.292	0.068	1.402***	0.397	0.038
LATE	0.579***	0.221	0.073	0.819***	0.334	0.022
p-value test for essential heterogeneity		(0.036)			(0.075)	

Note: The table reports the average treatment effects (ATE), the average treatment effects on treated (ATT), average treatment effects on the untreated (ATU) and the local average treatment effect (LATE) for the two outcome variables. The *p*-values are given in parentheses. Bootstrapped standard errors are reported with 150 replications. +HDD and FCS are measured in scales, so the percentage change is calculated based on their mean values from the sample. ***Significant at 1% level, ** significant at 5% level, * significant at 10% level

This means that household heads who are more likely to adopt (due to innate ability or changes in the quality of production such as mechanised farming) usually benefit more from adoption in terms of food security as measured by HDD and FCS. The ATE shows that adopting SAPs improves the household HDD score by 27.3 per cent. The ATT shows adoption had an even greater positive impact on HDD for adopters by increasing it by 34.1 per cent. The estimates of ATU indicate that the HDD score for non-adopters will improve by 6.8 per cent if they adopt SAPs. Similar results were obtained for FCS. The ATE is also positive and significant at 5 per cent, indicating that adopting SAPs improved food security as measured by FCS by 4.9 per cent. The p-values for both observed and essential heterogeneity are significant at 1 per cent and 5 per cent, for both HDD and FCS. The summary of treatment effect measures usually masks treatment effect heterogeneity. Therefore, further insights can be gained by graphing the MTEs as shown in Figures 5 and 6.

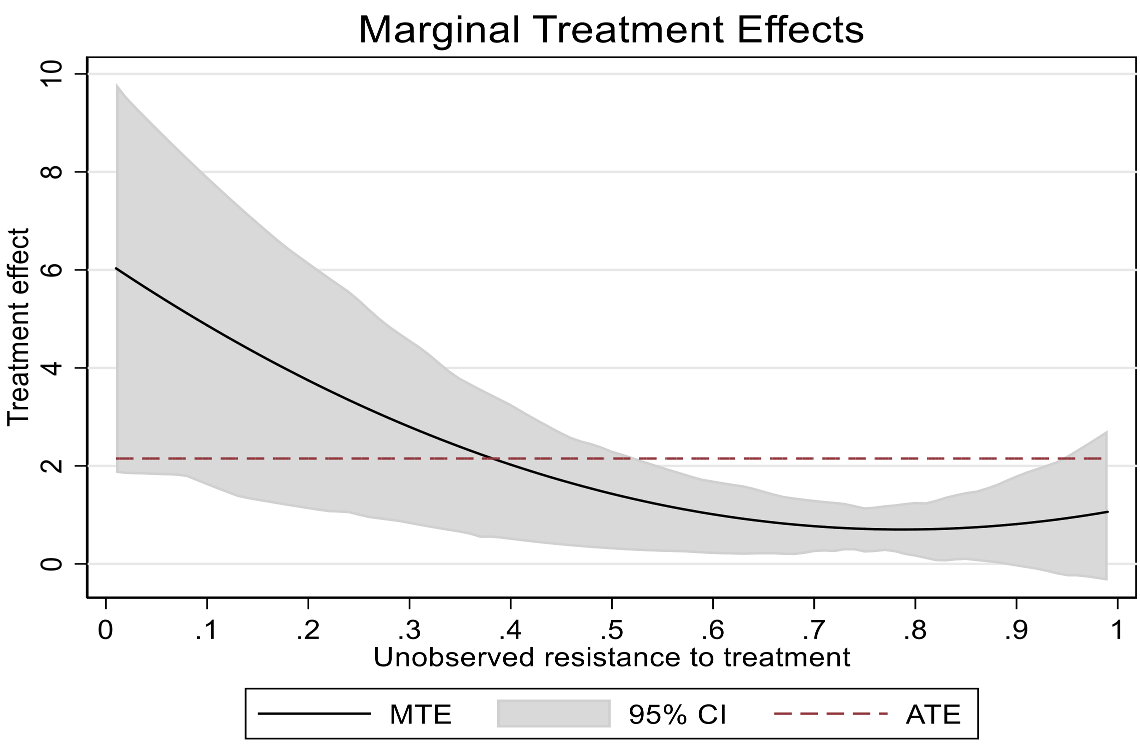

Figure 5: MTE curve for Household Dietary Diversity (HDD)

The MTE curves display the mean values of our observed characteristics (X_I) and relate the unobserved segments of outcomes $(U_1 - U_0)$, and the unobserved segments of adoption choice (UA_i). Higher values of (UA) indicate lower probabilities of adoption (i.e., higher resistance to adoption). The MTE curve for HDD shows that the MTE curve falls as resistance to adoption increases and goes below the ATE curve when resistance is 39 per cent. The MTE curve for FCS shows that, as resistance to adoption increases beyond 30 per cent, the MTE curve falls below the ATE line, meaning households increasingly become food insecure. Both MTE curves display a pattern of reverse selection on gains for observable characteristics of households. Thus, adopting SAPs makes households more food secure. Given the unobserved characteristics, households most likely to adopt SAPs appear to benefit the most from adoption, as shown by the significant p-value for essential heterogeneity.

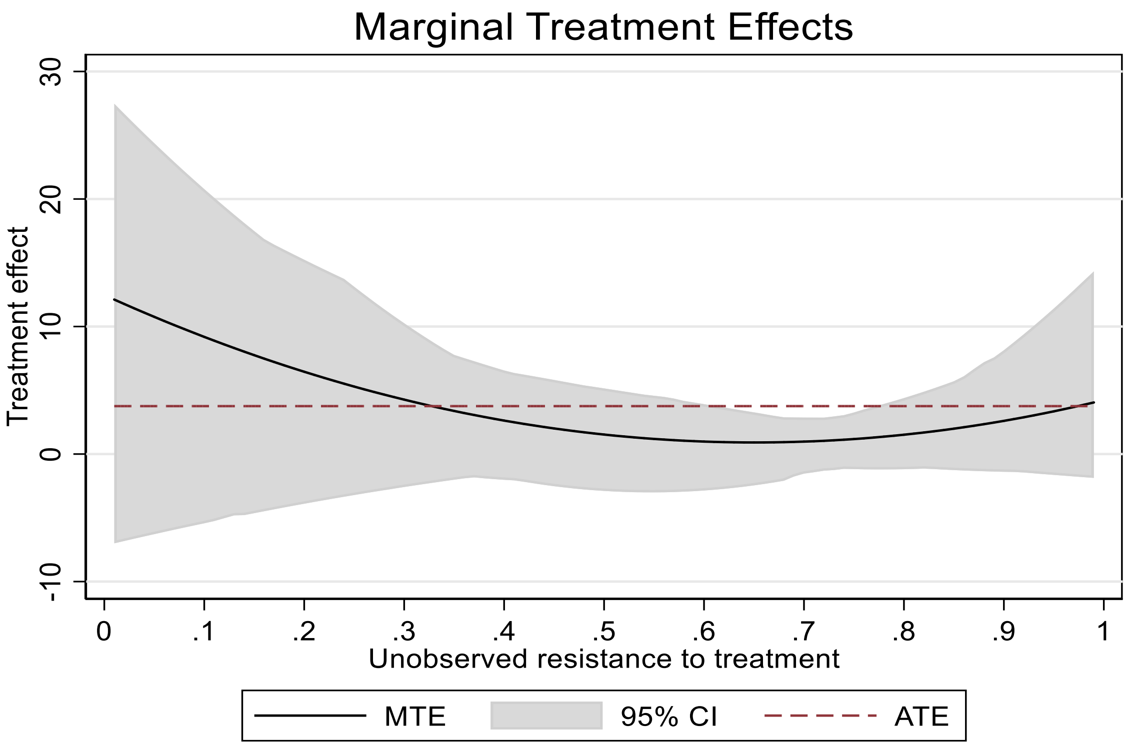

Figure 6: MTE curve for Food Consumption Score (FCS)

5.4.4 Robustness checks

To examine the robustness of our estimates, we estimated different functional form specifications (linear, cubic and quartic) of the propensity score. The graphs in Figure B.6 and B.7 in appendix B, indicates that robustness checks further confirm the results. The MTE curves confirm that our results for HDD and FCS are robust and generally do not vary using linear and higher-order specifications.

5.5 Conclusions and policy implications

This paper examined the heterogeneity in the effects of SAPs adoption on food security of smallholder farmers in northern Ghana. Though a simple comparison of the outcome variables (HDD and FCS) shows significant differences, these differences are not significant enough to explain the effect of SAPs adoption on the outcome variables because they do not account for other confounding factors. We employed the marginal treatment effects approach (MTE) to investigate the heterogeneity in gains from SAPs adoption in both observed and unobserved factors that influence adoption.

The results showed heterogeneity in the gains from SAPs adoption. We observed a pattern of positive selection on unobserved gains across the outcome variables, i.e., HDD and FCS. We found that households who are more likely to adopt SAPs tend to benefit from adoption in HDD and FCS. These results show that adopting SAPs can help improve smallholder food security. We found that cost of inorganic fertilizer and improved seeds, had a negative effect on adoption, whilst engaging in off-farm work enhanced adoption of SAPs. Government and NGOs should pursue policies that reduce the cost of inputs such as providing input credit for inputs (improved seeds, fertilizer and machinery). Government and NGOs should encourage participation in off farm work, by helping farmers to access low interest rate loans from microfinance institutions which can be used to start other businesses especially during during the off season. There should be other extension activities that train farmers in different small crafts skill, which they can use to support their incomes especially during the off-season. This will improve the household income, increase the adoption of SAPs and reduce food insecurity in Northern Ghana, thereby contributing to the achievement of SDG goal 1 and 2.

Chapter 6

General conclusions and recommendations

6.1 Introduction

This thesis assessed the determinants of multiple SAPs adoption by smallholders in northern Ghana and the impact of adoption on their farm income and food security. This was achieved by :

(1) Comparing food security measures and investigating the determinants of household food security (HFS); using spearman's rho and probit regression.

(2) Determining the factors that influence smallholder farmers' decisions to adopt multiple SAPs, using a multinomial endogenous switching regression

(3) Estimating the impact of SAPs adoption on the farm income (gross margins) and food security status of smallholder farmers; using a multinomial endogenous switching regression

(4) Examining the heterogeneous effect of SAPs adoption and its impact on food security of smallholders in northern Ghana; using the marginal treatment effects model

The thesis drew on primary and secondary data. The secondary data was collected in 2014, covering 1284 households and 5500 plots, for the Africa RISING project; this data was used in the analysis for Chapter 4. Primary data was also collected in 2019 from 494 smallholder households in three northern (i.e., Northern, Upper East, Upper West) regions of Ghana; this data was used in the analysis for chapters 3 and 5. Food security is estimated using seven measures of food security i.e., HFIAS, HHS, FCS, HDD, rCSI, CSI and SAF.

6.2 Summary of results

In Chapter three, the convergence of seven measures (i.e., HFIAS, HHS, FCS, HDD, rCSI, CSI and SAF) was assessed using percentages and correlations. The determinants of food security by measured FCS, HHS, CSI, and SAF was also assessed using probit regression. We found strong correlations between FCS and HDD, between HFIAS, HHS, CSI and rCSI, and between SAFS and HFIAS. Food insecurity prevalence varied across the measures with HDD giving the least prevalence whilst FCS and HFIAS gave the highest prevalence of food insecurity. In as much as comparing measures is important, we probed further to understand what influences food security and its policy implications. We also found that food security amongst smallholders in northern Ghana is mainly influenced by socio-demographics of household head, farm size, drought, membership in farmer group, duration of food storage, ownership of animals, and geographic locations.

In Chapter four, using a multinomial endogenous switching regression model, we assessed the factors influencing SAPs adoption by smallholders in northern Ghana, and the impact of adoption on farm income and food security. We found that social demographics of the households, plot characteristics, location, extension, satisfaction with extension, and membership in the Africa RISING FBO, influence the adoption of multiple SAPs. Also, the treatment effects results indicate that adopting SAPs had a positive influence on farm income and food security, with farmers adopting improved seeds, fertilizer use and soil and water conservation practices simultaneously, obtaining a higher positive impact on farm income and food security than adopting individual SAPs.

In Chapter five, we investigated the factors that influence smallholders' decisions to adopt SAPs and examined the heterogeneous effects of the adoption on food security, measured by household dietary diversity (HDD) and food consumption score (FCS). The marginal treatment effect model was used to analyse survey data collected from northern Ghana in 2019. We found that there is heterogeneity in gains from SAPs adoption with respect to both observed and unobserved characteristics. The results showed ATT is greater than ATE and ATU, which indicates positive selection on gains across both HDD and FCS. This means households who are less resistant to adopting SAPs due to innate ability usually benefit more from adoption in terms of food security.

6.3 Conclusion and recommendations

Overall, the analysis undertaken within this study provides insights into key issues surrounding the adoption of SAPs and food security. The study concluded that estimates of the prevalence of food-insecure households vary considerably across the seven measures of food security. This would appear to have important practical and policy implications. Therefore, one must be cautious about which measure to use, especially when measuring acute food insecurity for better targeting of households or beneficiaries during an intervention. The FCS or HFIAS can be used as an indicator for interventions that seek to target a wider range of food-insecure households, whilst the HDD or HHS can be used as indicators for interventions that seek to target the severely food insecure households. To get a holistic view of HFS, we recommend the use of at least two measures of food security, i.e., a dietary diversity measure (HDD and, FCS) and a behavioural (rCSI and, CSI) or experiential measure (HFIAS and, HHS). The analysis also suggests that other policies that encourage longer food storage durations and improve credit access should also be pursued to improve food security in northern Ghana.

We found that being a member of a farmer group positively influences both SAPs adoption and food security. This could be because membership in farmer groups improves access to training, provides input support (such as input subsidy or input credit), and gives them collective bargaining power in the market. This suggests that policies that support group membership may be fruitful in terms of the adoption of SAPs and improving levels of food security.

Our findings highlight the importance of extension in improving adoption and food security. We recommend that policies that improve the extension agent to farmer ratio should be pursued since access to extension had a positive influence on the adoption of SAPs. However, the satisfaction with the extension agent variable also had a positive influence on the adoption of all the SAPs package, this highlights the need to improve the quality of the extension service to minimize the risk to adoption due to inadequate information transfer.

We also found that adopting SAPs had a positive impact on households' net farm income and food security; with households adopting all the SAPs (i.e., improved seeds, fertilizer, and soil and water conservation practices) obtaining arguably the biggest gains with almost all the outcome variables. The government and NGO's should pursue policies that advocate for the comprehensive adoption of all SAPs package and provide incentives to motivate the adoption of all SAPs package. Improving access to extension by training more extension workers and ensuring the extension agency is well resourced and efficient. Also, forming, and strengthening FBOs, may increase adoption of all SAPs package as indicated earlier.

We found heterogeneity in the gains from SAPs adoption on food security. The results indicated a pattern of positive selection on unobserved gains across the outcome variables, i.e., HDD and FCS. This means households who are more likely to adopt SAPs tend to benefit from adoption and are more food secure. We found the cost of inputs (fertilizer and improved seed) negatively influenced adoption and whilst engaging in off-farm work positively influenced SAP adoption. This suggests that policies that reduce the cost of inputs and enhance the opportunity for household members to work off-farm may be fruitful in encouraging adoption. Overall, the findings indicate that the adoption of SAPs and their effects on farm income and food security in Northern Ghana can be improved through interventions that provide input subsidies, improve extension service, encourage farmer group membership and encourage farmers' engagement in off-farm work.

6.4 Limitations and future research directions

Although we sampled households in 2019 based on the AR baseline survey from 2014, we were unable to interview the specific respondents interviewed during the AR baseline survey, because of incorrect addresses. This made it impossible for us to use the difference in difference method, to evaluate the impact of SAP adoption. Therefore, impacts of SAP adoption on farm income and food security were analysed using cross-sectional data rather than panel data. Because of the static nature of the data used, the thesis is unable to capture the dynamic relationship between SAP adoption and farm income and food security. However, this might be an interesting area to explore in the future because smallholder farmers' decisions to adopt SAPs might change over time. When required data is available, future studies can also analyse whether farmer-based organizations can help increase and accelerate SAP adoption over time, given the important roles of those organizations in facilitating and diffusing advanced technologies in rural areas and the benefits of adopting SAPs. Improving the technical efficiency of crop production is a prerequisite to increasing farm productivity and ensuring food security. Adoption of SAPs requires the adjustment of production modes and farm management practices. Thus, future studies can also investigate whether SAP adoption can help improve production efficiency, aimed at finding appropriate policy instruments that improve farm performance. This thesis has focused on food crops production in general, without considering any specific crops. There is scope for future work to deepen our understanding of the issues raised in this thesis by focusing on specific crops and investigating whether the effects of SAP adoption on crop production are homogeneous or heterogeneous. In addition the complemetarity or substitutability of SAPs can also be usefully investigated in more detail in future studies.

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Appendix A

A.1 Questionnaire used in primary data collection

EFFECTS OF SUSTAINABLE AGRICULTURAL PRACTICES ON FOOD SECURITY AND SUSTAINABILITY OF SMALLHOLDER FARMS IN NORTHERN GHANA

This questionnaire is for an academic survey and all information given shall be used solely for the purpose of research. I would be grateful if you could provide the necessary answers to the questions stated. Your responses would be added to those of other respondents for analysis. I would strongly like you to note that the confidentiality of your responses is assured. All household identifying information will be held in strict confidence and used only for research purposes. No identifying information (e.g., respondent name) will appear in any reports. Participation in this interview is voluntary and you may refuse to participate, discontinue the interview at any time, or skip any question you do not want to answer with no penalty or loss of benefits to which you are otherwise entitled. You can ask questions concerning the research, both before agreeing to participate in the interview, during, and after the interview. As head of the household or spouse of the head, I would like to ask you questions mainly about agricultural activities and consumption. Thank you for considering this request.
May I proceed with interviewing you and other household members?

Yes ☐ *No* ☐ *Signature: ………………………….*

Please key or tick the appropriate response where applicable.

Questionnaire No.	Date	Time started & ended	Respondents Phone No.	Household ID/GPS Coordinates
		/		

HOUSEHOLD LOCATION

Region	District	Community	Religion	Ethnic Group

SECTION A: SOCIO-ECONOMIC BACKGROUND OF HOUSEHOLD

A1. What is the gender of household head (HHH)? 1=Male 2= Female
A2. What is the marital status of household head (HHH)? 1= Married 2=Single 3= Divorced 4= Widow/widower 5= Separated 6=other please specify……………..
A3. What is the age of the household head (HHH) in years? …………………………..
A4. Age of spouse if married in years? ………………………………….
A5. What is the household size?...
A6. What number of (HH) members are below 15 years ?……………………….
A7. What number of (HH) members are above 65 years ?………………….
A8. What is the highest education level of HHH? 1= No formal education 2= Primary 3= Secondary 4 = Technical 5= Vocational 6= Tertiary 7= Other please specify…………….
A9. What is the highest education level of HHH in years?..
A10a. What is the primary occupation of household head (HHH)? 1= Farming 2= Petty trading 3= Formal work (working with a government institution) 4= Artisanry 5= Other please specify ………………………………….
A10b. What is the secondary occupation of household head (HHH)? 1= Farming 2= Petty trading 3= Formal work (working with a government institution) 4= Artisanry 5= Other please specify ………………………………….
A11. How many years have you been involved in farming?………………
A12. How many seasons did you farm in 2018? ……………………….

A13. What was your income from farming in 2018? 1= bellow GHS100 2 =GHS100 -1000 3= GHS 1001 -10000 4= Above GHS10000
A14a. Did you engage in off farm work in 2018? 0= No 1=Yes
A14c. If so, what is the nature of your off-farm work? 1= Farm related work 2= non- farm related work 3= Other please specify.............................
A15a. Do any of your neighbors participate in off- farm work in 2018? 0= No 1=Yes 2=I don't know
A15b. If so, how many?......................................
A16a. Do any of your close friends participate in off-farm work in 2018? 0=No 1= Yes 2= I don't know
A16b. If so, how many?......................................
A17a. Do any of your relatives participate in off-farm work in 2018? 0=No 1= Yes 2= I don't know
A17b. If so, how many?......................................
A18. How much income did you earn from your off- farm work? ………………..
A19. What is the frequency of your off-farm income? 1= Daily 2= Weekly 3= Monthly 4= Other please specify……………….
A20. Using your usual mode of transport, what is the distance between your homestead and:

i. Farm (a)………………minutes and (b)…………………km
ii. Off-farm work (a) ………………. minutes and (b) …………….km
iii. Closest place you may find off-farm work (a) ………………. minutes and (b) ……………km

A21. What other economic activities were you involved in 2018? 1= HH non-farm enterprise 2= Pito Brewing 3=Sale of firewood and other forest products including charcoal and wild foods 4= other please specify…………………………………………

A26.What are your other sources of income? Please tick the appropriate answer		A27. If yes, what is the amount of income from other sources of income?	A28. If Yes, what is the frequency of income from these sources? 1= daily 2= weekly 3= monthly 4 =other please specify………………
a. Pension	0= No 1=Yes		
b. Remittance	0= No 1=Yes		
c. Welfare Payments (LEAP)	0= No 1=Yes		
d. Other Please Specify ………………….	0= No 1=Yes		

A29. In 2018, did you experience any of the following shocks?		A30. If yes, how often did you experience these shocks in 2018?	A31. If yes, how did it affect your farming activities? 1= no impact 2= little impact 3= high impact
a. Drought	0= No 1=Yes		
b. Flooding	0= No 1=Yes		
c. Unregulated bush fire	0= No 1=Yes		
d. Crop diseases or pests	0= No 1=Yes		
e. Other please specify ……………………………	0= No 1=Yes		

SECTION B: PLOT CHARACTERISTICS FOR THE 2018 CROPPING SEASON (kindly fill both tables by the plot ID)

Plot Id	Size (Acres)	How was land Acquired 1=Family land 2= Own land 3= Lease 4=community land 5= other please specify	If leased, how much did you pay for it and for how long? (a)…..for (b)……		Soil type 1= Clay 2=Loam 3=Sand 4=Sand/loam 5=Silt 6=Other please specify	Soil colour 1=Black 2=Brown 3=Red 4=Red/Brown 5=Grey/Brown 6=Grey	Perceived Soil Fertility 1= low 2= moderate 3= high	Slope of Plot 1=Flat 2=Terraced 3=Gentile slope 4=Moderate slope 5=Steep slope 6=Depression	Distance to homestead in minutes	Experience soil erosion 0=No 1= Yes	Irrigation used 1 =Ground water 2 =River diversion 3 =Pond diversion 4 =Shallow well 5= Deep well 6 =Water harvesting 7 =Water cans 8 =Drip irrigation 9 =None	Minimum tillage/ grass strips 0= No 1= Yes	Agro-forestry 0= No 1=Yes
	B1	**B2**	**B3a**	**B3b**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**
1													
2													
3													
4													
5													
6													
7													

Plot Id	Crops Cultivated. Fill B13a and B13b if mixed cropping is done		Proportion of crop B11a	Yield of crop B13a	Yield of crop B13b	Improved Seed Use 0= No 1= Yes	Fertilizer Use 0= No 1= Yes	Pesticide Use 0=No 1= Yes	Mulching Use 0=No 1= Yes	Composting Use 0=No 1= Yes	Terracing/ contour ploughing Use 0=No 1= Yes	Organic Manure Use 0=No 1= Yes	Fallowing Practiced 0=No 1= Yes	Crop Rotation Use 0=No 1= Yes
	B13a	**B13b**	**B14**	**B15**	**B16**	**B17**	**B18**	**B19**	**B20**	**B21**	**B22**	**B23**	**B24**	**B25**
1														
2														
3														
4														
5														
6														
7														

B24.Crop Cultivated	B25. Quantity Harvested	B26. Unit	B27. Price /Unit	B28. Total Revenue
i. Maize				
ii. Rice				
iii. Millet				
iv. Yam				
v. Groundnut				
vi. Others Please Specify				

SECTION C: VARIABLE INPUTS USED IN THE 2018 CROPPING SEASON

INPUTS	QUANTITY/NO. USED (a)	UNIT PRICE (GH¢)
C1. Improved seeds (kg)		
C2. Insecticides (Kg/L)		
C3. Fungicides (Kg/L)		
C4. Nematicide (Kg/L)		
C5. Herbicides (Kg/L)		
C6. Pre-emergence chemicals (Kg)		
C7. Inorganic fertilizer (Kg) • NPK/ Ammonia		
C8. Organic manure (kg)		
C9. Fuel (gallons)		

SECTION C: LABOUR USED IN THE 2018 CROPPING SEASON

	FAMILY LABOUR			HIRED LABOUR		
Nature of work/activity	**No. of people (a)**	**Number of days**	**Cost per day (c)**	**No. of people (d)**	**Number of days**	**Cost per day (f)**
C10.Land preparation • Ploughing • Harrowing • Ridging						
C11. Planting						
C12. Fertilizing						
C13.Weeding						
• 1st weeding • 2nd weeding • 3rd weeding • 4th weeding						
C14. Application of organic manure						
C15.Chemical application • Pre-emergence chemical • Pesticide • Fungicide • Herbicide						
C16. Irrigation						
C17. Harvesting						
C18. Carting from farm to house						

SECTION D: ANIMAL PRODUCTION IN 2018

In 2018, have members of your household raised or produced [ANIMAL TYPE]?	How many [ANIMAL TYPE] does your household currently own	What is the estimated total value of all [ANIMAL TYPE] your household currently own?	which of the following feed for [ANIMAL CATEGORY] have you used? [LIST UP TO THREE SOURCES] 1= Crop residue 2= Green forages 3= Grazing/open air 4=Concentrate feeds 5=Legumes, fodder trees, shrubs 6= Multiple 7= Other please specify			What type of management system does the household use for [ANIMAL TYPE]? 1=Grazing/open air only 2=Intensive/Caging only 3=Mixed 4=Housed 5= Other please specify	How much have you spent in total on costs for [ANIMAL TYPE] such as veterinary supplies, taxes, and hired labor?	How much have you generated in sales of animal or animal product in the past year	Number of Labour for animal production used in Man days		
									Family Labour	Hired labour	Wage rate
D1	**D2**	**D3**	**D4a**	**D4b**	**D4c**	**D5**	**D6**	**D7**	**D8a**	**D8b**	**D8c**
Large ruminants (cattle)											
Equines (e.g., horses, donkeys, and mule)											
Chickens and poultry											
Small ruminants (e.g. sheep, goats)											
Pigs											

SECTION E: ACCESS TO INFORMATION, CREDIT AND MARKET.

E1. Have you received advice/information on vegetable gardens, crops, livestock, or soil and natural resource management from [SOURCE] in 2018?		E2. During the 2018 cropping season, how often did [SOURCE] interact with you to exchange advice on farming/raising livestock? 1=At least once a week 2= Not weekly but at least once a month 3 =Not every month but at least once during the cropping season 4 = Just once 5 = Never 6 = Other please specify
0= None	0= No 1 =Yes	
1=Friend/neighbor	0= No 1 =Yes	
2= Farmer's group	0= No 1 =Yes	
3=Agricultural extension agent	0= No 1 =Yes	
4=Model farmer	0= No 1 =Yes	
5= Other please specify …………………		

E3. How do you market your produce? a. b. c. d. e. f. g.	E4. What proportion of your output do you sell using these market outlets?
Farm gate 0= No 1 =Yes	
Local Market 0= No 1 =Yes	
Urban Market 0= No 1 =Yes	
Contract 0= No 1 = Oral 2= Written	
Export 0= No 1 =Yes	
Subsistence 0=No 1 =Yes	
Other please specify ………………………………	

E5. If funds are obtained through borrowing, what are the sources? From (List all the answers that applies)
1= informal sources (Family, neighbor, friends)
2= Formal Sources (Banks, microfinance, co-operative)
3=Governmental/ NGO
4= Other please specify …………………………………………

E6. How far is your local Farmer Training Center (one way in minutes) using the usual mode of transport? a. ……………minutes &……………….km

E7. Have you ever participated in the activities of your Farmer Training Center? 0= No 1 =Yes

E8. Have you tried any new agricultural technologies/management practices during the 2018 farming season? 0= No 1 =Yes

E8a. If yes, which ones ? i. .... ii. .... iii…………………………………

E8b.Why, do you use these ones?...

E9. Think of the agricultural extension/development agent you interact with the most. How long have you known that agent? ……………………….

E10. Are you/your household satisfied with quantity, quality and timeliness of extension? 0= No 1 =Yes

E10a. Why? ………………………………………………………………………..

E11. Are you/your household satisfied with quantity, quality and timeliness of input supply services? 0= No 1 =Yes

E11a. Why?..

E12. Do you/your household currently participate in any social organization in 2018? 0= No 1 =Yes

E13. What type of social organization did you participate in? 1= Community group 2= Religious group 3= Farm-related group 4=Other, please specify ………………..

E14. Have you/your household ever participated in any group that focuses on the conservation of natural resources? 0= No 1 =Yes

E15. Have you heard of Africa RISING program? 0= No 1= Yes

E16. If yes, which Africa RISING-related activity did you get involved in? 1= Community meetings 2= trainings 3= On-farm experimentation of new or improved agricultural technology 4= Demonstration field days 5 =Other please specify ……………………………………….

E17. Where do you get your seeds from? 1= Own stock 2= Other farmers' 3=agrochemical shop 4=Other please specify ………………………………………………

E18. Do you do seed selection? 0= No 1 =Yes

E19. Using your usual mode of transport, what is the distance between your homestead and:

i. Nearest agro-inputs shop (a)………………minutes & (b)…………………km
ii. Nearest market (a) ………………. minutes & (b) …………….km
iii. Closest credit source (a) ………………. minutes &a ` (b) ……………km

E16. During 2018**,** did anyone in this household apply for credit or ask for a loan of at least 50 GHC? 0= No 1 =Yes
E17. During 2018 cropping season, did the household receive a loan (the amount requested for)? 0= No 1 =Yes
E18. If no, was the loan received, small than requested for? 0=No 1=Yes
E19. During 2018 cropping season, did the household member receive any crop inputs or agricultural equipment on credit? 0= No 1 =Yes
E20. During 2018 cropping season, did the neighbor receive any crop inputs or agricultural equipment on credit? 0= No 1 =Yes
E21. During 2018 cropping season, did the friend receive any crop inputs or agricultural equipment on credit? 0= No 1 =Yes
E22. How do you store the produce? 1= Sack /Bags 2= Granary 3= Pit in the ground 4= Drums 5= Raised Roofed Platform 6= Other please specify………………………………….
E23. How long did you store produce in 2018 cropping season? ……………………………………..

SECTION F: HOUSEHOLD FOOD SECURITY MEASURES

HFIAS & HHS

Occurrence Questions: In the past 4 weeks	Answer (a)	Frequency (b)
	0 = No 1 = Yes	1 = Rarely 2 = Sometimes 3 = Often
F1. Did you worry that your household would not have enough food?		
F2. Were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?		
F3. Did you or any household member have to eat a limited variety of foods due to a lack of resources?		
F4. Did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?		
F5. Did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?		
F6. Did you or any household member have to eat fewer meals in a day because there was not enough food?		
F7. Was there ever no food to eat of any kind in your household because of lack of resources to get food?		
F8. Did you or any household member go to sleep at night hungry because there was not enough food?		
F9. Did you or any household member go a whole day and night without eating anything because there was not enough food?		

*Rarely: <1 Time/ Week, Sometimes 1-2 Times /Week, 3-6 Times /Week

CSI & rCSI

Occurrence questions: In the past 4 weeks	Answer	Frequency
	0 = No 1 = Yes	1 = Rarely 2=Sometimes 3 = Often
F10. Rely on less preferred and less expensive foods?		
F11. Borrow food, or rely on help from a friend or relative?		
F12. Purchase food on credit?		
F13. Gather wild food, hunt, or harvest immature crops?		
F14. Consume seed stock held for next season?		
F15. Send household members to eat elsewhere?		
F16. Send household members to beg?		
F17. Limit portion size at mealtimes?		
F18. Restrict consumption by adults for small children to eat?		
F19. Feed working members of HH at the expense of non -working members?		
F20. Ration the money you have and buy prepared food?		
F21. Reduce number of meals eaten in a day?		
F22. Skip entire days without eating?		

HDD AND FCS

QUESTIONS AND FILTERS	CODING CATEGORIES		
F23	Now I would like to ask you about the types of foods that you or anyone else in your household ate yesterday during the day and at night. READ THE LIST OF FOODS. PLACE A *ONE* IN THE BOX IF ANYONE IN THE HOUSEHOLD ATE THE FOOD IN QUESTION, PLACE A *ZERO* IN THE BOX IF NO ONE IN THE HOUSEHOLD ATE THE FOOD.		F24. Frequency of food consumed in the past 7 days.
A	Any [INSERT ANY LOCAL FOODS, E.G. Tuo Zaafi, NSHIMA], bread, rice noodles, biscuits, or any other foods made from millet, sorghum, maize, rice, wheat, or [INSERT ANY OTHER LOCALLY AVAILABLE GRAIN]?	A|___|............................	
B	Any potatoes, yams, manioc, cassava or any other foods made from roots or tubers?	B|___|............................	
C	Any vegetables?	C|___|............................	
D	Any fruits?	D|___|............................	
E	Any beef, pork, lamb, goat, rabbit wild game, chicken, duck, or other birds, liver, kidney, heart, or other organ meats?	E|___|........................	
F	Any eggs?	F|___|............................	
G	Any fresh or dried fish or shellfish?	G|___|............................	
H	Any foods made from beans, peas, lentils, or nuts?	H|___|............................	
I	Any cheese, yogurt, milk or other milk products?	I|___|............................	
J	Any foods made with oil, fat, or butter?	J|___|............................	
K	Any sugar or honey?	K|___|............................	
L	Any other foods, such as condiments, coffee, tea?	L|___|............................	

F25.Did you worry about food in the last 7 days? 0=No 1= Yes	F26.Did you worry about food in the last 12 months? 0=No 1 =Yes

F27.Which of the following months did you worry about food in the 2018 cropping season? Kindly tick either Yes (Y) for the months you were worried.

Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N

F28.Which of the following months did you worry about food in the 2019 cropping season? Kindly tick either Yes (Y) for the months you were worried.

Jan	Feb	March	April	May	June	July
Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N

SECTION G: FESLM -DSS

Productivity:

G1. Do you regard your average yield as an indicator of your productivity? 0=No 1= Yes

G2. In the past 5 to 10 years what has your average yield been 1= less than the village mean by more than 25%,
2= less than village mean by 25%
3=less than village mean by 0–25%, *4=greater than* village mean

G3. Do you regard plant growth as a good indicator of productivity? 0=No 1= Yes

G4. Plant growth on your plots is it? 1= stunted 2= normal 3= vigorous

G5. Do you regard the colour of the leaves (when they are in season) a good indicator of your productivity? 0=No 1= Yes

G6. The leaf colour of your plants (when in season) is it? 1= Yellowish on the tips, older leaves purple, 2=normal yellowish on the whole leaf, 3= dark green

Security

G7. Do you regard annual rainfall average a good indicator of security for your production? 0=No 1= Yes
G8. would you say that the average rainfall in the past 2 years is excessive, enough or limited? 1= Limited: <1200mm, 2=Enough: 1200– 2400mm, 3= Excessive: >2400mm per year
G9. Do you regard residue (stover) management a good indicator for security for your production? 0=No 1= Yes
G10. What is your residue (stover) management regiment? 1= keep less than 50% of stover or keep stover for less than 3 years, burnt or removed
2= keep less than 50% of stover for 3 years or more, 3=keep 50% of stover for less than 3 years, 4= keep 50% of stover for 3 years or more.
G11. Do you regard drought frequency a good indicator of the security of your production? 0=No 1= Yes
G12. How often have you experience drought is it? 1= less than 8months continuously, 2= more than 8months in 2 years, 3= 2 years continuously
G13. Do you regard amount of income a good indicator of security of your production? 0=No 1= Yes
G14. How much does income from your livestock contribute to your total income? 1= less than 10%, 2= 10 – 25 %, 3= less than 25 %.

Protection

G15. Do you regard topsoil erosion as a good indicator of protection of your production system? 0=No 1= Yes
G16. What is your perception of the amount of topsoil eroded from your plots (in last 7 years)?1= limited 2= enough 3=excessive
G17. What cropping intensity and extent of protection do you use? 1 = 1 crop, no conservation, 2 = 1 crop with conservation, 3 =2–3 crops, no conservation
4 = 2–3 crops with conservation
G18. Do you regard the rate of cropping intensity and extent of protection you use as a good indicator of your production system? 0=No 1 =Yes.
G19. What is your cropping pattern? 1= cereal crop then fallows, 2= cereal crop then another cereal crop, 3= cereal crop then legume crop 4= cereal crop between perennial 5= Include fruit gardens and agroforestry 6= Other please specify ………………………………………………

Viability

G20. Do you regard availability of farm credit as a good indicator for viability? 0= No 1=Yes
G21. Do you regard percentage of farm produce sold in market as a good indicator for viability? 0=No 1=Yes
G22.What percentage of farm produce sold in market? 1= <25% of produce sold, 2=25–50% of produce sold, *3*= >50% of produce sold
G23. Do you regard net farm income as an indicator for viability? 0=No 1=Yes
G24. Is your net farm income ? 1= Fluctuating, 2=Constant (B:C=1) 3=Declining (B:C<1) 4= Rising (B:C>1.25)
G25. Do you regard off- farm income as a good indicator for viability? 0=No 1=Yes
G26. Do you regard the difference between market price and farm gate price as an indicator for viability?0= No 1=Yes
G28. What is the difference between market price and farm price? 1= <25% 2= 25–50% *3*= >50%
G29. Do you regard availability of farm labour as a good indicator for viability? 0=No 1=Yes
G30. Do you regard land holding size as a good indicator for viability? 0= No 1=Yes

Acceptability (land use methods can be expected to fail, in time, if their social impact is unacceptable). Please note the question is: Have the land use methods assisted in the community getting access to social infrastructure such as school, health centre etc.

G31. Do you regard access to primary schools as an indicator for acceptability? 0= No 1=Yes
G32. How close is the nearest primary school? *1*=<1 km, 2= 1–3 km, 3= >3 km
G33. Do you regard access to health centre as an indicator for acceptability? 0= No 1=Yes
G34. How close is the nearest health centre? *1*=<3 km 2= 3–5 km 3= >5 km
G35. Do you regard subsidy for conservation practices as a good indicator for acceptability? 0= No 1=Yes
G36. Have you received subsidy for conservation practices? 0= No subsidy 1= Yes Subsidy
G37. Do you regard training in conservation practices as an indicator for acceptability? 0= No 1=Yes
G38. Have you received training in conservation practices? 1= None available 2= Once in 3 years 3= Once in 5 years
G39. Do you regard village road links to major roads as an indicator for acceptability? 0= No 1=Yes
G40. Do you have village road links to major roads? 1= No access 2=Limited access 3= Full access

Appendix B

Chapter 5 Appendix

B.1 Descriptive statistics and definition of selected variables

Variable	Definitions	Mean	Std. Dev.
Adopt SAPs	1 if farmer adopts SAPs , 0 otherwise	0.753	0.431
FCS	Food consumption score (0-112 scale),where 0 represent food insecure, while 112 represent food secure	36.421	17.269
HDD	Household dietary diversity score(0-12 scale), where 0 represent food insecure , while 12 represent food secure	7.858	2.894
Gender	1 if household head is male, 0 otherwise	0.510	0.500
Hh_size	Number of people in the household	10.060	6.110
Hh_size over 65	Number of people in the household over 65 years	0.840	1.202
Education in years	Number of schooling years household head completed (years)	1.923	3.739
Farming experience	Number of years in farming	21.063	14.346
Off farm activity	1 engaged in off-farm work, 0 otherwise	0.587	0.493
Upper west	1 if farmer resides in Upper West region, 0 otherwise	0.302	0.459
Upper East	1 if farmer resides in Upper East region, 0 otherwise	0.310	0.463
Extension	1 if farmer has contact with extension agent, 0 otherwise	0.852	0.355
Total shock impact	Perception of impact of production shocks(4-10), 4 represent little impact, while 10 represent maximum impact	6.429	1.424
Clayey soil	1 if soil at farm is clayey soil, 0 otherwise	0.158	0.365
Red soil	1 if soil at farm is couloured red, 0 otherwise	0.115	0.320
Soil fertility	Perception of soil fertility of soil on farm, (1-3), where 1 represent little fertility, 3 represent very fertile	2.099	0.544
Organic Fertilizer cost	Log of organic fertilizer cost per acre	0.418	1.152
Inorganic fertilizer cost	Log of inorganic fertilizer cost per acre	1.166	0.869
Seed Cost	Log of seed cost per acre	1.609	0.877
Farm size in acres	Farm size in acres	1.561	0.508
SAP Training	Number of SAP training received	2.312	0.987
SAP information sources	Number of SAP information sources	4.621	1.725
Farmgate	1 if farmer sells farm produce at farmgate, 0 otherwise	0.235	0.424
Distance-market	Distance to market in kilometres	2.593	2.249

Input credit	1 if farmer received input credit in last cropping season, 0 otherwise	0.295	0.456
Accessed credit	1 if farmer received credit in last cropping season, 0 otherwise	0.549	0.498
Farmer group	1 if farmer is a member of a farmer group, 0 otherwise	0.533	0.499

B.2 Descriptive statistics and mean difference between Adopters and Non-adopters

Table 2. Mean difference between adopters and non- adopters

Variables	Adopters	Non-Adopters	Mean difference	Std Errors
Number of SAPs information sources	4.745	4.246	-0.498**	0.194
SAPs training	2.395	2.057	-0.338***	0.105
Gender	0.492	0.566	0.076	0.052
FCS	37.538	33.018	-4.519***	1.792
HDD	7.905	7.713	-0.192	0.302
Education in years	1.968	1.787	-0.181	0.390
Farming Experience	21.679	19.188	-2.491*	1.396
Off farm activity	0.597	0.557	-0.039	0.052
Hh_Size	10.054	10.081	0.028	0.638
Hh_size under 65	0.815	0.918	0.104	0.125
Distance to market	2.776	2.036	-0.739***	0.232
Upper East	0.336	0.230	-0.107**	0.045
Upper West	0.296	0.320	0.024	0.048
Extension	0.876	0.779	-0.019**	0.041
Total shock impact	6.486	6.254	-0.232	0.146
Farm gate	0.218	0.287	0.069	0.044
Loamy soil	0.608	0.426	-0.181***	0.051
Red soil	0.073	0.246	0.173***	0.041
Soil fertility	2.131	2.000	-0.132**	0.052
Organic fertilizer cost	0.442	0.344	-0.098	0.113
Chemical fertilizer cost	1.244	0.927	-0.317***	0.092
Seed cost	1.678	1.397	-0.281***	0.082
Farm size	1.546	1.607	0.061	0.053
Input credit	0.310	0.246	-0.065	0.048
Accessed credit	0.553	0.533	-0.021	0.052
Farm group	0.570	0.421	-0.148***	0.052

Note: *** significant at 1% level, ** significant at 5% level and * significant at 10% level.

B.3 Test of validity of instrument for HDD

Table B3: Test of validity of the selection instruments HDD

HDD	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Distance-market	0.115	0.128	0.900	0.370	-0.131	0.368
Constant	6.691	0.363	18.410	0.000	5.971	7.410
Number of obs	=	122				
F(1, 120)	=	0.810				
Prob > F	=	0.369				
R-squared	=	0.007				
Adj R-squared	=	-0.002				
Root MSE	=	2.799				

B.4 Test of validity of instrument for FCS

Table B4. Test of validity of the selection instrument FCS

FCS	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Distance-market	0.370	0.813	0.460	0.649	-1.239	1.979
Constant	33.100***	2.309	14.340	0.000	28.529	37.671
Number of obs =		122				
F(1, 120)	=	0.21				
Prob > F	=	0.649				
R-squared	=	0.002				
Adj R-squared	=	0.006				
Root MSE	=	17.776				

Note :*** $p< 0.01$,** $p< 0.05$,* $p< 0.10$

B.5 Matrix of correlations

Table B5. Matrix of correlations

Variable	Dismarketkm	HDD	FCS
Dismarketkm	1		
HDD	0.0819	1	
FCS	0.0416	0.462	1

B.6 Robustness checks for HDD

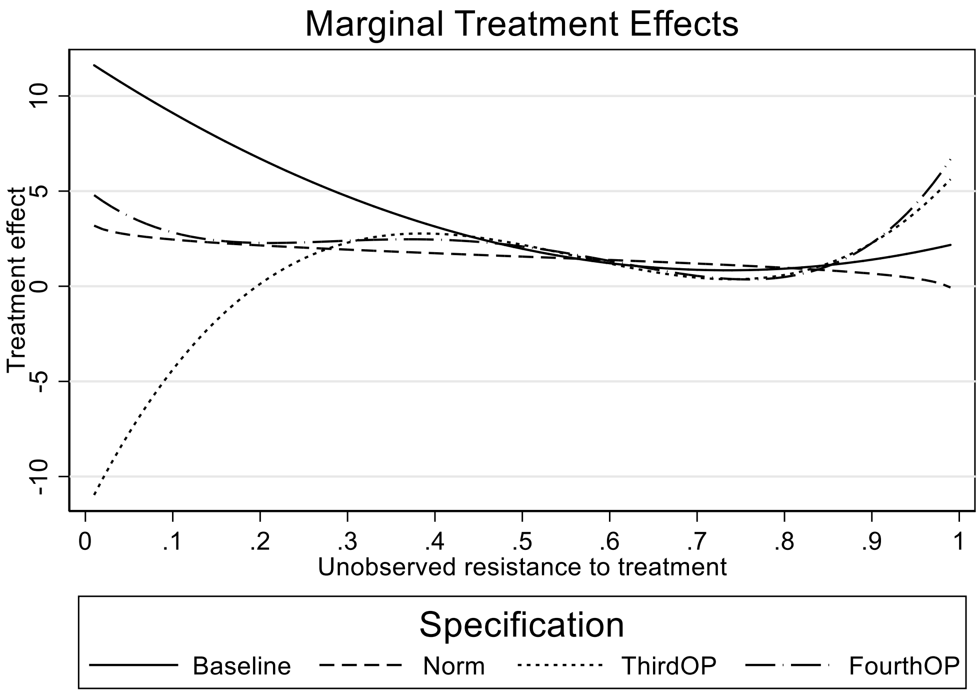

Figure B1: Robustness checks HDD

B.7 Robustness checks for FCS

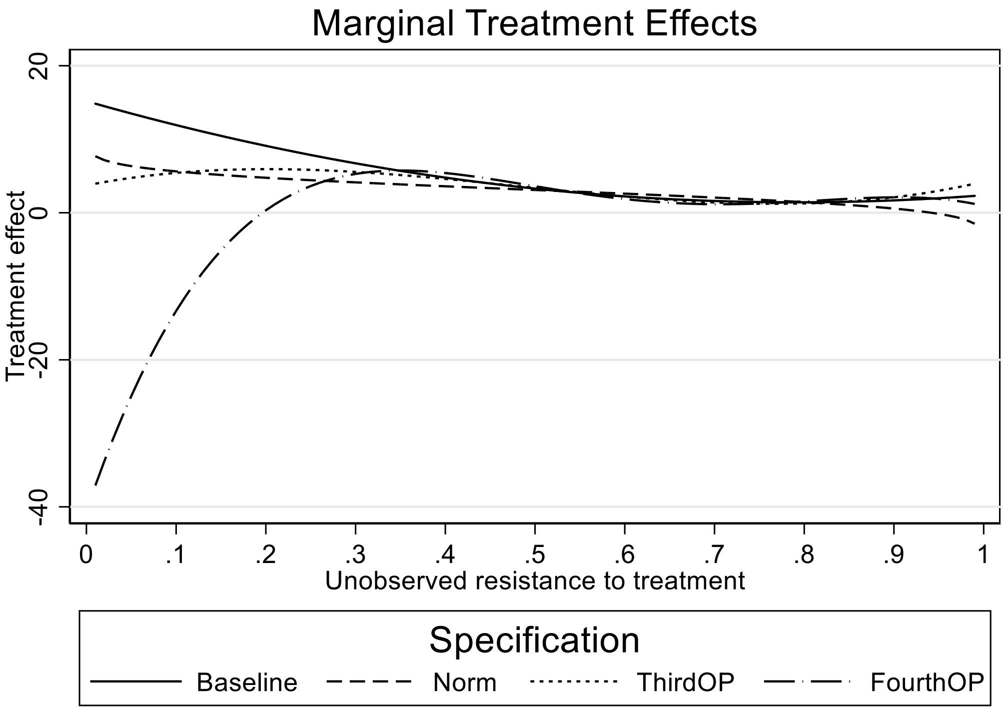

Figure B2 Robustness checks for FCS