Zentrum für Entwicklungsforschung

Sustainable Agricultural Practices (SAPs) in Northern Ghana - Impacts on Welfare, Environmental Reliance, and Agricultural Land Expansion

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Referent:	Prof. Dr. Joachim von Braun
Korreferent:	Prof. Dr. Tobias Wünscher

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Abstract

Sustainable agriculture has become an important issue in the development-policy agenda in Sub-Saharan Africa (SSA), as a major avenue to simultaneously raise smallholder agricultural productivity and enhance climate change adaptation and mitigation. Sustainable Agricultural Practices (SAPs) are believed to play a vital role in addressing these issues while improving households' welfare. While literature provides robust evidence on the welfare impacts of SAPs in isolation, there is limited evidence on how combinations of SAPs contribute to households' welfare. Furthermore, previous experimental studies show that SAPs can reduce environmental footprints of agriculture by conserving organic matter, nitrogen fixation, increasing water infiltration, reducing soil erosion. However, the effect of SAPs on environmental outcomes such as household's reliance on environmental products and cropland expansion into forest areas is not well addressed. To shed light on these issues, we investigate the adoption and impacts of SAPs on welfare and environmental outcomes using a cross-sectional survey data collected from 421 household and 1229 plots from the Upper East Region of Ghana.

The thesis comprises three primary chapters. In the first chapter, we estimate the adoption and impacts of different combinations of SAPs on crop income per acre and consumption expenditure per capita as welfare outcomes. It is found that adoption decisions are affected by household and plot characteristics. The adoption of SAPs either in isolation or in combinations significantly increases welfare. SAPs are however found to have a stronger effect when adopted as a package rather than in isolation.

The effects of SAPs on households' environmental reliance are analysed in the second chapter. From the results, it is found that, on average, income from environmental resources account for about 30% of total household income. The adoption of different combinations of SAPs is found to reduce per capita environmental income by 7 to 15%. In addition, the adoption of different combinations of SAPs reduces the share of environmental income in total household income by 20 to 72%. The effect is higher when SAPs are adopted in combination than in isolation, confirming the synergistic effects of SAPs in reducing environmental pressure.

In the third chapter, we analyse the effects of SAPs on cropland expansion into forest areas. It is found that about 20% of the households expanded their cropland into forest areas within the 12 months prior to the survey date and cleared about 0.21 acres on average. From the results of a two-stage churdel double hurdle model regression, we find no direct evidence of SAPs-induced cropland expansion into forest areas.

In conclusion, this study provides empirical evidence on the adoption and welfare effects of different combinations of SAPs. Furthermore, this study extends the previous literature by analyzing the effects of SAPs on environmental outcomes, i.e., environmental reliance and cropland expansion into forest areas. This analysis helps us to understand if there are positive or negative 'indirect environmental benefits' of SAPs to the already known biophysical and economic benefits at the farm and household levels. It is found that SAPs have positive impacts on crop income and consumption expenditure and reduce environmental resources extraction (as a livelihood strategy). Recognition and promotion of SAPs from both welfare and environmental outcome perspectives could therefore prove worthwhile.

Zusammenfassung

Die nachhaltige Landwirtschaft ist ein wichtiges Thema in der Agenda der Entwicklungpolitik in Subsahara-Afrika (SSA) geworden. Sie ist ein wichtiger Methode, um die landwirtschaftliche Produktivität von Kleinbauern gleichzeitig zu steigern und die Anpassung und die Abschwächung des Klimawandels zu verbessern. Man nimmt an, dass die Vorgehenweisen der nachhaltige Landwirtschaft (SAPs) eine entscheidende Rolle bei der Bewältigung dieser Probleme spielen und gleichzeitig die Wohfahrt der Haushalte verbessern. Während die Literatur robuste Beweise für die Wohlfahrtswirkungen von SAPs isoliert liefert, gibt es nur begrenzte Beweise dafür, wie Kombinationen von SAPs an Wohl der Haushalte mitwirken. Darüber hinaus zeigen frühere experimentelle Untersuchungen, dass SAPs den ökologischen Fußabdruck der Landwirtschaft reduzieren können, indem sie organisches Material konservieren, Stickstoff fixieren, die Wasserinfiltration erhöhen und die Bodenerosion reduzieren. Die Wirkungen von SAP auf Umweltauswirkungen wie die Abhängigkeit des Haushalts von Umweltprodukten und die Ausdehnung von Ackerflächen in Waldgebiete werden jedoch nicht gut berücksichtigt. Um Licht auf diese Probleme zu werfen, untersuchen wir die Annahme und die Wirkung von SAPs auf Wohlfahrts- und Umweltprodukte unter Verwendung von Querschnittserhebungsdaten, die von 421 Haushalt- und 1229 Grundstücken aus der Upper East Region von Ghana gesammelt wurden.
Die Arbeit besteht aus drei Hauptkapitel. Im ersten Kapitel schätzen wir die Übernahme und die Wirkungen verschiedener SAP-Kombinationen auf das Ernteeinkommen pro Hektar und die Konsumausgaben pro Person als Wohlfahrtsergebnisse. Es zeigt sich, dass Adoptionsentscheidungen von den Eigenschaften von Haushalten und Grundstücken beeinflusst werden. Die Einführung von SAPs, entweder isoliert oder in Kombination, erhöht das Wohlbefinden erheblich. SAPs haben jedoch eine stärkere Wirkung, wenn sie als Paket statt isoliert angenommen werden.

Die Auswirkungen von SAP auf die Abhängigkeit der Haushalte von der Umwelt werden im zweiten Kapitel analysiert. Aus den Ergebnissen geht hervor, dass das Einkommen aus Umweltressourcen im Durchschnitt etwa 30% des gesamten Haushaltseinkommens ausmacht. Die Einführung verschiedener SAP-Kombinationen verringert das Umwelteinkommen pro Kopf um 7 bis 15%. Darüber hinaus verringert die Einführung verschiedener SAP-Kombinationen den Anteil des Umwelteinkommens am gesamten Haushaltseinkommen um 20 bis 72%. Der Effekt ist höher, wenn SAPs kombiniert kombiniert werden, was isoliert die synergistischen Effekte von SAPs bei der Verringerung des Umweltdrucks bestätigt.

Im dritten Kapitel analysieren wir die Wirkungen von SAP auf die Ausdehnung von Ackerflächen in Waldgebiete. Es wurde festgestellt, dass etwa 20% der Haushalte innerhalb der letzten 12 Monate vor dem Erhebungszeitpunkt ihre Anbauflächen in Waldgebiete auswuchsen und im Durchschnitt etwa 0,21 Acres roden. Aus den Ergebnissen einer zweistufigen Churdel-Doppelhürden-Modell-Regression ergibt sich kein direkter Hinweis auf eine SAPs-induzierte Erschließung von Ackerflächen in Waldgebiete.

Zusammenfassend liefert diese Studie empirische Belege für Annahme - und Wohlfahrtseffekte verschiedener Kombinationen von SAPs. Darüber hinaus erweitert diese Studie die bisherige Literatur, indem sie die Auswirkungen von SAPs auf die

Umweltauswirkungen, d. H. Die Abhängigkeit von der Umwelt und die Ausdehnung von Ackerflächen in Waldgebiete, analysiert. Diese Analyse hilft uns zu verstehen, ob es positive oder negative "indirekte Umweltvorteile" von SAPs zu den bereits bekannten biophysikalischen und wirtschaftlichen Vorteilen auf der Ebene der landwirtschaftlichen Betriebe und der Haushalte gibt. Es zeigt sich, dass SAPs positive Auswirkungen auf Ernteerträge und Konsumausgaben haben und die Gewinnung von Umweltressourcen reduzieren (als Strategie für den Lebensunterhalt). Die Anerkennung und Förderung von SAPs sowohl aus Wohlfahrts- als auch aus Umweltperspektive könnte sich daher lohnen.

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Abbreviations

CA	Conservation Agriculture
FAO	Food and Agricultural Organization
GCA	Ghana Common Country Assessment
GDP	Gross Domestic Products
GFDMP	Ghana Forestry Development Master Plan
GH¢	Ghanaian cedi
GSS	Ghana Statistical Services
MDGs	Minimum Development Goals
MNL	Multinomial Logit Model
MT	Minimum Tillage
NGO	Non-Governmental Organization
SAPs	Sustainable Agricultural Practices
SDGs	Sustainable Development Goals
SRI	System of Rice Intensification
SSA	Sub-Saharan Africa
TLU	Total Livestock Units
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
USD	United States Dollar
WASCAL	West African Science Service Center for Climate Change and Adoptive Land Use

Chapter I

General introduction

1. Introduction

1.1 Background

Despite two decades of unprecedented economic growth, Sub-Sharan Africa (SSA) faces many challenges, including a high prevalence of food insecurity and poverty. This is demonstrated by the fact that about 43% of the people in SSA earn less than $1.9 a day (Manda, 2016; Beegle, et al., 2016). FAO's (2015) report shows that 220 million people on the continent are undernourished (consuming less than 2100 kcal/day), while over 50 million African children suffer from stunting (UNICEF, 2016). In most countries of SSA, agriculture is the mainstay of the economy, but the sector has been threatened by climate change, including increasing weather variability and frequency of extreme events (FAO, 2014). Decreasing soil fertility of smallholder farmers in SSA is also one of the major concerns of environmental problems that cause low agricultural productivity. In the absence of appropriate resource management practices, the conventional farming methods inescapably lead to degradation of the resource base with important implications for soil productivity, household food security, and rural poverty (Kassie et al., 2015). In addition, SSA's growing population, which is now over 1.1 billion (World Population Statistics, 2014), is exacerbating the demand for environmental resources as a form of livelihood strategies such as firewood, wild meat, shelter and land for crop expansion, leading to deforestation and forest degradation.

Like other SSA countries, agriculture in Ghana is one of the most important sectors of the economy and society. Estimates show that 22.6% of the national gross domestic product (GDP) comes from the agricultural sector (MoFA, 2013). Furthermore, it is estimated that over 50% of the working population is engaged directly in agriculture (Government of Ghana 2007, 2010). About 90% of the 2.72 million smallholder farmers own less than two hectares of land. As a result, the country is net deficient in terms of production, covering only 51% of its cereal demand, 60% of fish requirements, 50% of meat demand, and 30% of the raw materials used for agro-based industries (Darfour and Rosentrater, 2016). Future climate change is projected to have significant impacts on Ghana; the trend for temperature over the period 2010–50 indicates warming in all regions. The study area of this thesis, Upper East Region, is among the regions that will experience temperature increases in the near future (The World Bank Group, 2010).

Most development organizations (FAO, IFAD, & WFP 2015) argue that finding appropriate sustainable agricultural intensification technologies is the way forward for more equitable and balanced economic growth and development. To reaffirm the importance of sustainable development, the United Nations (UN) have recently adopted 17 Sustainable Development Goals (SDGs) and 169 targets which balance the three dimensions of sustainable development—economic, social and environmental to build on the Millennium Development Goals (MDGs) and to complete the flaws that have not been addressed by MDGs.

Improving agricultural production is widely regarded as a major objective through which the widespread lack of food security and poverty in Africa can be tackled and even eradicated (Future Agricultures, 2010). Sustainable agricultural practices hold a promise for meeting the rising demand for agricultural output while maintaining the agro-ecological systems (Droppelmann, et al, 2016). While the assurance of the food security of many already vulnerable households in developing countries is a major target in the post-2015 sustainable development agenda, maintaining the natural ecosystem for the future generation also remains critical. In instances where appropriate sustainable agricultural practices (SAPs) are absent, the traditional farming method inevitably leads to degradation in the resource base with important implications for the future deterioration of soil quality, household food insecurity, and rural poverty. The low income from traditional agriculture can also force rural households to seek for alternative livelihood strategies. Among the livelihood strategies is the extraction of natural environmental resources for food, feed, and liquidity requirement, among others. Households may also look for alternative productive areas by clearing grasslands, shrubs and savannah and natural forest areas. The heavy dependence on natural resources could finally lead to overexploitation and biodiversity loss, which in turn, can exacerbate the adverse effect of climate change.

SAPs can be defined as any interventions that are aimed at sustaining or restoring the productive capacity of land to deliver more productivity and income (Teklewold et al., 2013). Practices that are considered SAPs in the literature include, improved crop varieties, complimentary use of organic fertilizers, soil and water conservation structures, cereal-legume diversification, conservation tillage and residue retention. They can address some of the environmental and ecosystem problems through soil carbon sequestration, improving soil fertility, and enhancing crop yields and incomes (Lee, 2005; Woodfine, 2009; Branca et al., 2011; Manda et al., 2015; Teklewold et al., 2013).

1.2 Problem statement and research gap

More than 80% of SSA farmers are smallholders who predominately produce under rain-fed agriculture (AGRA 2014). Smallholder farming plays a significant role in reducing food insecurity and sustainable development in SSA. However, its contribution to sustainable livelihoods has been constrained by extreme weather events, climate change, and variability, deteriorating land productivity and market constraints. It is therefore important to find ways in which smallholder farming in SSA could in a sustainable way contribute towards increasing agricultural productivity while reducing crop variability and climate risks (Tessema, 2015).

Over the past few decades, empirical studies have shown that the negative impacts of climate change can be tackled through the adoption of appropriate technologies and innovations (Kassie et al., 2015; Ngoma, et al., 2015). However, previous studies focuses on the adoption and impact of single agricultural practices (e.g. Abdulahi and Huffman, 2014; Amare et al., 2012; Asfaw et al., 2012; Bezu et al., 2014; Becerril and Abdulai, 2010; Elias et al., 2013; Faltermeier and Abdulai, 2009; Garnett et al., 2013; Kassie et al, 2014; Kassie et al., 2011; Khonje et al., 2015; Mendola, 2007; Minten and Barrett, 2008; Olrinade et al., 2011; Shiferaw et al., 2014; Shiferaw, et al., 2008; Wu et al., 2010). As a result, there is limited empirical research on how smallholder farmers make adaptation decisions in the face of multiple strategies that can be adopted in combinations (Beyene, et al., 2017; Teklewold et al., 2017).

Households adopt multiple technologies because of their synergies to enhance crop output, reduce soil erosion, and reduce the damage from pests and diseases, among others (Teklewold et al., 2013). However, understanding of the joint adoption of a combination of adaptation practices and their economic implications is still quite weak (Di Falco and Veronesi 2013). The previous few kinds of literature on SAPs found that SAPs have generally positive and significant impacts on households' welfare outcomes. In Ethiopia, Teklewold et al., (2013; 2017), Beyene et al., (2017) and Di Falco and Veronesi (2013) have found positive and significant effects on crop yields and incomes. In Malawi, Mutenje et al., (2016), have found positive and significant impacts of SAPs on maize yield and income. Similarly, Manda et al., (2016), reports a positive impact of SAPs on yield and income. Verma, (2017) analysed the adoption and impacts of the system of rice intensification (SRI) technologies in India and reported that all combinations (individually and as a group) of SRI had a positive impact on rice yield. We contribute to the emerging literature by analyzing the adoption and impact of SAPs on households' welfare. Our main contribution is that we investigate the effects of risk preference, which are elicited using an experiment with real payoffs, of households on the adoption and impacts of multiple combinations of SAPs, which has never been addressed in the previous literature.

Households in developing countries have many livelihood strategies such as crop production, animal husbandry, off-farm employment and extraction of environmental resources. For example, a global study by (Angelsen, et al., 2014)[1] shows that environmental income accounts for about 28% of total household income. But, no study has been done on the effects of SAPs on environmental reliance and cropland expansion. While it is known that SAPs have economic (welfare) and biophysical (low footprints in the plots) benefits, they might also have positive or negative effects on the environment; in terms of dependence on natural resources for livelihoods. We, therefore, extend the previous literature by analyzing the effects of SAPs on measures of environmental quality. We test the hypothesis of whether the adoption of SAPs translates into less reliance on environmental resources as a livelihood strategy. This analysis helps us to understand if there are positive or negative 'indirect environmental benefits' of SAPs to the already known biophysical and economic benefits at the farm and household levels.

Previous research also reports SAPs to have a positive impact on farm productivity and welfare (Beyene et al., 2017; Teklewold et al., 2017; Manda et al., 2016; Mutenje et al., 2016; Di Falco and Veronesi, 2013 and Teklewold et al., 2013). This means that SAPs might have a negative or positive effect on the decision and extent of cropland expansion like the general discourse in the wider literature on the relationship between agricultural change and deforestation. On the one hand, higher yield through SAPs means that the same output could be harvested from less land, and should, therefore, reduce the pressure on forests. This is referred to as the Borlaug hypothesis (Angelsen and Kaimowitz, 2001). However, on the other hand, it has been demonstrated (Lambin and Meyfroid, 2011; Angelsen et al., 2001; Rudel et al., 2009) that policies that improve agricultural output could aggravate deforestation. This is because SAPs could make agriculture more attractive in comparison to alternative land uses (such as forestry), thereby encouraging expansion of the agricultural frontier (Strassburg at al., 2014; Villoria et al., 2014; Angelsen et al., 2001). This scenario is known as the Jevons' paradox (Villoria et al., 2014; Rudel et al., 2009; Lambin and Meyfroidt,

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[1] The authors documented that the share of environmental income to total household income varies slightly across regions: 30.1 % in Africa, 22.0% in Asia, and 32.1% in Latin America.

2011) due to its similarity to the situation described by Jevons, who found that an increase in the efficiency of coal utilization leads to an aggregate increase in demand (Alcott 2005). Because the constant output assumption does not hold (Ngoma and Angelsen, 2017) the real effects of SAPs on cropland expansion is indeterminate a priori and the Borlaug-Jevons paradox holds, instead.

Therefore, while contributing to the analysis of SAPs effects on households' welfare, we extend the previous literature by analyzing the effects of SAPs on measures of 'environmental quality' indicators. We test the hypothesis of whether the adoption of SAPs translates into less reliance on environmental resources as a livelihood strategy and also reduces agricultural land expansion into grasslands, shrubs, and natural forest areas. This analysis helps us to understand if there are positive or negative 'indirect environmental benefits' of SAPs to the already known biophysical and economic benefits at the farm and household levels. Therefore, the dissertation addresses the following objectives:

1.3 Objectives of the thesis

Given the problem statement and research gaps mentioned above, this study aims to examine the determinants and welfare impacts of combinations of SAPs on rural households. Furthermore, this study analyses whether SAPs help to reduce reliance on environmental resources as a livelihood strategy and help to reduce cropland expansion into forests. Specifically, the study aims to address the following research questions:

1. What are the determinants of SAPs adoption and what are the impacts of SAPs on households' welfare?
2. Can SAPs reduce reliance on environmental resources as a livelihood strategy?
3. Do SAPs encourage or discourage cropland expansion into forest areas?

1.4 Data and study area

The study was conducted in the Upper East Region of Ghana – one of the West African Science Service Center for Climate Change and Adapted Land Use (WASCAL) project research sites. The region shares boundaries with two regions of Ghana (Northern and Upper West regions), and with two countries (Burkina Faso and Togo). The total population of the region is 1,046,545 in 177,631 households, from which the Male population covers 48.4% (GSS, 2012, 2013). The region covers a total area of 8,842 km^2

from the total 238,533 km^2 area of Ghana. Between the years 2000 and 2010, the region had the lowest population growth rate (13%) as compared to other regions in Ghana. However, it constitutes one of the highest population density (118 people per km^2) areas in the country (GSS, 2012). The region is characterized by high levels of poverty and food insecurity as compared to other regions in Ghana, and the majority of the households (79%) live in rural areas (Tambo, 2015; GSS, 2013). The main source of livelihood for the households is agriculture. As compared to other regions of Ghana, the region has the highest percentage of households (83.5%) who are involved in agricultural activities (Tambo, 2015; GSS, 2013). However, households are also involved in other livelihood strategies such as off-farm income activities (petty trade, temporary employment, and brewing of local drinks), and extraction of environmental resources (shea nut and butter, firewood, charcoal, wild meat, and fruits) and livestock rearing.

1.4.1 Data collection

The details of the data collection process are given in each chapter of the thesis. But in general, the data used in this thesis is from a survey of 421 sampled households conducted between April and July 2015 in the Upper East Region of Ghana. The sampled households were selected via multiple stages. In the first stage, we have identified 7 districts from a total of 13 districts found in the region based on their agricultural performance, SAPs distribution and forest cover. We then randomly selected four districts (Bongo, Bawku West, Kassena Nankana East and Builsa South). The selected districts are shown on the map presented in Figure 1.1 below. From each district, we selected seven communities except for Bongo district, where we have selected six because the numbers of households in each of the community were higher than the others. Finally, households were randomly selected based on the propensity to the size of each community. A survey questionnaire was prepared and administered by trained enumerators who collected the data from households through personal interviews. The survey was designed to collect data on detailed information about the socio-demographic composition of the interviewed households, consumptions of a wide range of food and non-food items by the household, asset and wealth positions of the household, labor allocation and activities of the household members, health status, educational achievements, household income from different livelihood strategies including income from agricultural activities, livestock husbandry, off-farm income and environmental resources income.

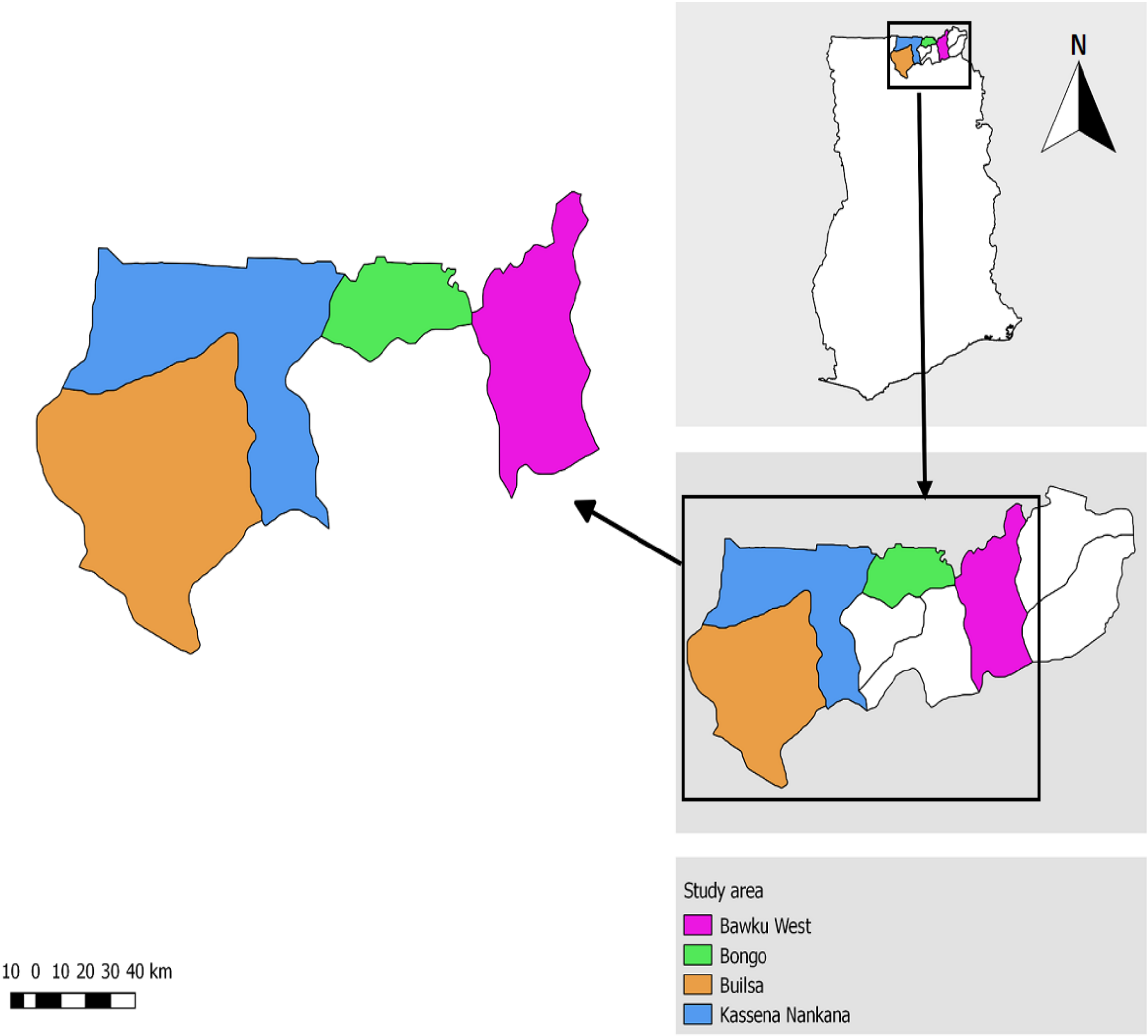

Figure 1. 1 Map of the study districts

1.4.2 SAPs Used in the study

Low crop yields, crop pests, and soil erosion are major factors for food security. Farmers adopt integrated/portfolio of innovations and practices that have complementary benefits to address those challenges. We have considered three[2] of the most common SAPs in this study. The first SAP is improved maize varieties. Agricultural productivity in an era of climate change may be possible if farmers transform agricultural systems via the use of improved crop seeds (Bryan et al., 2011). When appropriately used, modern seeds can

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[2] The reason why we have selected only these three SAPs, which leads to eight possible categories, is because they are the most common in the study area. The model used in the study can allow up to only 10 categories.

enhance crop productivity and help to produce higher crop residues to ensure soil cover under smallholder conditions (Teklewold et al., 2017; Vanlauwe et al., 2014). Improved maize varieties have been one of the core development aspects of African agriculture. Teklewold et al., (2013) indicated that adoption of improved seeds is likely to be an important strategy for adaptation to future climate change, especially when it is combined with other SAPs such as cereal-legume rotation.

The second SAP used in the study is the adoption of soil & water conservation measures. Soil & water conservation measures can improve the health of the soil by conserving moisture, reduce soil erosion and runoff and improve water infiltration into the soil. In the presence of erratic rainfall and prolonged drought, soil & water conservation measures can help to moderate the impact of climate change on agricultural productivity (FAO, 2014). Moreover, in the presence of high intensity of rainfall, soil& water conservation measures can help to reduce the risk of soil erosion, crop damage and flooding which optimizes and diversifies land use according to the terrain, enhances vegetation cover, rainwater capture, and infiltration, and ensures safe discharge of excess runoff water in waterways and low-lying land (FAO, 2014).

The third SAP considered in this study is cereal-legume diversification. Cereal-legume diversification has been proven to deliver many ecosystem services, including soil carbon sequestration, nitrogen fixation, breaking the life cycle of pests, and improving weed suppression (Di Falco et al., 2010; Jhamtani, 2011; Tilman et al., 2002; Woodfine, 2009) while increasing crop yield. Teklewold et al., (2013) further reports that cereal-legume diversification can also reduce the use of chemical fertilizer and pesticides and hence contributes to mitigation of climate change.

In other words, those SAPs can be considered as climate-smart technologies as they help farmers cope with adverse impacts of climate-induced crop failure and also they could help in improving households’ welfare through improving agricultural productivity.

1.5 Conceptual framework

The conceptual framework leading to the synthesis of the thesis is presented below. Figure 1.2 summarizes the adoption and impact pathways through which SAPs affect the welfare of households (presented by crop income per capita and consumption expenditure) and environmental quality indicators (agricultural land expansion and reliance on environmental resources for augmenting livelihoods).

Based on previous literature (e.g. Di Falco and Veronesi, 2013; Teklewold et al., 2013, Manda et al., 2016; Mutenje et al., 2016 and Beyene et al., 2017), we first show how SAPs adoption is conditioned by a group of covariates. The adoption of SAPs is conditioned by household characteristics such as the age of the head, gender of the head, family size and education of the head. Variables related to resource constraint and market access such as asset ownership, TLU, and distance to market are also important determinants of SAPs adoption (Beyene et al., 2017; Teklewold, et al., 2017). Other categories of variables responsible for the adoption and impact of SAPs are also those related institutional and social networks such as whether the household is a member of a farmer group, the number of relatives within and outside of the community etc. Plot-level characteristics such as the slope and fertility level indicators are also included as determinants of SAPs. We have also included risk preference of households as determinants of adoption of SAPs as well as other outcome variables such as cropland expansion into forest areas.

The adoption of SAPs affects household crop production. Increased crop yields play an important role in the generation of household income through direct consumption and the sale of surplus crops. More income translates into less poverty, and less food insecurity. The adoption of SAPs can affect households' resource allocation and the decision to depend on environmental resources. SAPs can also affect the extent of cropland expansion decision of households. The environmental income obtained from the environmental resources collected by the household contributes to the total household income available. SAPs adoption may encourage or discourage cropland expansion. The crop yield obtained from recently cleared lands, if any, contributes to crop yield and total household income. Finally, the effect of SAPs on environmental resources reliance and cropland expansion can be considered as the 'indirect environmental effects' of SAPs.

In summary, the conceptual framework shows the determinants of SAPs. It also shows the potential pathways through which SAPs could affect the welfare and environmental outcomes. Following, this framework, the thesis answers the research questions identified from the problem statement and research gap in the literature.

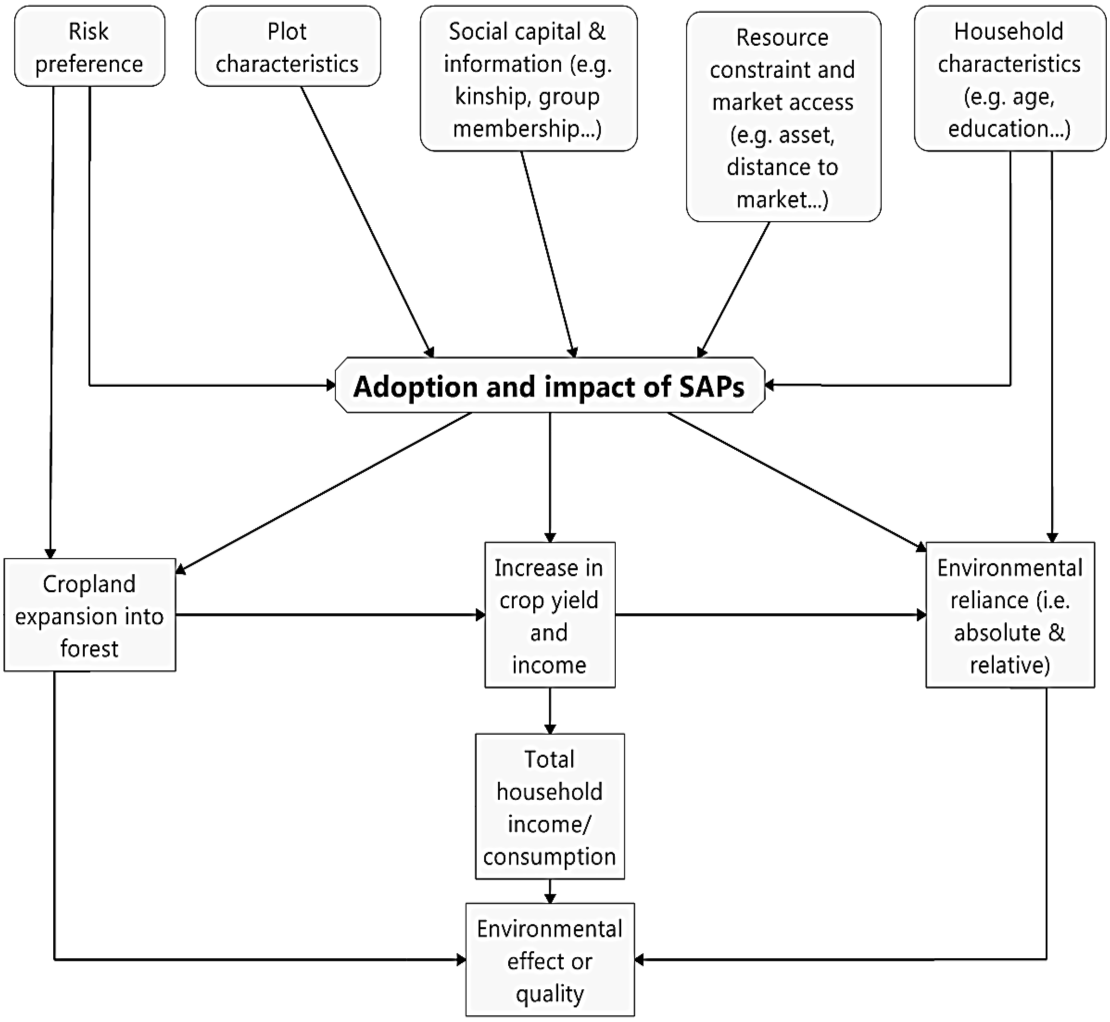

Figure 1. 2 Conceptual framework on the adoption and impacts of SAPs on welfare and environmental outcome indicators

1.6 Overview of the thesis

In the post-2015 sustainable development agenda where the assurance of the food security of many already vulnerable households in developing countries is a target while maintaining the natural ecosystem for the future generation remains critical. In the situation where appropriate sustainable agricultural practices are absent; the traditional farming method inevitably leads to degradation in the resource base with important implications for the future deterioration of soil quality, household food insecurity, and rural poverty. The low income from traditional agriculture can also force rural households to seek for alternative livelihood strategies for their survival. Among the livelihood strategies is the extraction of natural environmental resources for food, feed, and liquidity requirement. The heavy dependence on environmental resources would finally lead to overexploitation and biodiversity loss, which in turn, would exacerbate the adverse effect of climate change. Concern over the environmental quality deterioration due to the traditional agricultural systems led many government and non-governmental organizations to encourage a wide range of sustainable agricultural practices (Teklewold et al., 2013; Pretty and Bharucha, 2014 and Beyene, et al., 2017). In this thesis, we have presented the welfare and environmental effects of SAPs. The general overview of the thesis is presented below.

The second chapter, titled, 'Combining Sustainable Agricultural Practices (SAPs) pays off: Evidence on Welfare Effects from Northern Ghana', contributes to the growing but yet few empirical works on sustainable agriculture and welfare effects of SAPs to households'. We applied a multinomial treatment effect model that allows assessing the joint probabilities of Adoption of SAPs. We used the most commonly applied three SAPs i.e., improved maize varieties, cereal-legume diversification, and soil & water conservation. We included a risk preference indicator in the adoption and impact evaluation of SAPs as a departure from the existing literature on the welfare effects of SAPs. Our findings show that SAPs adoption is determined by household characteristics, resource constraint and market access, social capital and information, plot level and risk preference covariates. We find that SAPs have positive and significant effects on crop level income and household consumption expenditure. Higher results are obtained when SAPs are adopted in combinations than in isolations.

The third chapter, titled "Sustainable Agricultural Practices (SAPs) and Environmental Resources Extraction: Empirical Evidence from Northern Ghana", analyses the effect of

SAPs on environmental resources reliance. We defined an environmental resource following (Sjaastad et al., 2005; Angelsen et al., 2014 and Lopez-Feldman & Chavez, 2016) as an income that comes from wild or uncultivated natural resources and therefore, their stock determined is not as a result of the human productive process. We first identify the environmental resources collected in the communities via focus group discussion with the households and forestry experts from the Ghana Forestry Commission. We then carefully collect the amount of each environmental product harvested in a year by the respective household. We measure environmental income both in absolute and relative terms. Absolute environmental income per capita is calculated by dividing the total environmental income collected in a year by the adult equivalent of the household. Relative environmental income is calculated by dividing the total environmental income by the total household income. Our findings show that, on average, environmental income contributes around 30% of the total household income among the households. This share of environmental income to total household income ranges between 15% and 40% among the households categorized by their SAPs adoption status. SAPs significantly reduce absolute environmental reliance between 9 to 14%. Similarly, SAPs reduce relative environmental reliance between 21 and 72%. SAPs reduce environmental reliance more when they are adopted in combinations than in isolation due to their synergistic effects.

The fourth chapter titled “Do SAPs encourage agricultural land expansion into forest areas? Empirical evidence from Northern Ghana”, estimates the effects of SAPs on cropland expansion into forests. We used a two-stage churdel double hurdle model to account for observed and unobserved heterogeneities when estimating the impact of SAPs on cropland expansion. We find no significant effects of SAPs on cropland expansion. Cropland expansion is rather affected by other variables such as shadow wage, having a relative in a leadership position, experience of crop failure prior to the current season etc.

The fifth chapter concludes the study and discuss the main findings of this thesis, including a critical review of the findings, limitations of the study and offer recommendations for future research.

Chapter 2

Combining Sustainable Agricultural Practices Pays Off: Evidence on Welfare Effects from Northern Ghana

Gebrelibanos Gebremariam[1] and Tobias Wünscher[1,2]

[1] Center for development research (ZEF), University of Bonn

[2] EARTH University, San José, Costa Rica.

Abstract

Sustainable Agricultural Practices (SAPs) are believed to play a vital role in addressing adverse effects of climate change and improving households' welfare. While literature provides robust evidence on their welfare impacts in isolation, there is limited evidence on how combinations of SAPs contribute to households' welfare. Due to complementarity and substitution effects and cost involved in adopting SAPs, combinations may have impacts that are higher or lower than individual effects. To shed light on this question, we investigate the adoption and impacts of SAPs on net crop income per acre and consumption expenditure per capita using a cross-sectional survey of 421 household and 1229 plots from northern Ghana. A maximum simulated likelihood estimation of a Multinomial Endogenous Treatment Effect Model was used to account for observable and unobservable heterogeneity that influences SAPs adoption decisions and the outcome variables. As a departure from existing studies, our paper incorporated the effects of individual risk preferences, quantified using an experimental game with real payoffs, on the adoption and impacts of SAPs. The results reveal that adoption decisions are affected by household and plot level characteristics including risk preferences of households. The results show that adoptions of SAPs significantly increase net crop income and consumption expenditure. The results show that SAPs have a stronger effect on plot income and consumption expenditure when adopted as a full package (all together) rather than in isolation or in subgroups. Policy implications to be derived from this study are that promoting adoption of integrated SAPs and improving access to SAP inputs could yield beneficial welfare and productivity effects in the face of climate change.

Keywords: Net crop income; Consumption Expenditure; SAPs, Multinomial Endogenous Treatment Effect, Ghana

JEL Classification: O13, Q1, Q12, Q16

2.1 Introduction

Feeding a surging population which is expected to double by 2050 (close to 2 billion) becomes a major agricultural research, development and policy challenge in Sub-Saharan Africa (SSA) (FAO, 2006). Improving agricultural production is widely regarded as a major objective through which the widespread lack of food security and poverty in SSA can be tackled (Future Agricultures, 2010). In effect, much emphasis has been placed on how to transform the stagnant and low performing African agriculture into a more productive and dynamic sector. Previous studies in SSA have recommended the use of improved technologies such as improved seeds, pesticides, and chemical fertilizer as a means of transforming the region's agriculture to improve the welfare of rural households (e.g. Amare et al., 2012; Asfaw et al., 2012; Bezu et al., 2014; Faltermeier and Abdulai, 2009; Garnett et al. 2013; Kassie et al., 2014; Minten and Barrett, 2008; Ricker-Gilbert and Jones, 2015; Shiferaw et al., 2014; Tilman et al., 2002; Vanlauwe et al., 2014). However, emphasis should also be given to the protection of natural resources and ecosystems that play a vital role in environmental regulation and mitigating the adverse effects of climate change (Pingali, 2012; Tambo and Abdoulaye, 2012). In fact, the literature points out that many ecosystem services such as nitrogen fixation, nutrient cycling, soil regeneration, and biological control of pests and weeds are already under threat in key SSA food production systems (Jhamtani, 2011; Lee, 2005; Pretty, 1999; Teklewold et al., 2013; Woodfine, 2009). Given adverse effects of climate change, crop intensification through continued use of only high-input technologies is riskier for SSA farmers who largely depend on rain-fed systems (Hillocks, 2014). Therefore, a paradigm shift from the old system of improving agricultural production to a sustainable agricultural practice system is essential to achieve the intended welfare objectives and addressing adverse effects of climate change (Brooks and Loevinsohn, 2011; Lybbert and Sumner, 2012; Juma et al., 2013; Pretty et al., 2011; Pretty et al., 1996; Ringler et al., 2014; The Montpellier Panel, 2013). Sustainable Agricultural Practices (SAPs) are believed to play this vital role by increasing households' welfare with little impact on the environment, and biodiversity losses of ecosystems.

SAPs which include improved crop varieties, complementary use of organic fertilisers, soil and water conservation structures, cereal-legume diversification[3], conservation tillage and residue retention, can address some of the environmental and ecosystem problems through

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[3] In this study Cereal-legume diversification refers to cereal-legume intercropping or cereal-legume rotation applied at household and plot level

sequestering soil carbon, improving soil fertility, and enhancing crop yields and incomes (Lee, 2005; Woodfine, 2009; Branca et al., 2011; Manda et al., 2015; Teklewold et al., 2013). In other words, those SAPs can be considered as climate-smart technologies as they help farmers cope with adverse impacts of climate-induced crop failure and help in improving households' welfare through improving agricultural productivity.

This study focus on three SAPs: modern maize varieties, cereal-legume diversification, and soil & water conservation structures. Improved varieties (e.g. maize varieties) have been one of the core development aspects of African agriculture. Teklewold et al., (2013) indicated that adoption of improved seeds is likely to be an important strategy for adaptation to future climate change, especially when it is combined with other SAPs such as cereal-legume rotation. Cereal-legume diversification has been proven to deliver many ecosystem services, including soil carbon sequestration, nitrogen fixation and breaking the life cycle of pests, improving weed suppression (Di Falco et al., 2010; Jhamtani, 2011; Tilman et al., 2002; Woodfine, 2009) while increasing crop yield. Teklewold et al., (2013) further reports that cereal-legume diversification can also reduce the use of chemical fertilizer and pesticides and hence contributes to mitigation of climate change. Adoption of soil & water conservation structures is another important aspect of SAPs especially in areas where there is low distribution of rainfall as it can help to increase soil moisture and reduce soil erosion. A review of empirical studies shows that farmers tend to take-up a single practice or a combination of those agricultural practices due to the complementary and substitutive nature of SAPs.

There is a long established literature on the adoption of different single agricultural technologies and their impact on rural household's welfare. Previous empirical studies (e.g. Abdulahi and Huffman, 2014; Amare et al., 2012; Asfaw et al., 2012; Bezu et al., 2014; Becerril and Abdulai, 2010; Elias et al., 2013; Faltermeier and Abdulai, 2009; Garnett et al., 2013; Kassie et al, 2014; Kassie et al., 2011; Khonje et al., 2015; Mendola, 2007; Minten and Barrett, 2008; Olrinade et al., 2011; Shiferaw et al., 2014; Shiferaw et al., 2008; Wu et al., 2010) have estimated the adoption and impact of single agricultural technologies on household welfare, as measured by outcomes such as productivity, household income and food security. However, despite the potential complementarity or substitution among individual or combination of SAPs, very few studies have analyzed the simultaneous adoption and impacts of SAPs on smallholder farmer's welfare. To the best of our knowledge, the only studies known to have analysed the adoption and impacts of individual and different combinations of SAPs on households' welfare are those by Teklewold et al., (2013) in Ethiopia, Kassie et al., (2014) and Mutenje et al., (2016) in Malawi and Manda et al., (2015) in Zambia. However, Ghana might have different ecological setup and agricultural policies compared to Ethiopia, Malawi or Zambia, hence the adoption and impacts of SAPs could be different in the Ghanaian context. We also included soil & water conservation structure as one part of the SAPs groups as very little empirical evidence exists on the effects of soil & water conservation structure (especially when it is combined with other SAPs such as improved maize seed varieties and cereal-legume rotation/intercropping) on households' welfare.

Therefore, while this paper contributes to the limited but emerging literature on the adoption and impacts of different packages of SAPs in SSA, this chapter makes two substantive contributions. Our first contribution is the investigation of the impacts of SAPs on net crop income and consumption expenditure. The previous few studies (Manda et al., 2015; Mutenje et al., 2016; Teklewold et al., 2013) have used either maize yield or maize income per area and household income as indicators of welfare outcomes, showing that their main interest was only on maize plots ignoring plots which are covered by other crops. But this could under- or overestimate the true impacts of SAPs for the following reasons: Firstly, SAPs such as soil & water conservation and cereal-legume diversification may bring benefits to other crops including maize, which could not be captured by considering only maize yield or maize income. Secondly, a recent bioeconomic study from Ethiopia on conservation agriculture (Tessema et al., 2015) indicated that higher maize yield could be obtained under the maize-legume diversification SAP but this yield gain in maize yields comes at the expense of reduced legume yields in every consecutive season to come. This shows that focusing solely on maize yield per area or maize income might again mislead the true effects of SAPs on households' welfare. To address these deficiencies, this study estimates net crop income per acre as a measure of welfare outcome for the plot level analysis. We valued all crops that have been grown on a plot using market prices and deducted the variable costs of production. We have considered all plots owned by the sampled households in our analysis. This is important, especially in study areas comparable to ours, where other crops such as sorghum and millet play a role as important as maize, and farmers apply different SAPs. We also took consumption expenditure per capita instead of income per capita as the former is less susceptible to errors. To the best of our knowledge, no attempt has been made so far to look at the combined effects of SAPs on consumption expenditure.

Furthermore, we have also contributed to the literature by including a measure of the risk preferences of sampled households as a determinant of adoption of SAPs. We accounted for households' subjective risk preferences[4] using the Ordered Lottery Selection design with real payoffs (Harrison and Rutström 2008). Previous studies (Binswanger 1980, 1981; Wik and Holden, 1998; Yesuf and Bluffstone, 2009) suggest that rural households in developing countries are generally risk-averse. Despite this fact, however, very few studies have attempted to address the effect of risk preferences on adoption of agricultural innovations in general and SAPs in particular. In addition, this paper employs detailed plot level and household data which enables us to build a quasi-panel data set to partly control for endogeneity and selection bias which might arise due to the correlation of unobservable heterogeneities and observed explanatory variables.

The objective of this chapter is therefore to identify the determinants and impacts of SAPs on rural households' welfare measured in net crop income per acre and consumption expenditure per capita. To address this objective, we specifically answer two questions: What are the determinants of adoption of single and combined[5] SAPs and what is the adoption's impact on net crop income per acre and consumption expenditure per capita? Further, what are the SAPs packages that yield the highest welfare effects? We have applied a maximum simulated likelihood estimation of a multinomial endogenous treatment effect model (METEM) to account for observable and unobservable heterogeneity to address our objective. We find that generally, SAPs increase rural households' welfare and payoffs are higher when combinations of SAPs are adopted both at the household and plot level, except when soil and & water conservation is adopted in isolation.

The chapter proceeds as follows: The next section outlines the data used and its source. The conceptual framework, model specification and estimation strategy applied in the study are presented in section three. Section four presents the descriptive statistics of the variables. Results and the discussion are presented in section five. The last section concludes.

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[4] We quantify the risk preference of households by playing a lottery game with real payoffs where a player could get from 0 up to maximum 8 Ghana Cedis (2$) as a reward. The experimental approach we have used is discussed further in section 2

[5] We use the terms 'combination' and 'packages' interchangeably in this paper

2.2 Study area, data and sampling procedure

Our data comes from a survey of 421 farm households and 1229 plots conducted between April and July of 2015 in the Upper East Region of Ghana. Our study is part of the WASCAL project currently running since 2010 in collaboration with the Center for Development Research (ZEF), University of Bonn and partners in ten West African countries.

The survey was conducted in four districts (Bongo, Bawku West, Kassena Nankana East and Builsa South) of the Upper East Region of Ghana. The region is characterized by low income and is among the most vulnerable regions of Ghana to adverse effects of climate change. An extensive household survey was administered by trained enumerators who had knowledge of the local languages and had an earlier experience in data collection through direct interviews. Community-level data was also collected.

Stratified random sampling was used to select our sampled households. At first stage seven of the thirteen districts of the Upper East Region were identified based on their intensities of SAP use (specifically improved maize). From the seven identified districts, four districts were randomly selected. In the second stage, seven[6] communities were randomly selected from each district. Finally, farm households were randomly selected from each selected community, with the number of households selected from each community being proportional to the size of the community.

In addition to the socio-demographic household characteristics[7] (e.g highest education attained, age, gender, and family size) we have also collected plot level data which includes land tenure of each plot, the distance of plot from the homestead, fertility level of plot, the size of plot and slope of the plot. This allows us to estimate the Mundlak fixed effects using the mean value of plot-varying explanatory variables to, in part, control for unobserved heterogeneity that may be correlated with observed explanatory variables. Data on expenditure, environmental based income, crop yields and the use of SAP's such as improved maize varieties, cereal-legume intercropping and or diversification and soil & water conservation structure were collected.

We have also collected data on risk preference of households. In this study, we follow the experimental design developed by Binswanger (1980) and applied recently by (Bezabih and

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[6] Six communities were selected from the Bongo districts because the districts has bigger population than the others.

[7] Variables used in the model and their definitions are presented in Table 8-1 in the appendix.

Sarr, 2012; Teklewold and Köhlin, 2011; Yesuf and Bluffstone, 2009) to unearth the risk preference of rural households. We developed an experiment which reflects actual farming decisions through predetermined choices approach by observing the reactions of farmers to a set of actual gambles in one period game. In our experimental game, respondents were presented with six certain realistic lotteries of the form (maximum payoff, minimum payoff, P), promising a monetary prize for maximum payoff with probability P, or minimum payoff with probability (1 – P). For each alternative from A to F, the expected gain and spread increased (Table 2.1)[8]. Once they had selected one of the six categories, a coin was tossed to determine the actual payment which has a 50% probability of getting either the maximum or minimum payoffs.

Table 2. 1Choice sets for the risk preference experiment

Choice	Maximum payoff (GH¢)*	Minimum payoff (GH¢)	Expected gain (E)	Spread	Risk-Aversion category
A	3	3	3	0	Extreme
B	4	2.5	3.25	1.5	Severe
C	5	2	3.5	3	Intermediate
D	6	1.5	3.75	4.5	Moderate
E	7	1	4	6	Slight
F	8	0	4	8	Neutral

*GH¢= Ghanian currency (Cedi). 1$=3.66 GH¢

The choice of an alternative from the choices classifies respondents into a risk aversion class (Binswanger, 1980). As can be seen in Table 2-1, the experiment consisted of offering farmers a set of alternatives where higher expected gain could only be obtained at the cost of higher variance—thus a decline in risk aversion. Basically, individuals are considered as risk-averse when they chose a certain outcome with a lower payoff instead of an uncertain outcome with a higher expected payoff. On the other hand, the risk-seeking behavior occurs when individuals consistently choose an alternative with an uncertain payoff with a higher payoff value (Bezabih and Sarr, 2012; Teklewold and Köhlin, 2011). For example, choice A is a safe alternative where respondents could earn GH¢ 3, with both a maximum or minimum payoff and the payment can be offered without tossing the coin. In alternative D, a coin was tossed, and the respondent received GH¢ 6 if the coin showed heads and GH¢ 1.5 if the coin showed tails. Compared to choice A, the individual's expected gain now increased by GH¢ 0.75, but if tail (minimum payoff) turned up, it would reduce the return by

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[8] To make the experiment simpler and understandable to our respondents, we present a figure version of the table which contains a picture of the minimum and maximum payoffs of the award in each choice.

GH¢ 1.5. In the meantime, the spread in gain increased from GH¢ 0 to GH¢ 4.5. Therefore, with such uncertainty in gains, choice D involves more risk than the previous choices (choices A, B, and C). As can be seen in Table 2-1, the extreme risk aversion category represents households who are willing to take the smallest spread in gains and losses, followed by severe, moderate, intermediate, and slight risk aversion categories, while the neutral risk aversion category corresponds to respondents willing to take the biggest spread in gains and losses. We measure the risk aversion behavior by generating a set of six dummy variables each representing the various categories of risk aversion revealed by the experiment.

As explained in the introduction of this chapter, the study considered improved maize varieties (V), cereal-legume diversification (D) and soil & water conservation (C) as components of SAPs in this study. This results in eight possible combinations of SAPs which are, improved maize seed varieties only ($V_1C_0D_0$) , soil & water conservation only ($V_0C_1D_0$), cereal-legumes diversification only ($V_0C_0D_1$), improved maize varieties and soil & water conservation only ($V_1C_1D_0$), soil & water conservation and cereal-legume diversification only ($V_0C_1D_1$), improved maize varieties and cereal-legume diversification only ($V_1C_0D_1$), improved maize varieties, soil & water conservation and cereal-legume diversification ($V_1C_1D_1$) and finally the base category which constitutes none of the three SAPs ($V_0C_0D_0$). But we find that the improved maize varieties and soil & water conservation only ($V_1C_1D_0$) SAP have been adopted by only nine plots and eight households. This shows that we have got too few observations in this category such that treating it separately would make the model not to converge due to the negative degrees of freedom. Hence, we have combined[9] this category with the soil & water conservation and cereal-legume diversification only ($V_1C_1D_0$) category, which leads us to have seven SAPs categories. The distribution of SAPs over plots and households[10] are presented in Table 2.2 below.

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[9] This method of combining different packages in the case of few observation in certain packages have been used in the literature. For example, see Mutenje, et al., 2016 and Di Falco and Verona, 2013

[10] We consider household as an adopter if the household adopts at least in one of his plots

Table 2. 2Distribution of SAPs packages on plot and household level

SAP Categories	HH freq	Per(%)	Cum.	Plot freq	Per(%)	Cum.
$V_0C_0D_0$	96	22.8	22.8	474	38.57	38.57
$V_1C_0D_0$	42	9.98	32.78	73	5.94	44.51
$V_0C_1D_0$	31	7.36	40.14	68	5.53	50.04
$V_0C_0D_1$	102	24.23	64.37	416	33.85	83.89
$V_1C_1D_0$ & $V_0C_1D_1$	40	9.5	73.87	86	7	90.89
$V_1C_0D_1$	51	12.11	85.99	72	5.86	96.75
$V_1C_1D_1$	59	14.01	100	40	3.25	100
Total	**421**	**100**		**1229**	**100**	

Table 2.2 above shows that 22.8 % of households and 38.57% of plots did not adopt any of the three SAPs. Cereal-legume diversification is the most common SAP practiced by households in the Upper East Region of Ghana, being practiced by 24.23% of households and in 33.85% plots. The most comprehensive package ($V_1C_1D_1$) is adopted by 14.01% of households but this package is employed in only 3.23% of the 1229 plots.

We have presented the crop income, cost of fertilizer used and the different forms of labor used per acre by the household in Table 2.3. As can be seen in Table 2.2 the average crop income is estimated to be about 380 GH¢ for the plots that did not adopt any of the SAPs. The results in Table 2.2 show that, in general, adopters of the SAPs have higher level of crop income than the non-adopter with a high level of statistical significance. For example, households that have adopted all the three SAPs in their plot gained about 780 GH¢ per acre and it is significant at less than 1% level.

Table 2. 3 Crop income, fertilizer cost and labor allocation

	$V_0C_0D_0$	$V_1C_0D_0$	$V_0C_1D_0$	$V_0C_0D_1$	$V_1C_1D_0$/ $V_1C_0D_1$	$V_1C_0D_1$	$V_1C_1D_1$
Crop Income	308.5	631.6***	426.3**	443.1***	434.6***	627.8***	780.1***
Fertilizer cost	19.05	104.6***	49.8***	26.37	59.17***	163***	76.07***
Labor							
Male labor	26.68	19.77*	32.10*	24.54	17.56**	25.48	19.11*
Women labor	23	16.79**	27.13	19.08**	15.68**	18.7*	15.25**
Child labor	21.33	9.46	15.25	11.18	8.13	12.91	9.3

Sample size is 1229 plots. ***, ** &* represents significance level at less than 1%, 5% and 10% respectively.

Table 2.3 also shows that SAP adopters spend more on fertilizers than non-adopters. On average, households who adopted improved maize varieties spent about 105 GH¢ per acre, while the non-adopters spent around 19 GH¢. In general, the results indicated that SAPs groups that involve improved maize varieties have spent more on fertilizers. This could be due to the fact that improved maize varieties are mostly distributed with fertilizers.

We have calculated the number of labor days employed of male, female, and child labor of the household per acre. The result shows that the non-adopters group supplied around 27 male labor days per acre. The group of households who adopted improved maize varieties spent about 20 male labor days per acre and it is significant at less than 10% level. Soil and water conservation adopters employed the highest male labor (around 32 man days) than any other groups of SAPs. This is not surprizing because construction and maintenance of soil and water conservation demand labor. Regarding allocation of women labor, it is found that all the SAP categories allocated fewer women labor except the soil & water conservation group, which is not statistically significant. We did not find a significant difference in the allocation of child labor among the SAP categories.

2.3 Conceptual and econometric framework

2.3.1 Conceptual framework

This study adopts a theoretical framework of (Singh, et al., 1986), a neoclassical model of agricultural household production and consumption in a typical developing country context where factor markets are either absent or ill-functioning. The model integrates the decisions about sustainable agricultural practices to implement, crop combinations and varieties to grow, the amount of land to allocate to each crop, and available labor to allocate into different activities in a single framework (Becker, 1965; Sadoulet and de Janvry, 1995). Production and consumption are interacted due to imperfect input and output markets, which implies that rural households act as producers and consumers of goods and services with the objective of maximizing expected utility. For example, market imperfection influence labor allocation into different activities and hence labor allocation decision is likely to be endogenously determined by the shadow wage rate rather than the market equilibrium wage rate. Furthermore, imperfect access to credit limits households to depend on only their savings and already accumulated capital. This precludes smallholder households from investing in capital-intensive SAPs (Mutenje et al., 2016). Market imperfections, information asymmetry, compounded with high transaction costs could also force farmers to be subsistence oriented instead of market-oriented (Barrett, 2008). Furthermore, market imperfections could limit the implementation of SAPs such as cereal-legume diversification in a mixed crop-livestock farming systems as it might fail to provide sufficient feed for livestock as compared to the scenario where only cereal production is implemented (Tessema et al., 2016). In such circumstances, a non-separable household model that partially or fully incorporate input and output market imperfections are suitable for modelling household decisions and resource allocations.

Following (Fernandez-Cornejo et al., 2005; Weersink et al., 1998), utility (*U*), depends on the consumption of purchased goods (*G*) and leisure (*L*), subject to exogenous factors such as human capital (H) and other household characteristics (Z_h). Thus:

$$Max U(G, L; H, Z_h) \tag{2.1}$$

The utility is maximized subject to

Time constraint: $T = L_f(d_j) + L_e + L, L_e \geq 0$ (2.2)

Production Constraint: $Q = Q\lfloor X(d_j), L_f(d_j), H, d_j, R \rfloor, d_j \geq 0$ (2.3)

Income Constraint: $P_g G = P_q Q - W_x X + W_e L_e + A$ (2.4)

The farm household's utility function is subjected to three constraints. The first constraint relates to household labor decisions into, leisure (*L*), working on the farm (L_f), or off-farm work (L_e) which cannot exceed the total households' time endowment (T). The second constraint is a convex continuous production function, assuming that the quantity of crops produced (Q) depends on, farm inputs(X), family labour deployed in agricultural production process (L_a), human capital (H), the choice of SAP adopted (d_j) and a vector of exogenous factors that shift the production function (*R*). *X* and L_f are functions of d_j since some of the SAPs directly affect the input or labor demand of farm households. For example, soil & water conservation affects the labor supply of the farm household as some amount of labor is needed when soil & water conservation structure is constructed or repaired. The choice of SAP adopted (d_j) in turn is determined by households' experience of shocks (S), social capital (S_c), household assets (Ö), plot level characteristics (P_l), risk preference (RP), H, and Z_h. Thus:

$$d_j = (S, S_c, \ddot{o}, P_l, RP, H, Z_h) \tag{2.5}$$

Equation 2.4 depicts the final constraint, where, the household has a standard budget constraint such that the total household expenditure (price of purchased goods (Pg) times quantity of purchased goods) is expected to be less than or equal to the net income from agriculture, off-farm income (wage rate (W_e) times (L_e)-total off-farm labour supplied by the household) and other income sources such as remittances and pension (A).

Substituting equation 3 into equation 4 yields a farm technology-constrained measure of household income:

$$P_g G = P_q Q\lfloor X(d_j), L_f(d_j), H, d_j, R\rfloor - W_x X + W_e L_e + A \tag{2.6}$$

The Kuhn-Tucker first-order conditions can be obtained by maximising the Lagrangian expression (ℓ)over (*G, L*) and minimising it over (*λ, η*):

$$\begin{aligned} \ell = {} & U(G, L; H, Z_h) \\ & + \lambda\{P_q Q[X(d_j), L_f(d_j), H, d_j, R] - W_x X + W_e L_e + A - P_g G\} \\ & + \eta[T - L_f(d_j) - L_e - L] \end{aligned} \tag{2.7}$$

Where λ and η represent the Lagrange multipliers for the marginal utility of income and time, respectively.

Following Tambo and Wünscher, (2014) and Fernandez-Cornejo et al., (2005) solving the Kuhn-Tucker conditions leads to a reduced-form expression of the optimal level of household income (*Y**). This is specified as:

$$Y^* = Y(d_j, W_x, P_q, P_g, A, H, T, R, Z_h) \tag{2.8}$$

and household demand for consumption goods (G) can be expressed as:

$$G = G(d_j, W_e, P_g, Y^*, H, T, Z_h) \tag{2.9}$$

Thus, the reduced forms of Y* and G are influenced by a set of explanatory variables, including d_j. Equation 2.8 and 2.9 motivates the econometrics procedure outlined in the next section since the choice of SAP is a result of optimal household decision making. The main objective of this chapter is, therefore, to estimate the effect of d_j on net crop income per acre and consumption expenditure per capita.

2.3.2 Empirical Model

Several components of agricultural innovations are usually introduced in packages (Manda et al., 2015). The technologies could be substitutes or complements, and their use and adoption depend on household-specific observed and unobserved characteristics. Farmers may adopt combinations of technologies in response to agricultural constraints such as drought, weeds, pest, and diseases.

Farmers' decision to adopt one of the above-mentioned SAPs in a single plot or at the household level is voluntary (self-selection). This implies that farm households who adopt a specific SAP may have systematically different characteristics from those households that did not adopt or adopted a different SAP package; because farm households that adopt a particular SAP are not a random sample of the population (as our study is not based on a controlled experiment but an observational study). Therefore, the adoption decision of SAPs is likely to be influenced by variables which are unobservable or impossible to quantify using standard household surveys (such as managerial skills and motivation) and these unobservable could be correlated with the outcome variable of interest (net crop income and consumption expenditure).

This necessitates a selection correction estimation method. In response, we apply maximum simulated likelihood estimation of a multinomial endogenous treatment effect model proposed by Deb and Trivedi (2006a,b) to account for observed and unobserved heterogeneity. In the first stage, the adoption decision of SAP packages is analyzed using a mixed multinomial logit selection model. In the second stage, the impact of each SAPs on the outcome variables is estimated using ordinary least square (OLS) with selectivity correction terms.

2.3.3 Multinomial Endogenous Treatment Effect Model

The multinomial endogenous treatment effect model consists of two steps. In the first stage, a farmer chooses one of the eight possible combinations of SAPs in a given plot or at the household level. Following Deb and Trivedi (2006a,b), let V_{ij}^{*} be the latent variable that captures the expected net crop income per acre or consumption expenditure per capita from adopting SAP packages j (j=0,1….J) instead of implementing any other strategy k. We specify the latent variable as

$$V_{ij}^{*} = z_i^{'}\alpha_j + \sum_{k=1}^{J} \delta_{jk} l_{ik} + \eta_{ij} \tag{2.10}$$

Where z_i is a vector of exogenous socio-economic, social capital, risk aversion and plot-level covariates that affect the decision to adopt a specific SAP package and the outcome of interest, α_j is the vector of corresponding parameters to be estimated; η_{ij} are the independently and identically distributed error terms; l_{ik} is the latent factor that incorporates the unobserved characteristics common to the households implementation of SAPs and the outcome variables (Net crop income per acre and annual expenditure per capita), such as the technical abilities of the farmer in examining new technologies, imperfect rural labor market structure, information asymmetry and/or high transaction cost incurred (Mutenje et al., 2016; Manda et al., 2015; Abdulai and Huffman, 2014; Pender and Kerr, 1998). Following Deb and Trivedi (2006b), let j=0 represent non-adopters of any of the SAPs in a plot or at the household level and $V_{i0}^{*} = 0$. While V_{ij}^{*} is not observed, one can observe the choices of SAP packages in the form of a set of binary variables and these are collected by a vector, $d_i = d_{i1}, d_{i2}, d_{i3} \ldots\ldots\ldots\ldots d_{iJ.}$ Similarly, let $l_i = l_{i1}, l_{i2}, l_{i3} \ldots., l_{iJ.}$ Then the probability of treatment can be written as:

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

(2.11)

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

$$\Pr(d_i|z_i,l_i)=\frac{\exp(z_i^{\prime}\alpha_j+\delta_j l_{ij})}{1+\sum_{k=1}^{J}\exp(z_i^{\prime}\alpha_k+\delta_k l_{ik})} \tag{2.12}$$

In the second stage, we investigate the impact of adopting the SAPs packages on two outcome variables: the natural logarithm of net crop income per acre and total household consumption expenditure per capita. The expected outcome equation is formulated as follows:

$$E(y_i|d_i,x_i,l_i)=x_i^{\prime}\beta+\sum_{j=1}^{J}\gamma_j d_{ij}+\sum_{j=1}^{J}\lambda_j l_{ij} \tag{2.13}$$

In the above equation y_i is the welfare outcome measures, net crop income per acre and consumption expenditure per capita, for a household i; x_i represents exogenous covariates with parameter vectors β. Parameters γ_j represent the treatment effects relative to the non-adopters. Specifically, coefficients γ_j indicate the impacts of SAPs on the welfare of farm households. Since $E(y_i|d_i,x_i,l_i)$ is a function of the latent factors l_{ij}, the outcome variables are affected by unobserved characteristics that potentially affect the selection of treatments. It is also important to note that when the factor-loading parameters (λ_j), is positive (negative), treatment and outcome are positively (negatively) correlated with unobservable characteristic, i.e there is positive (negative) selection, with γ and λ, the associated parameter vectors, respectively (Manda, et al., 2015). Because our outcome variables are continuous, we follow a normal (Gaussian) distribution function. The model was estimated using Maximum Simulated Likelihood (MSL) method[11].

Parameters of the fitted model can be identified even when an exclusion restriction variable is not included in the treatment equation. But Deb and Trivedi (2006a) recommend the use of at least one exclusion restriction or instrumental variable for a more robust identification. Previous studies indicated that (Manda et al., 2015; Teklewold et al., 2013; Di Falco et al., 2011), getting a valid instrument is theoretically and empirically challenging. We used previous information or training about SAPs as an instrumental variable. Our instrumental variable is a binary variable which takes one if a sampled household had

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[11] We have estimated the model using the Stata command known as *mtreatreg* which is an extension of the *treatreg* Stata command of a multinomial approach by Deb (2009). 100 simulation draws were used.

information or prior training about SAPs in a demonstrations plots and zero if no information or training on SAPs was obtained. Though in most cases the primary sources of information are usually through government extension agents, demonstration plots are also important sources of information on SAPs (Manda, et al., 2015). In addition, in our study area, there have been training programs for households through demonstration in the past. For example, the Root and Tuber Improvement and Marketing Programme (RTIMP) of the Farmers Field Fora (FFF) where giving training for farmers about best practices in agriculture. Information or previous training about SAPs is likely to enhance SAPs adoption but is unlikely to have any direct effects on net crop income per acre or household consumption per capita unless through the adoption of SAPs for the adopter sub-sample households. Previous studies in Africa have proven that information or training about SAPs can be used as a valid instrumental variable (e.g. Di Falco et al., 2011; Di Falco and Veronesi, 2012; Manda et al., 2015).

Following Di Falco *et al.,* (2011) we conducted the admissibility test of the instrument by performing a simple falsification test. According to this test, a variable is a valid instrumental variable if it affects the decision of adopting SAPs equations but will not affect the outcome variables among the non-adopting sub-samples (Di Falco et al, 2011; Di Falco and Veronesi, 2013). Results show that (Table 2.4 and Table 2A.2) information or previous training on SAPs is statistically significant among most of the adoption equations and is not statistically significant in affecting the outcome variables for the non-adopting sub-sample households (Table 2A.4). This suggests that our instrument[12] is valid.

Most importantly, we exploit plot-level characteristics to deal with farmers' unobserved effects such as their innate abilities. Plot specific information can be used to construct a panel data and can help to control for farm-specific unobservables (Udry, 1996). Including standard fixed effects, where farm specific variables are created in deviations from their averages, is, however, complex in a multinomial treatment effect approach. We, therefore follow the Mundlak (1978) approach to control for unobservable characteristics. We exploit the plot level information and insert the mean values of the plot-specific characteristics in the multinomial equation.

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[12] Following Deb and Trivedi, 2006a, we have also tested for the exogeneity of our treatment variables using the likelihood-ratio which is a test for the joint hypothesis that the λs are equal to zero. Our results show that our treatments are indeed endogenous. This confirms the use of instrument to get rid of endogeneity problem.

2.4 Variables and descriptive statistics

The outcome variables used in this study are net crop income per acre and total consumption expenditure per capita for the 2014/15 agricultural season. All crops produced by the household in a certain plot were valued at the market price and all variable inputs such as the cost of fertilizer, seed, hired labor, plowing and manure used were deducted. Finally, the net crops income was divided by the total plot size to get the net crop income per acre. We have also used per capita consumption expenditure in favour of per capita income because it is more reliable (Deaton, 1997). A 7-day recall period was used to capture food expenditure by the household, and a 30-day recall period was used for frequently purchased items or services and non-durable goods; while a 12-month recall period was used for durable items and transfer payments spent by the household. All the consumption categories were converted into their respective total annual consumption levels. The total annual household consumption expenditure was standardized by the adult equivalent of the household to get the consumption expenditure per capita.

Our empirical model relies on a review of similar adoption and impact studies (Di Falco and Verona, 2013; Di Falco et al., 2011; Kassie et al., 2010, 2011; Manda et al., 2015; Mutenje et al., 2016; Neill and Lee, 2001; Teklewold et al., 2013; Wollni et al., 2010). Previous studies suggest that many factors affect the adoption decision and intern affect the outcome variables. Those factors include household characteristics (such as age of the head, education level of the head of the household, family size and gender), resources ownership and market access (such as total livestock holdings, total asset, total cultivable land, distance to input market, credit constraint), social capital and information (membership in farmers association, number of relatives and friends that the household relies on times of difficulties or events within and outside the community, extension contacts, climate change awareness), plot specific characteristics (distance of plots from homestead, land tenure security of plots, self-reported slope, as well as fertility of plots); household risk preferences (which we have captured using an experiment with actual payments) and geographic locations (which we have captured using district dummies). Table 2.3 presents descriptive statistics[13] of the household and plot level characteristics based on the SAP packages as a pairwise comparative analysis with the base category of non-adopters.

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[13] The descriptive statistics are based on the plot level sample

Table 2. 4 Descriptive Statistics of the Variables included in the model

VARIABLES	$V_0C_0D_0$	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_1D_1$	Total Mean	Standard deviation
Household Characteristics									
Age of the household	55.02	50.94**	51.98*	52.48**	55.11	50.2**	56.35	53.5	0.4
Gender head	0.81	0.92**	0.76	0.84	0.8	0.8	0.97***	0.83	0.01
Family size	7.12	7.1	7.74	6.62**	7.77*	6.43*	6.17**	6.95	0.08
Education of head	1.09	2.97***	1.62*	2.24***	2.18***	2.31***	1.75	1.78	0.09
Resource Constraints and market access									
Distance to input market	111.13	99.08	97	113.16	93.58**	104.25	93.775	108	2.08
Credit constrained	0.24	0.19	0.34*	0.13***	0.07***	0.24	0.125	0.19	0.01
Assets value (log)	7.52	7.63	7.84**	7.74***	7.88***	8.05***	7.98***	7.69	0.02
Total livestock holdings	4.76	5.62	4.97	5.36	5.99*	6.8***	6.6**	5.3	0.18
Total cultivated land (log)	1.83	1.83	1.82	1.87	1.79	1.78	1.91	1.84	0.02
Death shock	0.63	0.55	0.71	0.55**	0.67	0.6	0.65	0.6	0.01
Social Capital and Information									
Group membership	0.33	0.53***	0.47**	0.4**	0.49***	0.65***	0.65***	0.41	0.01
Village kinship	3.77	4.34	4.26	4.18	4.1	5.61**	5.625**	4.16	0.16
Non-village kinship	1.9	2.11	3.37**	4.55***	3.08**	4.36***	1.45	3.1	0.18
Extension contact	0.503	0.73***	0.71***	0.46	0.64***	0.64**	0.7***	0.53	0.01
Climate change awareness	0.88	0.91	0.97**	0.95***	0.98***	0.94	0.975*	0.92	0.01
Plot level Characteristics									
Distance to plot (log)	5.65	5.73	5.91	5.08	5.84	5.07*	5.09*	5.43	0.67
Plot tenure right	0.9	0.94	0.88	0.93*	0.94	0.92	0.92	0.91	0.01
Moderate fertility	0.52	0.68***	0.67***	0.59**	0.69***	0.58	0.55	0.58	0.01
High fertility	0.10	0.21***	0.15	0.13*	0.15*	0.18*	0.18*	0.13	0.01
Moderate slope	0.34	0.18***	0.37	0.35	0.26*	0.36	0.25	0.33	0.01
Flat slope	0.62	0.79***	0.38***	0.60	0.67	0.53	0.7	0.61	0.01

Table 2.4 continued

VARIABLES	$V_0C_0D_0$	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_1D_1$	Total Mean	Standard deviation
Mundlack fixed effects									
Mean distance to plots(log)	6.3	6.41	6.44	6.05*	6.03	6.15	5.96	6.19	0.05
Mean plots tenure right	0.9	0.92	0.91	0.92	0.94*	0.88	0.93	0.91	0.01
Mean moderate fertility	0.46	0.29	0.17***	0.26***	0.17***	0.24**	0.202**	0.29	0.01
Mean high fertility	0.52	0.58	0.68***	0.6***	0.66***	0.59	0.59	0.57	0.01
Mean moderate slope	0.12	0.12	0.14	0.13	0.16	0.18	0.21**	0.13	0.01
Mean flat slope	0.03	0.03	0.18***	0.06**	0.07*	0.08**	0.05	0.06	0
Risk Preference									
Severe risk averse (RA)	0.23	0.12**	0.26	0.18*	0.19	0.11**	0.05***	0.19	0.01
Moderate RA	0.17	0.16	0.07**	0.16	0.09*	0.18	0.1	0.15	0.01
Intermediate RA	0.14	0.18	0.04**	0.13	0.104	0.15	0.15	0.14	0.01
Slight to neutral RA	0.22	0.2	0.2	0.1***	0.13**	0.1**	0.075**	0.16	0.01
Neutral to preferring RA	0.1	0.14	0.09	0.2***	0.16*	0.17*	0.1	0.14	0.01
Instrumental Variable									
SAPs Information/training	0.42	0.73***	0.63***	0.49***	0.73***	0.71***	0.75***	0.51	0.01
N	474	73	68	416	86	72	40	1229	

Note: each SAPs packages are compared with the base category (non-adopters) ($V_0C_0D_0$) which has 474 observations at plot level.*, **, *** denotes significance level at 10%, 5% and 1% respectively. [a] farmer ranked each plot as "low fertile" medium fertile" and "high fertile". [b] farmer ranked each plot as 'step' , 'moderate step' and 'flat' slope

2.5 Results and Discussion

This section presents results of the mixed multinomial logit model estimates. The first section presents the determinant variables that affect the adoption of a single SAP and/or combinations of SAPs. Then the implication and impacts of adopting these SAPs are presented in the welfare section.

2.5.1 Determinants of Adoption of SAPs

Parameter estimates of the mixed multinomial logit model of the plot and household level determinants of SAPs adoption are presented in Table 2.5 and Table 2A.2[14]. The base category is non-adoption of any of the SAPs indicated in a given plot (Table 2.5) and in a given household (Table 2A.2). Based on the results of the Wald test, where $\chi^2 =$ 1395.69; $P > \chi^2 = 0.000$ and $\chi^2 =$ 1278.20 $P > \chi^2 = 0.000$; for the plot and household level estimations of SAPs adoption models, respectively, it is noted that the model fits the data very well. The null hypothesis that all the regression coefficients are jointly equal to zero is hereby rejected.

The findings show that age of the head of the household has a significant negative effect on the adoption of the improved maize varieties only ($V_1C_0D_0$) package both at the plot and household level. Our results are consistent with previous studies who found age of the household head to have a negative effect on technology adoptions (Di Falco and Verona, 2013; Teklewold et al., 2013) but contrary to the findings of Kassie et al., (2014) who find age to have a positive effect on SAPs adoption. Our results also suggest that Male headed households are more likely to adopt improved maize varieties only ($V_1C_0D_0$) and all the three SAPs together ($V_1C_1D_1$).

A mixed effect of family size is found on the adoption of different combinations of SAPs. Households who have large family size are found to adopt the soil & water conservation with cereal-legume diversification or improved seed package ($V_1C_1D_0$ / $V_0C_1D_1$) both at plot and household level. This could be due to the fact that, soil & water conservation structure is labor-intensive and hence it is likely that it would attract households who have large family sizes. Nevertheless, the effect of family size is negative on the cereal-legume diversification only ($V_0C_0D_1$), improved seed in conjunction with cereal-legume diversification ($V_1C_0D_1$) as

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[14] Table 2A.2 is presented at the appendix

well as the combination of all the three SAPs ($V_1C_1D_1$). This could be due to the fact that, larger households need more staples rather than legumes which are produced mostly for cash. This is consistent with the findings of Kassie et al., (2014). As expected, we find a positive and significant effect of education on the adoption of most of the SAPs both at the household and plot levels. Education plays a vital role in understanding agricultural innovations and in processing available information about new innovations. This result also adds to the evidence of the positive effects of education on adoption of technologies in multiple combination scenarios (Kassie, et al., 2014; Manda, et al., 2015; Mutenje, et al., 2016; Teklewold, et al., 2017; Beyene, et al., 2017).

Distance to input markets is negatively associated with the adoption of SAPs and is significantly related to soil & water conservation with improved maize varieties or cereal-legume diversification package ($V_1C_1D_0/V_1C_0D_1$) at the plot level. This is because households that live farther from the input market have less exposure to information and incur the high cost of adoption. However, it is found to have been positively associated with the adoption of cereal-legume diversification ($V_0C_0D_1$). The negative and significant effect of credit constraint on the adoption of most of the SAPs packages is as expected. Specifically, credit constraint is negatively related to improved maize varieties only ($V_1C_0D_0$), cereal-legume diversification only ($V_0C_0D_1$), soil & water conservation with improved maize varieties or cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$) as well as with the adoption of the comprehensive package which contains all the three SAPs ($V_1C_1D_1$) at the plot level. At the household level, credit constraint is also negatively associated with the adoption of improved maize varieties only ($V_1C_0D_0$), in addition to the above packages mentioned at the plot level. This result is explained by the economic theory which posits credit constraint to be the most important bottleneck of technology adoption in developing countries. Our results are consistent with the findings of Teklewold et al., (2013, 2017).

Similar to the findings of the current literature, which documents the importance of assets in the adoption of agricultural technologies in general and SAPs in particular, it is found that total asset holding is positively and significantly correlated with the adoption of cereal-legume diversification ($V_0C_0D_1$), soil & water conservation with improved maize varieties or cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$) and improved maize varieties in conjuncture with cereal-legume diversification ($V_1C_0D_1$). One of the indicators of wealth and status of households' in developing countries is total livestock holding (TLU). Although we did not find any significant impacts of TLU on SAPs adoption at the plot level, we find some positive and significant impacts at the household level. TLU is positively and significantly associated with the adoption of improved maize varieties ($V_1C_0D_0$), soil & water conservation ($V_0C_1D_0$), improved maize varieties with cereal-legume diversification ($V_1C_0D_1$) and improved maize varieties with soil & water conservation and cereal-legume diversification ($V_1C_1D_1$), at the household level. This could be attributed to the presumption that wealthier farmers have both the capacity to adopt external technologies and risk-bearing abilities (Teklewold, et al., 2017). It is found that total cultivated land holdings is negatively associated with the adoption of improved maize varieties only ($V_1C_0D_0$) and the soil & water conservation with cereal-legume diversification or improved seed packages ($V_1C_1D_0/V_0C_1D_1$) at the plot level. This is contrary to our expectation, although it is not significant at the household level. Teklewold et al., (2013) found similar results and argues that it could be because smallholder farmers tend to achieve food security by sustainably intensifying production in their small lands.

Economic theory suggests social networks play an important role in agricultural technology adoption through facilitating learning. Consistent with this theory, membership in farmers association or group is found to positively affect the adoption of improved maize varieties and cereal-legume diversification ($V_1C_0D_1$) both at the household and plot levels. Furthermore, we find a positive relationship between farmer's group membership and the adoption of the three SAPs ($V_1C_1D_1$) all together at the household level. This proves that membership in farmers group could play an important role as a source of information, input, and innovation (Abebaw and Haile, 2013; Ma and Abdulai, 2016; Mutenje et al., 2016). Nonetheless, the effect of village kinships and non-village kinships on the adoption of technologies is mixed. Village kinship is strongly associated with the adoption of the full package ($V_1C_1D_1$) simultaneously but negatively related to cereal-legumes diversification ($V_0C_0D_1$) at the plot level. Non-village kinship, on the other hand, is positively associated with the adoption of soil & water conservation technologies ($V_0C_1D_0$), cereal-legume diversification only ($V_0C_0D_1$), soil & water conservation with cereal-legume diversification or improved maize varieties ($V_1C_1D_0/V_0C_1D_1$) and the improved maize varieties and cereal-legume diversification ($V_1C_0D_1$), but negatively related to with the adoption of the full SAPs ($V_1C_1D_1$) package. While arguments of the social capital would predict that more social networks increase the probability of information spreading and therefore, increase the adoption of SAPs, sometimes more social networks could also lead to negative outcomes in the case of compulsory sharing within networks which can lead to free-riding and could limit incentives to adopt SAPs (Di Falco and Bulte, 2013). Climate change awareness is strongly and significantly associated with the packages cereal-legume diversification ($V_0C_0D_1$) and improved seed and cereal-legume diversification ($V_1C_0D_1$) at the plot level. This highlights the importance of upgrading the climate change awareness of households for the adoption of SAPs.

Extension contact is positively and significantly related to the adoption of soil & water conservation only ($V_0C_1D_0$) package at the household level. But to our surprise, it is negatively related to the adoption of the cereal-legume diversification only package ($V_0C_0D_1$) at the plot level. This could be attributed to the presumption that crop diversifications are much known by farmers themselves, the majority of which rely on indigenous knowledge rather than on extension services (source of information).

Bio-physical plot level information was exploited to control in part the issue of unobservable heterogeneity such as hidden abilities of households in adopting SAPs. As expected, the distance of plot from homestead has a negative and significant effect on the adoption of cereal-legume diversification ($V_0C_0D_1$) and improved maize varieties with cereal-legume diversification ($V_1C_0D_1$). However, contrary to our expectation, distance to the plot is positively associated with the adoption of soil & water conservation with improved maize varieties or cereal-legume diversification ($V_1C_1D_0$/$V_0C_1D_1$). On the other hand, tenure security is not a significant determinant of the adoption of different combinations of SAPs. Plot-level fertilities are the main determinants in the adoption of improved maize varieties ($V_1C_0D_0$). Estimated results show that households tend to adopt improved maize varieties ($V_1C_0D_0$) in moderate and highly fertile plots than in the low fertile plots. Farmers who cultivate highly fertile plots are less likely to adopt the full SAP ($V_1C_1D_1$) package. Having moderately fertile or fertile plot is positively associated with the adoption of almost all of the SAPs packages. However, the probability of adoption of the SAPs which involve soil & water conservation (both in isolation and jointly with other SAPs) is low on plots with flat or moderate slopes than those with steeper slopes.

We also analyzed the role of risk preference of households, which was elicited using an experimental game, on the adoption of the different combinations of SAPs. Risk preference is one of the cited determinants of the adoption of agricultural technologies, but it is often excluded in most innovation studies (Feder et al., 1985). Hence, our empirical analysis investigates the relationship between adoption of different combinations of SAPs and risk preferences. As discussed in section 2 of this chapter, farmers' risk preference was categorized into six distinct categories i.e., extreme risk-averse, severe risk-averse, intermediate risk-averse, moderate risk-averse, slight risk averse and neutral to preferring risk based on the choices made in the experiment. Then, a dummy variable was created for all categories and extreme risk-averse is used as a base reference for the analysis and interpretation. Results of our plot level analysis (Table 2.5) indicate that, as compared to the base category (extremely risk averse), other relatively risk preferring households are less likely to adopt the soil & water conservation only ($V_0C_1D_0$) package. For the rest of the SAP categories, relatively risk preferring households are more likely to adopt SAPs than those extremely risk-averse households. For example, our result shows that risk-neutral households are more likely to adopt comprehensive SAPs as compared to extreme risk adverse households. Specifically, risk neutral households are more likely to adopt SAPs such as cereal-legume diversification ($V_0C_0D_1$), soil & water conservation with cereal-legume diversification or with improved maize varieties ($V_1C_1D_0$ / $V_0C_1D_1$), improved maize varieties with cereal-legume diversification ($V_1C_0D_1$) and all the three SAPs together ($V_1C_1D_1$) than extreme risk-averse households. Similarly, an analysis regarding the determinants of SAPs adoption at the household level (Table 2A.2) also shows that relatively risk preferring households are more likely to adopt SAPs than the baseline category of extremely risk-averse household's. This suggests the importance of reducing risks exposure through, for example, crop insurances to mitigate the adverse effects of risk aversion on adoption of SAPs.

Table 2. 5 Mixed Multinomial Logit model estimates of adoption of SAPs in Upper East Region of Ghana at plot level

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_0D_0$
Household Characteristics						
Age of the household	-0.0214*	0.000226	-0.0103	-0.000504	-0.00953	0.00829
	(0.0114)	(0.0132)	(0.00695)	(0.0127)	(0.0133)	(0.0169)
Gender head	0.808	-0.846*	-0.425*	-1.547***	0.0497	1.494
	(0.566)	(0.452)	(0.244)	(0.441)	(0.527)	(1.125)
Family size	0.0260	0.0255	-0.0969***	0.129**	-0.169***	-0.202**
	(0.0667)	(0.0592)	(0.0349)	(0.0589)	(0.0610)	(0.0943)
Education of head	0.116***	0.0187	0.117***	0.193***	0.0256	0.0975
	(0.0431)	(0.0686)	(0.0328)	(0.0559)	(0.0585)	(0.0891)
Resource Constraints and market access						
Distance to input market	-0.00189	-0.00188	0.00150	-0.00357*	5.57e-05	-0.00388
	(0.00187)	(0.00282)	(0.00127)	(0.00211)	(0.00238)	(0.00246)
Credit constrained	-0.667	0.343	-1.193***	-2.213***	-0.529	-1.069*
	(0.425)	(0.361)	(0.247)	(0.471)	(0.470)	(0.588)
Assets value (log)	0.135	0.319	0.300**	0.661***	0.572**	0.432
	(0.220)	(0.238)	(0.123)	(0.251)	(0.224)	(0.348)
Total livestock holdings (TLU)	0.0148	-0.0164	0.00590	0.0236	0.0372	0.0194
	(0.0261)	(0.0279)	(0.0167)	(0.0274)	(0.0237)	(0.0267)
Total cultivated land (log)	-0.645**	-0.365	0.155	-0.650**	-0.170	0.0226
	(0.327)	(0.380)	(0.206)	(0.324)	(0.352)	(0.461)
Death shock	-0.108	0.632	-0.155	0.0878	0.0423	0.443
	(0.330)	(0.394)	(0.193)	(0.350)	(0.342)	(0.453)
Social Capital and Information						
Group membership	0.351	0.114	0.313	0.0773	1.025***	0.798
	(0.341)	(0.395)	(0.216)	(0.334)	(0.348)	(0.532)
Village kinship	0.00543	-0.0584	-0.126***	-0.0554	-0.0459	0.0918**
	(0.0443)	(0.0382)	(0.0258)	(0.0375)	(0.0397)	(0.0361)

Table 2.5 Continued

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_1D_1$
Non-village kinship	-0.0138	0.0952**	0.167***	0.125***	0.103**	-0.248*
	(0.0632)	(0.0447)	(0.0293)	(0.0415)	(0.0442)	(0.136)
Extension contact	0.109	0.671	-0.639***	-0.649	-0.487	0.547
	(0.352)	(0.410)	(0.238)	(0.486)	(0.383)	(0.561)
Climate change awareness	0.329	1.097	1.476***	1.466	1.661***	1.113
	(0.540)	(0.914)	(0.422)	(1.066)	(0.618)	(1.422)
Plot-level Characteristics						
Distance to plot (log)	0.0555	-0.00902	-0.171***	0.260***	-0.250***	-0.127
	(0.0936)	(0.0945)	(0.0518)	(0.0951)	(0.0861)	(0.0975)
Plot tenure right	1.099	-0.446	-0.0719	0.423	0.501	-0.211
	(0.932)	(0.680)	(0.422)	(0.707)	(0.698)	(0.920)
Moderate fertility[a]	3.259***	-0.0877	-0.350	0.450	0.209	-1.571
	(0.704)	(0.660)	(0.359)	(0.614)	(0.605)	(0.998)
High fertility	5.066***	0.266	0.0842	0.435	0.865	-1.843*
	(0.967)	(0.766)	(0.518)	(0.923)	(0.785)	(1.028)
Moderate slope[b]	-0.864	-0.874	0.704	-0.155	-1.142	0.236
	(1.579)	(0.893)	(0.644)	(1.024)	(0.947)	(1.152)
Flat slope	-0.427	-1.876**	0.633	-0.361	-1.713*	0.129
	(1.491)	(0.864)	(0.629)	(0.961)	(0.965)	(1.452)
Mundlack fixed effects						
Mean distance to plots (log)	-0.00707	0.127	0.0475	-0.329**	0.172	-0.106
	(0.124)	(0.133)	(0.0671)	(0.129)	(0.116)	(0.142)
Mean plots tenure right	-0.324	1.282	0.787	1.925	-0.756	2.226
	(1.145)	(1.041)	(0.593)	(1.270)	(0.897)	(1.999)
Mean moderate fertility	-1.897***	1.537*	0.938**	1.572*	0.632	4.121***
	(0.697)	(0.916)	(0.449)	(0.838)	(0.671)	(1.402)

Table 2.5 continued

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_1D_1$
Mean high fertility	-4.798***	1.012	-0.129	1.270	-0.461	3.729**
	(1.249)	(1.144)	(0.635)	(1.112)	(1.033)	(1.510)
Mean moderate slope	0.141	-2.134	-2.226***	-1.212	-0.639	-2.659
	(2.013)	(1.347)	(0.830)	(1.517)	(1.429)	(1.678)
Mean flat slope	1.546	-1.997	-1.977**	-0.232	0.118	-1.729
	(1.956)	(1.274)	(0.798)	(1.466)	(1.409)	(1.904)
Risk Preference						
Severe risk averse (RA)[c]	0.292	-1.264*	0.445	-0.0443	0.666	1.865*
	(0.559)	(0.653)	(0.299)	(0.578)	(0.600)	(1.063)
Moderate RA	0.395	-1.828**	0.130	0.549	-0.318	2.801***
	(0.576)	(0.716)	(0.339)	(0.623)	(0.626)	(1.022)
Intermediate RA	0.292	-0.939**	-0.666**	-0.0759	-1.015	1.425
	(0.521)	(0.477)	(0.303)	(0.515)	(0.667)	(1.147)
Slight to neutral RA	0.445	-0.984*	1.087***	1.037**	0.740	2.447**
	(0.580)	(0.583)	(0.342)	(0.528)	(0.663)	(1.044)
Neutral to preferring RA	0.756	0.0927	0.667**	1.215***	1.000	3.484***
	(0.548)	(0.482)	(0.285)	(0.459)	(0.616)	(0.908)
Instrumental Variable						
SAPs Information/training	1.200***	0.537	0.445*	1.850***	0.976**	0.704
	(0.327)	(0.389)	(0.242)	(0.485)	(0.398)	(0.502)
Constant	-5.675***	-6.494***	-2.448**	-12.21***	-6.180***	-12.99***
	(2.193)	(2.432)	(1.112)	(2.665)	(2.173)	(3.890)
Observations	1,229	1,229	1,229	1,229	1,229	1,229

Sample size is 1229 plots generated from 421 households and 100 simulation draws were used.***<0.01, **<0.05, *<0.1. Robust standard errors in parenthesis. Fixed effects at plot level are included. Base categories are low fertile plots, step slope plots, and extremely risk-averse in ‘a’ ‘b’ and ‘c’, respectively. District controls are included but not reported.

2.5.2 Average treatment effects of SAPs

The study estimates the productivity and welfare effects of adoption of SAPs (in isolation or as a combination) and identifies which package(s) yield the highest economic impacts. To this effect, the impact was estimated on net crop income (a proxy for productivity) and per capita consumption expenditure (a proxy for welfare). Results of the analysis are summarised and presented in Table 2.6 below.

Interestingly, it is found that most of the SAPs have a positive effect on the two welfare indicators when adopted in isolation and in combination. Other exogenous determinants for the crop income per acre and household expenditure per capita are presented in Table 2A.3 at the appendix.

It is found that the average adoption effect of improved maize varieties only ($V_1C_0D_0$) package is about 8% increase in net crop income per acre after controlling for observed and unobserved heterogeneities. This is relatively low as compared to the impacts of improved maize seed varieties found elsewhere. For example, Manda, et al., (2015) and Mutenje, et al., (2016) found a 90% and 14.6% impacts of improved maize varieties in Zambia and Malawi, respectively. However, they use maize yield as an indicator, while we use net crop income per acre where we have deducted all the variable costs from the crop revenues and also consider all crops grown on a specific plot. The relatively low impact found in our study could also be partly explained by the difference in the agro-ecological context of Ghana and the farming systems particularly in the Upper East Region of Ghana. We did not find any significant impact of soil & water conservation only ($V_0C_1D_0$), cereal-legume diversification only ($V_0C_0D_1$) and soil & water conservation with improved maize varieties or with cereal-legume diversification ($V_1C_1D_0/V_0V_1D_1$) on net crop income per acre. The adoption of a combination of improved maize varieties and cereal-legume diversification ($V_1C_0D_1$) leads to about 17% increase in crop income per acre. Interestingly, net crop revenue per acre is found to increase by 19% when improved maize varieties, soil & water conservation and cereal-legume diversification ($V_1C_1D_1$) are adopted on a plot. This proves the complementarity of the SAPs and their synergistic effect. Although it is not possible to elicit the real complementarity effects figure of the SAPs between each other, due to the multinomial nature of the modelling, one can reveal that there is a strong synergistic effect among the SAPs. For example, improved maize varieties ($V_1C_0D_0$) leads to approximately 8% increase in crop income when it is adopted in isolation but, when it is complemented with cereal-legume diversification, the marginal effect increases to 17%. This shows that there is a strong synergistic effect among the two SAPs.

On the consumption expenditure per capita, Table 2.6 shows that improved maize varieties increase consumption expenditure significantly when they are adopted in isolation and when they are combined with the other two SAPs at different levels, although the degree of impact varies among the combinations. In quantitative terms, improved maize varieties lead to around 2.4% and 4.8% increase in consumption expenditure, when it is adopted in isolation and it is diversified with a legume, respectively. Soil & water conservation only ($V_0C_1D_0$) leads to about 2.5% increase in consumption expenditure, while the effect of cereal-legume diversification only ($V_0C_0D_1$) is estimated to be about 3.4%. Our results also show that soil and water conservation increases consumption expenditure per capita by 7.9% when it is adopted with improved maize varieties or cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$). Similarly, the combinations of improved maize varieties and cereal-legume diversification ($V_1C_0D_1$) generate about 4.8% increase in consumption expenditure. Our results also reveal that all the three packages ($V_1C_1D_1$) positively and significantly increase consumption expenditure per capita by 8.2%.

Interestingly, the highest payoffs in both net crop income per acre and consumption expenditure per capita are observed when all SAPs ($V_1C_1D_1$) are adopted. This finding is in contrast with earlier reports in Africa. For example, Manda et al., (2015) in Zambia found improved maize varieties to have the strongest impact when it is adopted in isolation than when it is implemented with any other SAPs. On the other hand, Mutenje et al., (2016) in Malawi reports that improved maize and improved storage package yields the highest payoff than even the most comprehensive package that combines all the three innovations that they have considered in their study (Improved maize, improved storage, and soil and water conservation). Furthermore, in Ethiopia, Di Falco and Veronesi, (2013), show that two climate change adaptation strategies, soil conservation and changing crop varieties, provide more payoff than when these strategies are combined with another climate change adaptation strategy (water strategy), and concluded that climate change adaptation strategies that are more comprehensive do not always provide higher net revenues when compared to less comprehensive packages. Similarly, Beyene, et al., (2017), studied the effects of soil conservation, tree planting and intercropping on crop income with these innovations adopted in isolation and in combinations. The authors found positive effects of the innovations on crop income when the innovations are adopted in isolations and in different combinations. However, they show that tree planting generates the highest income when it is adopted in isolation than when it is combined with the other innovations.

The difference between our results and previous studies could be due to the fact that we have used net crop income instead of maize yield or maize income as well as consumption expenditure instead of household income. Furthermore, agronomic and locational differences between our study area and the other studies could also be another source of difference. In fact, our study area is vulnerable to water stress and drought due to frequent seasonal rainfall deficit (and in some cases, dry spells) and drought due to shortages of enough rains and comprehensive SAPs practice implemented may decrease water stress, and therefore, can generate higher payoff.

Our study corroborates with the recent study by Teklewold, et al., (2017) who found that adopting all three strategies simultaneously generates the maximum return than the single and sub-combinations of SAPs. While Teklewold et al. (2017) considered a different combination of practices (agricultural water management, improved crop seeds, and fertilizer), our results lead us to the conclusion that multiple adoptions are always the best strategy especially in study areas like ours.

Table 2. 6Multinomial Endogenous treatment model estimates of SAPs impacts on net crop income and household consumption Expenditure

SAPs	**net crop income per acre (ln)**	**consumption expenditure per capita (ln)**
$V_1C_0D_0$	0.0794**	0.0238**
	(0.0322)	(0.0116)
$V_0C_1D_0$	0.000685	0.0252*
	(0.0391)	(0.0146)
$V_0C_0D_1$	0.0430	0.0341***
	(0.0303)	(0.0110)
$V_1C_1D_0$ / $V_0C_1D_1$	0.00849	0.0790***
	(0.0272)	(0.0151)
$V_1C_0D_1$	0.170***	0.0478***
	(0.0458)	(0.0139)
$V_1C_1D_1$	0.191***	0.0822***
	(0.0235)	(0.0116)
Selection terms (λ)		
$V_1C_0D_0$	0.0976***	0.0448***
	(0.029)	(-0.008)
$V_0C_1D_0$	0.0386	-0.007
	(0.0263)	(0.010)
$V_0C_0D_1$	0.0021	0.0122*
	(0.0315)	(0.0099)
$V_1C_1D_0$ / $V_0C_1D_1$	0.0548**	-0.0154**
	(0.025)	(0.0061)
$V_1C_0D_1$	-0.0694*	0.0087
	(0.0371)	(0.0073)
$V_1C_1D_1$	-0.0170	-0.0118
	(0.0111)	(0.0096)
lnsigma	5.07***	6.781***
	(0.4686)	(0.3932)
Other Variables	Yes	Yes
Observations	**1229**	**421**

The baseline is farm households that did not adopt any SAP. The sample size is 1229 plots and 421 households and 100 simulation draws were used. ***P<0.01, **P<0.05, *P<0.1. Robust standard errors in parenthesis.

2.6 Conclusion

Many ecosystem services such as nitrogen fixation, nutrient cycling, soil regeneration, and biological control of pests and weeds, are under threat in key African food production systems due to unsustainable cultivation and climate change. SAPs can potentially alleviate some of the environmental problems while increasing household's welfare by increasing agricultural income and reducing food insecurity. Previous research mostly focused on the adoption of single SAPs and their impact on productivity and welfare of households. But interestingly, simultaneous adoption and impact of SAPs on households in Africa have recently received attention and empirical evidence is still scant. In this chapter, we have identified the determinants of adoption of different combinations of SAPs both in isolation and in packages, and we assessed their impact on household welfare outcomes. We used a maximum simulated likelihood estimation of the Multinomial Endogenous Treatment Effect Model (METEM) to account for observable and unobservable heterogeneity that influence SAPs adoption decisions and in turn, the outcome variables to estimate the impacts of SAPs on net crop income per acre and consumption expenditure per capita.

Previous empirical studies on the adoption and impact of SAPs focus only on the household, institutional and plot characteristics as determinants of agricultural innovations. However, to our knowledge, no other study has looked into the effects of individual risk preferences on multiple SAP adoption. This study fills this gap by revealing the risk preferences of households using an experimental game which was played with the sampled households. The adoption part of the mixed multinomial logit model reveals that the probability of adoption of different combinations of SAPs are influenced by observable household characteristics such as education level of the household head and family size, plot-specific characteristics such as average distance of plots from homestead, plot fertility and plot slope, social capital and information sources such as group membership and households' awareness about climate change and risk preferences.

Our results show that generally, SAPs have a positive and significant effect on net crop income and consumption expenditure. The package that contains all three SAPs together (improved maize varieties, soil & water conservation, and cereal-legume diversification) generates the highest payoff both in terms of net crop income and consumption expenditure. This has important policy implications. Future interventions that aim to increase agricultural productivity and enhance consumption expenditure should combine improved maize varieties with other agricultural practices that enhance agronomic practices such as soil & water conservation and cereal-legume diversification.

2.7 Appendix

Table 2A. 1Variables definition

Variable	Definitions
Dependent	
Net Crop Income (ln)	Logarithm of Net Crop Income per acre
Consumption Expenditure (ln)	Logarithm of consumption expenditure per capita
SAPs Packages	
Improved maize varieties only ($V_1C_0D_0$)	Dummy=1 if the farm household adopted only improved maize varieties, 0 otherwise
Soil & Water Conservation only ($V_0C_1D_0$)	Dummy=1 if the farm household adopted only soil & water conservation, 0 otherwise
Cereal-legume diversification only ($V_0C_0D_1$)	Dummy=1 if the farm household adopted only cereal-legume diversification, 0 otherwise
Improved maize varieties and soil & water conservation ($V_1C_1D_0$)	Dummy=1 if the farm household adopted only improved maize and soil and water conservation, 0 otherwise
Soil & water conservation and Cereal-legume diversification ($V_0C_1D_1$)	Dummy=1 if the farm household adopted only soil & water conservation and cereal=legume diversification, 0 otherwise
Improved maize varieties and cereal-legume diversification ($V_1C_0D_1$)	Dummy=1 if the farm household adopted only improved maize varieties and cereal-legume diversification, 0 otherwise
Improved maize, soil & water conservation and cereal-legume diversification ($V_1C_1D_1$)	Dummy=1 if the farm household adopted improved maize, soil and water conservation & cereal-legume diversification, 0 otherwise
Explanatory	
Household Characteristics	
Age of the household	Age of the Head of the household
Gender head	Dummy=1 if head of the household is male
Family size	Family size of the household
Education of head	Years of education of head of the household
Resource Constraints and market access	
Distance to input market	Walking distance to input market from home in minutes
Credit constrained	Dummy=1 if Credit constrained (credit is needed but unable to get it)
Assets value (log)	Logarithm of value of total asset
Total livestock holdings	Total livestock holdings in TLU
Total cultivated land (log)	Logarithm of total cultivated landholding
Death shock	Dummy=1 if household has lost hh member or relative in the past 5 years
Social Capital and Information	
Group membership	Dummy=1 if household belongs to any group, 0 otherwise
Village kinship	Number of relatives and friends that the household deal with in the same community

Table 2A.1 continued

Variable	**Definitions**
Non-village kinship	Number of relatives and friends that the household deal with in outside the village
Extension contact	Dummy=1 if household had any contact with extension worker in the year, 0 otherwise
Climate change awareness	Dummy=1 if household is aware of climate change, 0 otherwise
Non-village kinship	Number of relatives and friends that the household deal with in outside the village
Extension contact	Dummy=1 if household had any contact with extension worker in the year, 0 otherwise
Climate change awareness	Dummy=1 if household is aware of climate change, 0 otherwise
Plot-level Characteristics	
Distance to plot (log)	Distance from homestead to plot
Plot tenure right	Tenure security of plot
Low fertile	Dummy=1 if plot is low fertile
Moderate fertility	Dummy=1 if plot is moderately fertile
High fertility	Dummy=1 if plot is high fertile
Step slope	Dummy=1 if plot is stepped slope
Moderate slope	Dummy=1 if plot is moderate slope
Flat slope	Dummy=1 if plot is flat slope
Mundlack fixed effects	
Mean distance to plots(log)	Logarithm of the mean distance of plots from home
Mean plots tenure right	Mean of plots land tenure security
Mean low fertile	Mean value of low fertile plots
Mean moderate fertility	Mean value of moderate fertile plots
Mean high fertility	Mean value of high fertile plots
Mean step slope	Mean value of step slop plots
Mean moderate slope	Mean value of moderate slop plots
Mean flat slope	Mean value of flat slop plots
Risk Preferences	
Extreme risk averse (RA)	Dummy=1 if Extreme risk preference
Severe risk averse RA	Dummy=1 if Sever risk preference
Moderate RA	Dummy=1 if Moderate risk preference
Intermediate RA	Dummy=1 if Intermediate risk preference
Slight to neutral RA	Dummy=1 if Slight risk preference
Neutral to preferring RA	Dummy=1 if Neutral risk preference
Instrumental Variable	
SAP_Inf	Dummy=1 if household had information about or training on SAPs, 0 otherwise

Table 2A. 2Household level mixed multinomial logit model estimates of adoption of SAPs in Upper East Region of Ghana (baseline category is non-adoption of SAPs)

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_0D_0$
Household Characteristics						
Age of the household	-0.0324*	-0.0144	0.00150	-0.0120	-0.0230	-0.0304*
	(0.0183)	(0.0198)	(0.0143)	(0.0174)	(0.0167)	(0.0180)
Gender head	0.486	-0.482	-0.447	-1.318**	0.665	0.573
	(0.688)	(0.712)	(0.508)	(0.666)	(0.703)	(0.765)
Family size	0.0830	0.0755	-0.0102	0.221**	-0.148	-0.0149
	(0.0894)	(0.0951)	(0.0749)	(0.0955)	(0.0948)	(0.0924)
Education of head	0.290**	0.259	0.308**	0.325**	0.199	0.276*
	(0.145)	(0.175)	(0.139)	(0.155)	(0.150)	(0.149)
Resource Constraints and market access						
Distance to input market	-0.00169	-0.00131	0.00444*	-0.00225	0.00280	-0.00165
	(0.00397)	(0.00367)	(0.00255)	(0.00383)	(0.00347)	(0.00344)
Credit constrained	-1.109*	-0.275	-2.559***	-3.246***	-0.147	-1.621***
	(0.673)	(0.560)	(0.598)	(0.766)	(0.574)	(0.629)
Assets value (log)	0.171	0.186	0.431*	0.349	0.574**	0.218
	(0.309)	(0.316)	(0.255)	(0.343)	(0.287)	(0.320)
Total livestock holdings	0.126**	0.0990**	0.0481	0.00631	0.120**	0.160***
	(0.0497)	(0.0442)	(0.0614)	(0.0660)	(0.0486)	(0.0468)
Total cultivated land (log)	-0.446	-0.356	-0.0950	-0.0783	0.0594	0.620
	(0.482)	(0.497)	(0.381)	(0.465)	(0.443)	(0.425)
Death shock	0.161	1.342**	-0.197	0.0228	0.684	0.284
	-0.00169	-0.00131	0.00444*	-0.00225	0.00280	-0.00165
Social Capital and Information						
Group membership	0.674	-0.140	0.289	0.295	1.278**	1.612***
	(0.513)	(0.616)	(0.475)	(0.587)	(0.543)	(0.536)

Table 2A.2 continued

VARIABLES	**(1)** $V_1C_0D_0$	**(2)** $V_0C_1D_0$	**(3)** $V_0C_0D_1$	**(4)** $V_1C_1D_0/ V_0C_1D_1$	**(5)** $V_1C_0D_1$	**(6)** $V_1C_1D_1$
Village kinship	0.0831	-0.0226	-0.0717	-0.103	-0.0781	0.0725
	(0.0537)	(0.0582)	(0.0532)	(0.0625)	(0.0726)	(0.0587)
Non-village kinship	-0.0483	0.110	0.164***	0.173***	0.125*	0.0493
	(0.0748)	(0.0672)	(0.0528)	(0.0619)	(0.0674)	(0.0641)
Extension contact	0.519	1.272**	-0.200	0.767	0.301	-0.469
	(0.575)	(0.622)	(0.484)	(0.655)	(0.558)	(0.602)
Climate change awareness	0.496	1.002	1.267	1.813	1.000	1.361
	(0.776)	(0.902)	(0.779)	(1.210)	(0.852)	(1.130)
Risk Preference						
Severe risk averse (RA)	-0.683	-0.522	0.429	0.0205	0.0543	1.928**
	(0.839)	(0.904)	(0.571)	(0.778)	(0.738)	(0.786)
Moderate RA	0.445	-2.081*	0.0165	0.285	-1.027	1.576*
	(0.840)	(1.161)	(0.720)	(0.907)	(0.900)	(0.831)
Intermediate RA	-0.0240	0.0596	-0.313	0.0597	-0.525	0.849
	(0.763)	(0.776)	(0.585)	(0.806)	(0.740)	(0.888)
Slight to neutral RA	1.846*	0.660	2.401**	2.378**	1.688	2.956**
	(1.050)	(1.075)	(0.988)	(1.050)	(1.060)	(1.187)
Neutral to preferring RA	1.378	1.333	1.451**	2.018**	1.499*	3.623***
	(0.873)	(0.932)	(0.688)	(0.866)	(0.844)	(0.888)
Instrumental Variable						
SAPs information/training	2.266***	1.313*	0.508	0.975	1.708***	2.070***
	(0.594)	(0.679)	(0.489)	(0.664)	(0.544)	(0.607)
Constant	-3.555	-6.533**	-5.874***	-8.812***	-7.773***	-9.400***
	(2.322)	(2.881)	(2.046)	(2.840)	(2.421)	(2.699)
District Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	**421**	**421**	**421**	**421**	**421**	**421**

Sample size is 1229 plots generated from 421 households and 100 simulation draws were used.***<0.01, **<0.05, *<0.1. Robust standard errors in parenthesis. Fixed effects at plot level are included. Base categories are low fertile plots, step slope plots and extremely risk averse in 'a' 'b' and 'c', respectively. District controls are included but not reported.

Table 2A. 3Other variables of the second stage determinants of crop income and consumption

VARIABLES	Net plot crop income (ln)	Consumption expenditure (ln)
Household Characteristics		
Age of the household	3.74e-05	-0.000662***
	(0.000408)	(0.000220)
Gender head	0.0196	-0.0111
	(0.0148)	(0.0106)
Family size	0.00413**	-0.0107***
	(0.00190)	(0.00123)
Education of head	0.00165	0.00184**
	(0.00150)	(0.000901)
Resource Constraints and market access		
Distance to input market	-8.41e-05	5.55e-05
	(6.39e-05)	(4.28e-05)
Credit constrained	0.00773	0.00977
	(0.0135)	(0.00905)
Assets value (log)	0.0165**	0.0100**
	(0.00754)	(0.00409)
Total livestock holdings	0.000793	0.000568
	(0.000967)	(0.000479)
Total cultivated land (log)	-0.0566***	-0.00889
	(0.0110)	(0.00661)
Death shock	-0.00477	-0.00660
	(0.0116)	(0.00707)
Social Capital and Information		
Group membership	-0.00227	-0.0161**
	(0.0113)	(0.00770)
Village kinship	-0.000168	-0.000745
	(0.00131)	(0.000635)
Non-village kinship	-0.00167	0.00174***
	(0.00112)	(0.000663)
Extension contact	0.00346	0.00918
	(0.0112)	(0.00740)
Climate change awareness	-0.00497	0.0160*
	(0.0189)	(0.00956)
Plot-level Characteristics		
Distance to plot (log)	0.00218	
	(0.00332)	
Plot tenure right	0.00515	
	(0.0230)	
Moderate fertility[a]	0.0128	
	(0.0201)	

Table 2A.3 continued

VARIABLES	**Net plot crop income (ln)**	**Consumption expenditure (ln)**
High fertility	-0.0393	
	(0.0306)	
Moderate slope[b]	-0.0952***	
	(0.0356)	
Flat slope	-0.0674**	
	(0.0331)	
Mundlack fixed effects		
Mean distance to plots (log)	0.00691*	
	(0.00388)	
Mean plots tenure right	-0.0213	
	(0.0297)	
Mean moderate fertility	0.0301	
	(0.0252)	
Mean high fertility	0.109***	
	(0.0374)	
Mean moderate slope	0.118***	
	(0.0409)	
Mean flat slope	0.0998**	
	(0.0390)	
Risk Preference		
Severe risk averse (RA)[c]	-0.00409	-0.00649
	(0.0163)	(0.00900)
Moderate RA	-0.00461	0.0107
	(0.0175)	(0.0110)
Intermediate RA	-0.00302	-0.00851
	(0.0174)	(0.0102)
Slight to neutral RA	0.0242	-0.0160
	(0.0168)	(0.0107)
Neutral to preferring RA	0.0289*	0.00367
	(0.0160)	(0.0109)
Constant	-3.559***	-4.810***
	(0.468)	(0.397)
Observations	1229	421
District dummies	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2A. 4 Test for the validity of instrument

VARIABLES	Net plot crop income (ln)	Consumption expenditure (ln)
Household Characteristics		
Age of the household	-0.00250	-0.00548*
	(0.00333)	(0.00296)
Gender head	0.0302	-0.0824
	(0.122)	(0.112)
Family size	0.0477***	-0.0674***
	(0.0172)	(0.0196)
Education of head	-0.00693	0.00739
	(0.0191)	(0.0306)
Resource Constraints and market access		
Distance to input market	-0.000713	0.000462
	(0.000618)	(0.000649)
Credit constrained	0.00779	0.150
	(0.106)	(0.104)
Assets value (log)	0.00234	0.0912
	(0.0622)	(0.0632)
Total livestock holdings	0.00703	-0.00345
	(0.00866)	(0.0148)
Total cultivated land (log)	-0.304***	0.0540
	(0.106)	(0.103)
Death shock	0.0992	-0.215**
	(0.0930)	(0.0921)
Social Capital and Information		
Group membership	-0.00687	0.0521
	(0.108)	(0.106)
Village kinship	-0.00325	0.0167
	(0.00994)	(0.0120)
Non-village kinship	-0.00959	0.00149
	(0.0122)	(0.0168)
Extension contact	0.117	0.0568
	(0.105)	(0.0917)
Climate change awareness	0.0356	0.216
	(0.154)	(0.139)
Plot-level Characteristics		
Distance to plot (log)	0.0130	
	(0.0255)	
Plot tenure right	0.161	
	(0.202)	
Moderate fertility[a]	-0.0870	
	(0.153)	

Table 2A.4 continued

VARIABLES	**Net plot crop income (ln)**	**Consumption expenditure (ln)**
High fertility	-0.265	
	(0.232)	
Moderate slopeb	-0.216	
	(0.324)	
Flat slope	-0.294	
	(0.312)	
Mundlack fixed effects		
Mean distance to plots (log)	0.0110	
	(0.0324)	
Mean plots tenure right	-0.560*	
	(0.291)	
Mean moderate fertility	0.207	
	(0.197)	
Mean high fertility	0.469	
	(0.298)	
Mean moderate slope	0.340	
	(0.434)	
Mean flat slope	0.354	
	(0.425)	
Risk Preference		
Severe risk averse (RA)[c]	-0.188	-0.0947
	(0.137)	(0.115)
Moderate RA	-0.219	0.0288
	(0.146)	(0.135)
Intermediate RA	-0.170	-0.221*
	(0.134)	(0.123)
Slight to neutral RA	-0.0329	-0.143
	(0.167)	(0.234)
Neutral to preferring RA	0.123	-0.106
	(0.151)	(0.167)
Instrumental Variable		
SAPs Information/training	**-0.104**	0.00174
	(0.108)	(0.0962)
Constant	5.735***	6.970***
	(0.557)	(0.447)
Observations	474	96
R-squared	0.088	0.564

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Chapter 3

Sustainable Agricultural Practices (SAPs) and environmental Resources Extraction: Empirical Evidence from Northern Ghana

Gebrelibanos Gebremariam[1] and Tobias Wünscher[1,2]

[1] Center for development research (ZEF), University of Bonn

[2] EARTH University, San José, Costa Rica.

Abstract

Extraction of environmental resources is among the important livelihood strategies for rural households in developing countries. While there is some evidence that Sustainable Agricultural Practices (SAPs) can improve agricultural production with little footprints on the corresponding production plots, little has been written on the relationship between adoption of SAPs and rural households' extraction of environmental resources. This chapter contributes to this body of the literature using data from a random sample of 421 households from the Upper East Region of Ghana. We utilize a multinomial endogenous treatment effect model to assess the impact of adoption of SAPs on environmental resources reliance while controlling for endogeneity of SAPs adoption. We find that, on average, income from environmental resources accounts for about 30% of the total household income, and the mean share of income from environmental resources ranges between 15 to 40% among the households, based on their SAPs adoption status. We find that adoption of different SAPs reduces per capita environmental income by 7 to 15%. Similarly, adoption of different combinations of SAPs also reduces the share of environmental income by 22 to 75%. The effect is higher when SAPs are adopted in combination than in isolation, confirming the synergistic effects of SAPs in reducing environmental pressure. The results of the study suggest that SAPs are environment-smart practices which do not only have biophysical and economic benefits but also reduce the pressure that rural households put on the environmental resources to support their livelihoods.

Keywords: Environmental reliance, Sustainable agricultural practices, Multinomial endogenous treatment effect model, Ghana

JEL Classification: O13, Q23, Q55, Q57

3.1 Introduction

Rural households in developing countries have many livelihood strategies such as crop production, livestock husbandry, off-farm income and extraction of environmental resources. Previous studies establish three potential channels through which extraction of environmental products supports rural livelihoods. First, they support current consumption as a form of food, medicine, and building materials. Second, they serve as safety nets at the time of idiosyncratic and/or covariate shocks. Third, they can provide means to generate cash income and to accumulate assets and serve as a pathway out of poverty (Cavendish, 2002; Chileshe, 2005; Angelsen and Wunder, 2003; Shackleton et al., 2007; Heubach et al., 2011; Angelsen et al., 2014; Wunder et al., 2014a; Wunder et al., 2014b; Dokken and Angelsen, 2015). Eenvironmental resources sustain human livelihoods not only through the provision of direct consumptive goods but also through non-pecuniary services (Ntuli & Muchapondwa, 2016). Some of the non-pecuniary benefits of environmental resources include ecosystem services such as water purification, flood mitigation, or carbon sequestration (Jack et al., 2008), health benefits of standing forests (Garg, 2015), and sedimentation prevention (Nguyen et al., 2013). That is why conservationists argue that environmental resources conservation is vital not only for direct livelihood generation but also for ecological sustainability such as regulating microclimate and water cycles (Stolton & Dudley 2010).

Despite these economic benefits, the importance of environmental products to rural livelihoods has been overlooked in conventional household socio-economic surveys (Cavendish, 2000). Angelson et al. (2014) argue that, in the last 10-15 years, income from environmental products and its contribution to livelihoods has got some attention. The few available empirical works in the literature illustrate that environmental products account for a substantial share of the total household income of rural households in developing countries. The share of cash and subsistence income from environmental products ranges between 15% and 60% (Angelsen et al., 2014; Appiah et al., 2009; Babulo et al., 2009; Debela et al., 2012; Gatiso and Wossen, 2014; L'Roe & Naughton-Treves, 2014; Kamanga et al., 2009; Asfaw et al., 2013; Mamo et al., 2007; McElwee, 2008; Uberhuaga et al., 2012; Shackleton et al., 2007). The significant difference in the share of environmental income to total household income among these studies is because of the difference in context, viability and availability of alternative income sources, and the products considered in the environmental product basket calculations, among others (Kaoma and Shackleton, 2015).

From the previous literature, it can be concluded that environmental products account for a substantial amount of the livelihoods of rural households. This is an indication of a high dependence of rural households on environmental resources.

Environmental resources extraction can be linked with economic, cultural, social and environmental concerns. However, the decision to extract environmental resources coupled with incomplete output and input markets can have implications on environmental quality, biodiversity conservation, and future natural resource stocks (Lopez-Feldman and Chavez, 2016). Earlier studies indicate that there is a significant biodiversity loss driven by human and global change (Foley et al., 2005; Halpern et al., 2008; Tittensor et al., 2014). As in other developing countries, environmental resources in Ghana have been under threat from increased rates of exploitation (GFDMP, 2016). Estimates show that Ghana has lost 1.9 million hectares of forest cover due to deforestation and forest degradation between the year 1990 and 2005 (UNEP, 2009). This made Ghana to be one of the countries with the highest rate of deforestation in West Africa (Benhin and Barbier, 2001). This could be a serious challenge to climate change mitigation efforts and it might have negative effects on the general ecosystem function.

Given the economic and environmental benefits of forest resources, there appears to be a trade-off associated with extracting environmental resources and their conservation. The crux of the matter is, therefore, how to minimize trade-offs between conservation objectives and economic utilization of environmental resources without compromising their future ecological values. One of the strategies that could be adopted to reduce rural households' dependence on the environmental resources could be by enhancing other livelihood strategies such as crop income through the dissemination of SAPs. This is imperative because environmental products have a vital role in conserving biodiversity and mitigating climate change, as well as in supporting local livelihoods. Thus, understanding the mechanisms of forest conservation and finding ways to reduce rates of loss is important on the conservation agenda (Balmford et al., 2009).

SAPs[15] are climate-smart agricultural practices that have potential biophysical and welfare benefits to farmers. The welfare benefits of SAPs are obtained through enhancing crop

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[15] This paper analyses the adoption of three SAPs and their impact on environmental reliance when they are adopted in isolation and in combination. The first SAP is the use of improved maize varieties (V). Improved maize varieties are intended to increase yields and thereby increase crop income and reduce food security. Previous studies have found a positive effects of improved maize varieties on crop yields (Khonje et al., 2015;

productivity to increase income and food security status of rural households (Brown and Funk 2008; Bryan et al., 2011, Teklewold et al., 2013; Tekelewold et al., 2017). The biophysical benefits of SAPs are attained through their role in strengthening households' resilience to climate change (Asfaw et al. 2016) decreasing greenhouse gas emissions, and increasing carbon sinks (FAO, 2011; Campbell et al., 2014; Arslan et al., 2014). Few but emerging studies find a positive effect of SAPs on crop production (Di Falco and Veronesi, 2013; Teklewold et al., 2013; Kassie et al., 2014; Manda et al., 2015; Mutenje et al., 2016, Beyene et al., 2017; Teklewold et al., 2017).

In this chapter, we are interested in exploring the effect of SAPs on households' reliance on environmental resources. From a theoretical point of view, the effect of SAPs on environmental reliance or forest extraction is ambiguous. We argue that the adoption of SAPs could reduce households' dependence on environmental resources through two channels. First, SAPs would increase agricultural productivity and income, and thus reduce households' extraction of environmental resources. Households livelihood based on SAPs can reduce the vulnerability and fluctuation in crop income, and thus concurrently ensure income increase and improvement in living standards that may also translates into less dependence on environmental resources. This channel is "income effect". Likewise, the profitability of farming could imply that households may prefer to convey their labor endowment to farming than collecting environmental products. For example, a study by Teklewold et al., (2013) show that the adoption of SAPs increases women labor supply into agriculture in Ethiopia. This is because as farming becomes profitable via SAPs, the opportunity cost of labor for the extraction of environmental products increases and could lead to less involvement of households in environmental products collection. This second channel is "labour supply effect". Furthermore, environmental products generate a low return and are often categorized as inferior livelihood strategies (Caviglia-Harris and Sills, 2005; Illukpitiya and Yanagida, 2008). However, the literature also points out wealth differentiation and unequal resource utilization among households (Ntuli and Muchapondwa, 2017). In most cases, environmental resources rich areas tend to be tenanted by poor households that have a complex relationship with their surrounding environment (López-Feldman and Chávez, 2017). Apparently, poorer households collect more environmental

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Manda, et al. 2015, Mutenje et al., 2016). The second SAP is adoption of cereal-legume diversification and the third SAP is soil & water conservation practices.

resources than better off households (have higher share of income from environmental resources), while richer households use greater quantities of environmental resources (Cavendish, 2000; Shackleton and Shackleton, 2006; Mamo et al., 2007; Kamanga et al., 2009; Heubach et al., 2011; Faße & Grote; 2013). In this regard, the direction of the effect of SAPs on environmental resource dependence is indeterminate and deserves further attention.

There are few studies that analyzed the effects of different interventions that can boost income from non-environmental livelihood strategies on the environmental reliance of households. For example, income diversification is found to reduce dependence on forests products in the Brazilian Amazon by colonist households (Caviglia-Harris and Sills, 2005). Similarly, Illukpitiya and Yanagida (2008) and Wei et al. (2016) report that income diversification reduces households involvement in forest collection activities in Sri Lanka and in China, respectively. Illukpitiya and Yanagida (2010) also find that forest extraction is a decreasing function of technical efficiency in agricultural production. Fisher and Shively (2005) estimate the effect of Malawi's subsidy program on marketed forest products and find that households who received an agricultural subsidy had lower forest dependance compared to their counterparts. López-Feldmana & Chávez (2016) also reported that remittance from the United States is negatively related to natural resources extraction of resident households in Mexico.

This chapter contributes to the literature on agricultural innovations and environmental resources extraction dependence pathway in many aspects. First, we study the impact of SAPs on environmental income which is measured as the sum of income obtained from the wild and uncultivated natural resources (Sjaastad et al., 2005 and Angelsen et al., 2014). We use an absolute (per capita environmental income) and relative (share of environmental income to total household income) measures of environmental income. Second, we combine household survey data with experimental data that elicit risk preferences of households to investigate the effect of various household characteristics, farm (plot) characteristics and risk preferences on adoption of SAPs and environmental income.

The rest of the chapter is organized as follows. In section two, the sampling procedure, description of SAPs and income accounting from the different livelihood strategies of the household are presented followed by analytical methods used for the empirical estimations in section three. Empirical findings are reported in section four, while we draw a conclusion with potential policy implications in section five.

3.2 Data and description

3.2.1 Sampling Design and data

The data used in this paper is from a survey of 421 households conducted between April and July 2015 in the Upper East Region of Ghana. Our study is part of the West African Science Service Center for Climate Change and Adapted Land Use (WASCAL) project currently running since 2010 in collaboration with the Center for Development Research (ZEF), University of Bonn and partners at ten West African countries.

We follow multi stage purposive and random sampling in selecting the sample households. In the first stage, seven of the thirteen districts in the region were identified based on intensities of SAPs use and forest cover (with the help of officials from the Upper East Region's Agricultural Office and Ghana Forestry Commission). Then, a three-stage stratified random sampling method was used to select the sampled households. At first, four districts (Bongo[16], Bawku West, Kassena Nankana East and Builsa South) were randomly selected from the previously selected seven districts. Second, seven communities were selected from each district. In the final stage, sample households from each community were randomly selected in such a way that the number of sample households taken from each community is proportional to the total number of resident households' in the respective communities.

The sample was drawn from 27 communities in four districts of the Upper East Region of Ghana. Pretesting and adjustment of the survey questionnaire were conducted among 30 randomly selected households prior to the main survey. The survey collected detailed information on agricultural production, inputs use, SAPs adoption, environmental resources extraction and socio-economic characteristics of the households.

We base our analysis on the data collected from the randomly selected 421 households. In addition to the normal household socioeconomic level data, we accounted for the risk preferences of sampled households[17]. We measured households' subjective risk preferences using the Ordered Lottery Selection design with real payoffs (Harrison and Rutström, 2008).

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[16] Six communities were selected from Bongo district because there were relatively high number of households in the communities than the others.

[17] The variables used in the model are presented in Table 2.1 at the appendix

Previous studies (Binswanger 1980, 1981; Wik and Holden, 1998; Yesuf and Bluffstone, 2009) indicated that farmers in developing countries are generally risk-averse and extract environmental resources to cope with risk *ex-ante* (Pattanayak and Sills, 2001) and to cope with shocks *ex-post* (Debela et al., 2012; Pattanayak and Sills, 2001). 'Despite this fact, there is limited information in the literature on the effect of risk preferences on adoption of SAPs and the consequent effect on environmental resources extraction.

Households were asked whether they have adopted the three SAPs (Improved maize seed varieties (V), soil & water conservation measures (C) and Crop-cereal diversification (D). The adoption of these three SAPs leads to eight possible combinations and households are assigned to one of the eight mutually exclusive options based on their conditional adoption of SAPs. The eight possible combinations are: Improved maize seed varieties only ($V_1C_0D_0$)[18], soil & water conservation measures only ($V_0C_1D_0$), cereal-legume diversification only ($V_0C_0D_1$), improved maize seed varieties and soil and water conservation ($V_1C_1D_0$), improved maize seed varieties and cereal-legume diversification ($V_1C_0D_1$), soil & water conservation and cereal-legume diversification ($V_0C_1D_1$), improved seed maize varieties, soil & water conservation and cereal-legume diversification ($V_1C_1D_1$) and the base category which contains the non-adoption of the three SAPs ($V_0C_0D_0$) at household level. Our treatment variables are, therefore, the adoption of these three SAPs in isolation and in the possible combinations. But, in our data, we find that the SAP category improved maize varieties and soil & water conservation only ($V_1C_1D_0$) was adopted by only eight households. This shows that we have too few observations in this category, treating it separately would make the model not to converge due to the negative degrees of freedom. Hence, we have combined this category with the soil & water conservation and cereal-legume diversification only ($V_1C_1D_0$) category[19]. This leads us to seven SAPs categories. The distribution of SAPs among households is presented in Table 3.1.

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[18] The subscript "1" shows the presence of the specific SAP and "0" indicates its absence

[19] This method of combining different packages in the case of few observation in certain packages have been used in the literature. For example, see Mutenje, et al., 2016 and Di Falco and Verona, 2013

Table 3. 1 Distribution of SAPs packages at household level

SAP Categories	Frequency	Percent (%)	Cum.
$V_0C_0D_0$	96	22.8	22.8
$V_1C_0D_0$	42	9.98	32.78
$V_0C_1D_0$	31	7.36	40.14
$V_0C_0D_1$	102	24.23	64.37
$V_1C_1D_0$ & $V_0C_1D_1$	40	9.5	73.87
$V_1C_0D_1$	51	12.11	85.99
$V_1C_1D_1$	59	14.01	100
Total	**421**	**100**	

Source: Authors calculation based on survey data

3.2.2 Income accounting and definition of terms

Through the household survey, we have collected detailed data on all income sources including income from environmental resources. Following Cavendish (2000, 2002) we define total income as the value of cash revenue, subsistence and net (cash or in-kind) gifts and transfer incomes minus the cost of variable inputs and hired labor. We use local market prices in weighing the different components of income generated by the household over one year period. We did not deduct the cost of family labour due to the difficulties of finding appropriate labour shadow wages in the presence of ill-functioning or absent labour markets as it is argued in the literature (Babulo et al., 2009; Babulo et al., 2008; Co´rdova et al., 2013; Campbell and Luckert, 2002; Dokken and Angelsen, 2015; Nielsen et al., 2012; Sjaastad et al., 2005). The total household income comes from four livelihood strategies: crop income, livestock income, non-farm income, and environmental income. We define and calculate the income from each of these four categories as follows.

Net Crop Income: Net crop income is estimated by valuing the total crop productions of the household in a year at the market prices minus the variable input costs. The values of variable inputs such as the cost of fertilizer, cost of seed, cost of manure, cost of plowing and cost of hired labor were estimated and deducted from the total gross crop income to obtain the net crop income.

Net Livestock Income: Livestock income consists of three sub-components: livestock products, livestock sales, and services. Summing the incomes from the three sub-components yields the total gross livestock income. To find the net livestock income, we deducted costs associated with the rearing of livestock such as the cost of animal feeds, veterinary medicines and hired labor from the total gross livestock income.

Non-farm Income: Non-farm income constitutes income that is not related to direct farming. This comprises income from petty trade, wage employment, remittances from friends and relatives and other cash-generating own business activities. Like the other income sources, non-farm income is also calculated in net terms, that is, the cost incurred in the process of obtaining it is deducted.

Environmental Income: There is no clear definition of what environmental products are and the definition of environmental income has been at the center of debate for many decades (de Beer and McDermott, 1989). We adopted the definition of environmental income following Sjaastad et al., (2005); Angelsen et al., (2014) and Lopez-Feldman & Chavez, (2016) who defined environmental income as an income that comes from wild or uncultivated natural resources and therefore, their stock is not as a result of human productive process. By this definition, income from commercial plantations and domesticated fruits were not included because commercial forests and fruits are investment ventures and the return from such plantations is considered as "profit", not an environmental income (Babulo et al., 2008)[20]. Therefore, in this study our environmental income comes from three sources (Babulo et al., 2009), income from protected forest areas, income from other communally owned forest lands & grazing fields and income from the communal forest which is found in homesteads & agricultural fields. Protected areas are forest areas owned by the state and community with restricted access. The harvesting of environmental products from protected areas is regulated mainly by the Ghana Forestry Commission with the help of local communities. However, illegal harvest from these protected areas is a common trend as in many African countries. This is mainly due to the institutional failure and public good nature of most of the environmental products and therefore it is subjected to excess extraction to supplement subsistence incomes. Hence, protected areas are one of the essential sources of environmental income either in the form of community regulated harvest or illegally. Income from the communal forest and grazing lands come from the community-level managed or semi-open access forest land use types such as community-owned woodlands and grazing fields. They are different from protected areas because their access is not restricted. Most of our sample households claim that their major source of fuelwood, farm implements, construction materials, household furniture, wild meat and wild fruits comes from these community forest areas and grazing fields. The third component of environmental income comes from forest plants found around

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[20] We have included income from commercial forests and perineal fruits in the crop income category

agricultural lands. These are normally naturally grown forest plantations which are found in crop fields. Their access and use are not restricted. For example, some farm households harvest shea nut from own agricultural lands as well as from shea trees found elsewhere in crop fields in the community.

Quantifying income from environmental products is a difficult and challenging task. In response, only a few studies have attempted estimating the economic value of environmental goods (Reddy and Chakravarty, 1999). The challenge ranges from not revealing the true quantities of environmental products harvested to totally neglecting some environmental products in the survey. In this study, a market-based approach and self-reported value of environmental products were used in calculating the income from the environmental products (Cavendish, 2002; Babulo et al., 2008; Pouliot et al. 2008; Obiri et al., 2011). To minimize the bias in environmental income accounting, we follow the following methods. First, with the help of local residents and experts from the Ghana forestry commission, we identified the possible environmental products collected in each of the communities and listed down all the environmental products in the questionnaire. We then ask one by one if the household had extracted the specified environmental product in the past 12 months prior to the survey. Then, we asked the household the common measurement units that are used to collect the specific environmental products and asked about the quantities of that specific environmental product collected in a year and the prices. We valued the environmental products using average own reported values for the non-marketed environmental products extracted in the year. As households use different measurement units to collect the environmental products, we find this to be justifiable and convenient.

3.2.3 Outcome Variables

We are interested in how SAPs affect environmental resources extraction as a means of livelihood. Environmental reliance can be measured in absolute or in relative terms. Absolute environmental income refers to the total value of environmental resources extracted in a given period in standardized terms such as per capita environmental income. The relative term refers to the relative importance of environmental resources to total household income. Therefore, relative environmental income is calculated by dividing the total value of environmental income extracted by the total income of the household. It has been claimed that poor households depend more on the environment in relative terms, while better off households depend more in absolute terms. Therefore, we have used both measures as indicators of environmental reliance.

3.3 Methodology

3.3.1 The Multinomial Endogenous Treatment Effect Model (METEM)

As in many developing countries, households in rural areas in Ghana rely on different activities (e.g. agriculture, non-farm, livestock and environmental resources extraction) for their livelihood, and do allocate their labor, capital and time to such activities to meet household needs. The estimation strategy is based on the assumption of an underlying process of household utility maximization. SAPs can affect the labor supply and crop incomes of households and therefore have an effect on households' livelihood strategies. As farmers may endogenously self-select in their adoption of SAPs, decisions of adoption are likely to be influenced systematically both by observed and unobserved characteristics that may be correlated with the outcome variables of interest (environmental reliance indicators). This suggests a valid methodology must be used to extricate the causal effect of SAPs on environmental reliance outcomes. Hence, we model the farmers' choice of the combinations of SAPs and the impacts of adoption in a Multinomial Endogenous Treatment Effect Model (METEM) framework (Manda et al., 2015; Mutenje et al., 2016).

It is assumed that farmers adopt a single SAP or combination of SAPs that can provide maximum utility to them. The multinomial endogenous treatment effect model consists of two steps. In the first stage, a farmer chooses one of the seven possible combinations of SAPs. Following Deb and Trivedi (2006a,b), let V_{ij}^{*} be the latent variable that captures the ith farmer's behavior in adopting SAP packages j (j=0,1….J) instead of implementing any other strategy k. The latent variable can be specified as

$$V_{ij}^{*} = z_i^{'}\alpha_j + \sum_{k=1}^{J}\delta_{jk} l_{ik} + \eta_{ij} \qquad (10)$$

Where z_i is a vector of observed independent variables such as socioeconomic, social capital, risk aversion that affect the decision to adopt a specific SAP package and the outcome of interest, α_j is the vector of corresponding parameters to be estimated; η_{ij} are the independently and identically distributed error terms; l_{ik} is the latent factor that incorporates the unobserved characteristics common to the households implementation of SAPs and the outcome variables (environmental reliance), such as the technical abilities of the farmer in examining new technologies, imperfect rural labor market structure, information asymmetry and/or high transaction cost incurred (Mutenje et al., 2016; Manda et al., 2015; Abdulai and Huffman, 2014; Pender and Kerr, 1998). Following Deb and Trivedi (2006b), let j=0 represents the non-adopters of any of the SAPs at the household level and $V_{i0}^{*} = 0$. While V_{ij}^{*} is not observed, one can observe the choices of SAP packages in the form of a set of binary variables and these are collected by a vector, $d_i = d_{i1}, d_{i2}, d_{i3} \ldots\ldots\ldots\ldots d_{iJ.}$ Similarly, let $l_i = l_{i1}, l_{i2}, l_{i3} \ldots, l_{iJ.}$ Then the probability of treatment can be written as:

$$\Pr(d_i | z_i, l_i) = g\left(z_i^{'}\alpha_1 + \sum_{k=1}^{J} \delta_{1k} l_{ik} + z_i^{'}\alpha_2 + \sum_{k=1}^{J} \delta_{2k} l_{ik} + \ldots\ldots + z_i^{'}\alpha_J + \sum_{k=1}^{J} \delta_{Jk} l_{ik} \right) \tag{11}$$

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

$$\Pr(d_i | z_i, l_i) = \frac{\exp(z_i^{'}\alpha_j + \delta_j l_{ij})}{1 + \sum_{k=1}^{J} \exp(z_i^{'}\alpha_k + \delta_k l_{ik})} \tag{12}$$

The impacts of the SAPs on the environmental reliance outcomes can be estimated in the second stage of the model. The expected outcome equation is formulated as below:

$$E(y_i | d_i, x_i, l_i) = x_i^{'}\beta + \sum_{j=1}^{J} \gamma_j d_{ij} + \sum_{j=1}^{J} \lambda_j l_{ij} \tag{13}$$

In the above equation y_i are the environmental reliance outcome measures, i.e., environmental income per capita and share of environmental income to the total household income, for a household i; x_i represents exogenous explanatory variables with parameter vectors β. Parameters represent the treatment effects of the SAPs adopted relative to the non-adopters. Specifically, coefficients γ_j indicate the impacts of SAPs on the environmental reliance of farm households. Since $E(y_i | d_i, x_i, l_i)$ is a function of the latent factors l_{ij}, the outcome variables could be affected by unobserved characteristics that potentially affect the selection into SAPs adoption. It is also important to note that when the factor-loading parameters (λ_j), is positive (negative), treatment and outcome variables are positively (negatively) correlated with unobservable characteristic, i.e there is positive (negative) selection, with γ and λ the associated parameter vectors, respectively (Manda, et al., 2015). Because our outcome variables are continuous, we follow a normal (Gaussian) distribution function and the model was estimated using Maximum Simulated Likelihood (MSL) method.[21]

The parameter coefficients of the multinomial treatment effect model can be obtained even when an exclusion restriction variable is not included in the treatment equation. But Deb and Trivedi (2006) recommend the use of at least one exclusion restriction or instrumental variable for a more robust identification. As previous studies indicated, getting a valid instrument is theoretically and empirically challenging (Manda et al., 2015; Teklewold et al., 2013; Di Falco et al., 2011). We used previous information or training about SAPs as an instrumental variable. The instrumental variable is a binary variable which takes 1 if a sampled household had information or prior training about SAPs in demonstration plots, and zero, otherwise. Though in most cases the primary sources of information are usually through government extension agents, demonstration plots are also important sources of information on SAPs (Manda et al., 2015). In addition, in our study area, there has been a demonstration training programs in the past, for example through the Root and Tuber Improvement and Marketing Programme (RTIMP) in the Farmers Field Fora (FFF) framework, where farmers were grouped and demonstrate agricultural activities. Information or previous training about SAPs is likely to enhance SAPs adoption but is unlikely to have any direct effect on environmental reliance, unless through the adoption of SAPs for the adopter sub-sample households. Previous studies in Africa have proven that information or training about SAPs can be used as a valid instrumental variable (Di Falco et al., 2011; Di Falco and Veronesi, 2012; Manda et al., 2015).

We conducted a simple admissibility test of our instrument following Di Falco et al., (2011). According to this test, an instrument is valid when it significantly affects the adoption decision of the different combinations of SAPs but should not significantly affect the outcome variables for the non-adopter subsamples. As can be seen from the results of the determinants of SAPs in Table 3.6 and Table 3A.1, our instrumental variable significantly correlates with the adoption of most of the SAPs categories but does not significantly affect

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[21] We have estimated the model using the Stata command *mtreatreg* which is an extension of the *treatreg* Stata command of a multinomial approach by Deb (2009).

our environmental reliance outcome variables for the sub-sample of non-adopters (See Table 3A.3 in the appendix). This suggests that our instrumental variable can be taken as a valid instrument.

3.4 Results and Discussion

3.4.1 Descriptive Statistics

Before we move on to the econometric analysis of the determinants of SAPs and the effect of SAPs on environmental reliance, it is imperative to first look at the characteristics of the sample households. The summary statistics of the explanatory variables used in the econometric model are presented in Table 3.2. The mean value of the descriptive statistics for the different SAPs adopters is compared to the base category of the non-adopters for the different variables of interest. The total sample mean of each of the explanatory variables is also presented in the 8th column of Table 3.2. These summary statistics show that there is a considerable significant difference between the different SAPs adopters and non-adopters in terms of the different explanatory variables used in our model. For example, household head of adopters of the SAPs spent from 1.68 to 3.05 years in school, while for the non-adopter households, the head spent only 0.46 years in school, on average. The sample average number of years spent in school is estimated to be 1.78 years.

Table 3. 2 Descriptive Statistics of the Variables included in the environmental reliance model

VARIABLES	$V_0C_0D_0$	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_0D_0$	Total Mean	Standard deviation
Household Characteristics									
Age of the household	56.5	50.69**	53.64	55.04	54.2	50.45**	51.88*	53.76	0.7
Gender head	0.76	0.88	0.77	0.83	0.75	0.9**	0.93***	0.83	0.02
Family size	6.4	7.1	7.06	6.44	7.83**	6.39	6.76	6.71	0.14
Education of head	0.46	3.05***	1.68***	1.92***	1.73***	2.31***	2.39***	1.78	0.16
Resource Constraints and market access									
Distance to forest	3326.56	2397.61*	4503.23**	3296.37	3829	3815.69	3384.75	3428.36	125.12
Distance to (forest) output market	72.29	73.36	72.52	99.46*	75.85	89.63*	63.63	80.22	4.07
Distance to input market	115.96	92.02*	90.03	120.93	91.08	107.08	100.14	107.20	3.58
Credit constrained	0.24	0.17	0.32	0.06***	0.05	0.33	0.15	0.18	0.02
Assets value (log)	7.28	7.58*	7.62*	7.63***	7.66**	8.04***	7.91***	7.64	0.04
Total livestock holdings	3.19	5.86***	4.59*	4.16	3.79	6.57***	7.3***	4.84	0.29
Total cultivated land (log)	1.64	1.82**	1.61	1.69	1.66	1.78	1.92***	1.73	0.03
Death shock	0.63	0.50	0.77	0.56	0.60	0.61	0.61	0.60	0.02
Social Capital and Information									
Group membership	0.24	0.52***	0.35	0.30	0.38	0.61***	0.66***	0.41	0.02
Village kinship	2.79	4.4*	4.58**	3.94	3.10	4.47**	5.95***	4.04	0.28
Non-village kinship	1.36	1.90	3.13**	4.16***	2.75**	3.88***	3.42***	2.95	0.30
Extension contact	0.35	0.76***	0.74***	0.37	0.65***	0.69***	0.66***	0.54	0.02
Climate change awareness	0.83	0.88	0.94	0.92*	0.98**	0.92	0.97**	0.91	0.01

Table continued 3.2

VARIABLES	**$V_0C_0D_0$**	**(1) $V_1C_0D_0$**	**(2) $V_0C_1D_0$**	**(3) $V_0C_0D_1$**	**(4) $V_1C_1D_0$/ $V_0C_1D_1$**	**(5) $V_1C_0D_1$**	**(6) $V_1C_1D_1$**	**Total Mean**	**Standard deviation**
Risk Preference									
Extreme risk averse	0.31	0.14**	0.26	0.23	0.20	0.14**	0.07***	0.20	0.02
Severe risk averse (RA)	0.21	0.10	0.13	0.18	0.13	0.16	0.17	0.16	0.02
Moderate RA	0.14	0.21	0.03	0.09	0.13	0.14	0.19	0.13	0.02
Intermediate RA	0.24	0.19	0.29	0.13**	0.13	0.16	0.08**	0.17	0.02
Slight to neutral RA	0.03	0.19***	0.10	0.2***	0.18***	0.18***	0.1*	0.13	0.02
Neutral to preferring RA	0.07	0.17*	0.19*	0.19**	0.25***	0.24***	0.40***	0.20	0.02
Instrumental Variable									
SAPs Information/training	0.24	0.79***	0.68***	0.36*	0.60***	0.69***	0.76***	0.52	0.02
N	**96**	**42**	**31**	**102**	**40**	**51**	**59**	**421**	

Note: Each SAPs packages are compared with the base category (non-adopters) ($V_0C_0D_0$) which has 96 observations at household level.*, **, *** denotes significance level at 10%, 5% and 1% respectively.

3.4.2 Income profile of the sample households

Table 3.3 presents the income portfolio of households with a focus on household income share of the four livelihoods described in section two. The main source of income is crop production, which constitutes 42% of the total household income. This result is consistent with previous studies in different countries where crop income is ranked first in terms of contribution to the total household income (Yemiru et al., 2010; Babulo et al., 2009; Illukpitiya and Yanagida, 2008; Ambrose-oji, 2003; Asfaw et al., 2013). However, other studies have shown that other income sources such as off-farm income and forest environmental income contribute more than any other income source to the total household income. For example, Kamanga et al., (2009) and Vedeld et al., (2007) reported that off-farm income contributes more to the total household income than any other income source. On the other hand, Mamo et al., (2007) report that income from crops and forest-related income contributes equally to the total household income of the households. Their further analysis based on the quantile income shows that forest-related income contributes more than any other income source for the poorest quantile in a village found in Ethiopia. In this study, it is found the income from livestock contributes only about 8% to the total household income. This is a prominent figure because African agriculture is believed to be a crop-animal mixture and the livestock sector to play a role equal to the crop sector. But this could not be a surprising result as our study area is characterized by prolonged dry season and hence fodder for livestock is always a challenge. As a result, farm households are forced to raise fewer animals. This result suggests that the livestock sector contributes less to the total household income.

Various types of environmental products are collected by the households. These include firewood, charcoal, vegetables and fruits, shear nut & butter, wild honey, wild meat (deer, birds, snakes, lizards, toads, mollusks, and flies), mushrooms, bamboo shoots, thatch grass, fencing materials, farm implements and other environmental products. As can be seen from the third column of Table 4, overall, the extraction of environmental resources contributes about 30% of the total annual household income in the study area. Our findings fall within the environmental income share found by previous studies elsewhere in Sub-Saharan Africa, although, the comparability of these studies is difficult as most of them include a subset of environmental products in most cases. For example, a study in Malawi by Kamanga et al., (2009) found that forest income contributes about 15% to total household income. In Ethiopia, Yemiru et al (2010) report that forest environmental income accounts for about

34% and 53% of the total annual household income and total cash income respectively. Other studies from Ethiopia by Gatiso and Wossen, (2014) and Babulo et al., (2009) found a 37.5% and 27% contribution of forest income to total household income, respectively. In the Republic of Congo, de Merode et al., (2004) found a 10% contribution of forest products to total household income. However, few studies of the semi-arid tropics of Western Africa have found the contribution of environmental resources to be a little higher than our findings. For example, in Northern Benin, Heucbach et al., (2012), found that non-timber forest products (NTFPs) contribute up to 39% of total household income and this income from NTFPs had a strong equalizing effect by reducing poverty gaps among the rich and poor households. Based on income quintile analysis, Pouliot et al., (2013), found the contribution of environmental income to be between the range of 30–35% of total annual household income for the poorest households and 9–10% of total annual income for the richest households in Burkina Faso and Ghana. In Southern Ghana, Appiah et al., (2009) found the contribution of forest income to be about 38% of the total annual household income. A recent comprehensive global study of over 8,000 households from 24 developing countries, found 28% of environmental income share (Angelsen et al., 2014). This shows that our findings concerning the share of environmental income to the total household income are consistent with results from previous studies, particularly with the previous studies that are conducted in the West African Savannah[22]. Finally, the fourth income category, off-farm income, contributes up to 21 % of the total household income.

Table 3. 3 Households annual mean income and their shares by income source

Income component	**Average income per capita by income source (GH¢)**[23]	**Income shares**
Crop income	497.51	41.74
Livestock income	109.88	7.62
Environmental income	326.69	29.9
Non-farm income	243.7	20.74
Total	**1177.78**	**100**

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[22] See for example Heucbach et al., (2012) and Pouliot et al., (2013)

[23] GH¢ is the sign for the Ghanian currency which is normally called "cedi"

3.4.2 Absolute environmental reliance of households

The importance of environmental income to the farm households is presented below. Table 3.4 reports the total environmental income of households in per capita terms for the seven categories of households based on their SAPs adoption status. The average environmental resources income per capita is estimated to be 327GH¢. When the total sample is divided into seven categories based on SAPs adoption status, in absolute terms, annual per capita environmental income is higher in the sub-category of non-adopter of SAPs (398 GH¢) and lowest in the sub-category of households who adopts all of the three SAPs (190GH¢).

Table 3. 4 Environmental income per capita by SAPs adoption

SAP Categories	Average environmental income per capita(GH¢)
$V_0C_0D_0$	397.61
$V_1C_0D_0$	281.91
$V_0C_1D_0$	383.45
$V_0C_0D_1$	390.41
$V_0C_1D_1$/$V_1C_1D_0$	225.52
$V_1C_0D_1$	305.64
$V_1C_1D_1$	189.98
Total	**326.69**

3.4.4 Share of Income Based on SAPs Adopted

Table 3.5 presents the income shares for the four livelihood categories based on the SAPs adoption status of the households. We find a significant difference in the share of income from crops among the households based on their SAPs adoption status. This share ranges between 30% for the base category of households and 61% for the category where all the three SAPs are adopted. This indicates the importance of SAPs in boosting crop production in the study area, not only to improve the welfare of households but also to reduce environmental degradation and deforestation. The share of livestock income to the total household income also ranges between 4% and 11% among the household groups based on their SAPs adoption. The share of environmental income ranges between 15 to 40%. An important observation is that the share of income from environmental resources to total household income decreases monotonically among the SAPs adoption pathways. In all the household categories crop income contributes more than any of the other income sources except for the base category of households where it is found that the environmental-related income contributes more to the total household income. The contribution of the fourth livelihood strategy (non-farm income) to the total household income ranges between 17-22%.

Table 3. 5 Income shares of livelihood strategies by SAPs adoption

Income component	$V_0C_0D_0$	$V_1C_0D_0$	$V_0C_1D_0$	$V_0C_0D_1$	$V_1C_1D_0$/ $V_0C_1D_1$	$V_1C_0D_1$	$V_1C_1D_1$
Crop income	30.17	42.34	38.33	39.95	44.41	44.79	60.56
Livestock income	8.72	6.71	9.52	6.98	6.77	11.08	4.17
Environmental income	39.44	28.15	34.81	33.18	27.95	22.41	15.23
Off Farm income	21.68	22.81	17.35	19.88	20.87	21.73	20.04
Observation	**96**	**42**	**31**	**102**	**40**	**51**	**59**

3.4.5 Determinants of SAPs Adoption

Previous literature (Beyene, et al., 2017; Teklewold et al., 2017; Manda et al., 2015; Teklewold et al., 2013) show that the adoption of SAPs is determined by a set of household socio-economic characteristics, institutional factors, risk preference, climatic and shock factors. Table 3.6 presents results from the maximum likelihood estimation of the multinomial treatment effect model on the determinants of SAPs adoption. The dependent variable is divided into six categories. The non-adopters group serves as a base category. Based on the results of the wald test $(\chi^2 = 1139.73 \qquad P > \chi^2 = 0.000)$, we note that our data fit the model well and we hereby reject the null hypothesis of the coefficients for the variables in the model being zero.

The respective coefficients of each of the explanatory variables measure the effect of the specific variable on the relative likelihood that the household chooses the particular SAPs compared to the non-adopters category. We estimated two different specifications of determinants of SAPs adoption for the two-second stage dependent variables: absolute and relative environmental reliance measures i.e., environmental income per capita and share of environmental income to household income. The results for the determinants of SAPs adoption are robust to the alternative model specifications, so unless otherwise stated, we focus our discussions below on the absolute environmental reliance model results. The results for the second model, where the share of environmental income to total household income is the second stage dependent variable, are also presented in Table 3A.1 in the Appendix.

Our results in Table 3.6 reveal that age of the household head has a negative effect on most of the SAPs categories adoption. Specifically, the age of the household head negatively and significantly affects the adoption of improved maize varieties only ($V_1C_0D_0$).Our result is consistent with other studies elsewhere for multiple technology adoption settings (Ndiritu et al., 2014; Kassie et al., 2015). Our result also shows that gender of the household head is positively and significantly related to soil & water conservation with the improved maize seed varieties or cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$) SAP package. Furthermore, family size of the household increased the adoption propensity of the SAP package soil & water conservation with improved maize seed varieties or cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$). This could be justified on the grounds that, the practice of soil & water conservation is labor-intensive and competes with other activities of the household and therefore, relatively larger-sized households are in a better position to adopt this strategy due to their higher labor availability than those with relatively smaller size. One of the important household-level characteristics is found to be the education level of the head. The education level of the head increases the adoption propensity of most of the SAPs combinations. Specifically, education level of the household head is positively and significantly related to the SAPs, improved maize varieties only ($V_1C_0D_0$), cereal-legume diversification only ($V_0C_0D_1$), soil & water conservation with improved maize seed varieties or cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$) and with the most comprehensive SAP category that holds all the three SAPs ($V_1C_1D_1$). This result suggests the importance of human capital in SAPs adoptions.

Variables related to resource constraint and market access are also found to affect the decision to adopt SAPs. We found that distance to the forest reserve negatively relates to the adoption of improved maize only ($V_1C_0D_0$) SAP. On the contrary, distance to the main market is positively related to the cereal-legume diversification only ($V_0C_0D_1$). The effect of credit constraint on the likelihood of adoption of SAPs conveys an interesting result. Farmers in developing countries faced with different challenges including lack of access to credit and markets. Our results show that credit constrained farmers are less likely to adopt the SAPs packages of improved maize varieties only ($V_1C_0D_0$), cereal-legume diversification only ($V_0C_0D_1$), soil & water conservation with improved maize seed varieties or cereal-legume diversification ($V_1C_1D_0$/$V_0C_1D_1$) and the most comprehensive SAP category that holds all the three SAPs ($V_1C_1D_1$). The effect of the credit constraint with respect to the adoption of multiple SAPs is consistent with the findings of Teklewold et al., (2013). Our results further show that wealth indicators of the household such as asset holdings, livestock holdings, and total land holdings are positively associated with the adoption of the different combinations of SAPs, and when they are found to influence in the contrary, their effect is not significant. This result is consistent with the economic theory that better-off farmers have better access to SAPs than their counterparts. Specifically, asset ownership positively and significantly affects the likelihood of adoption of improved seed maize varieties with cereal-legume diversification ($V_1C_0D_1$). Ownership of livestock, measured in tropical livestock units (TLU), positively and significantly increases the likelihood of adoption of improved maize varieties only ($V_1C_0D_0$), soil & water conservation only ($V_0C_1D_0$), improved maize seed varieties with cereal-legume diversification ($V_1C_0D_1$) and the most comprehensive SAP category that holds all the three SAPs ($V_1C_1D_1$).

The other strands of variables that are found responsible for the likelihood of adoption of the different combinations of SAPs are those related to social capital and information access. Membership in a group is found to have a positive effect on the adoption of SAPs such as improved maize seed varieties with cereal-legume diversification ($V_1C_0D_1$) and the adoption of all SAPs together ($V_1C_1D_1$). This can be justified by the fact that when farmers participate in group associations, they are likely to share information with each other and hence improve the adoption of best farm practices. Non-village kinships are also found to have a positive and significant effect on the adoption of some of the SAPs categories. We found contact with an extension agent in the year prior to the survey to have a positive effect on the likelihood of adoption of soil & water conservation ($V_0C_1D_0$). Extension service can be a panacea for farmers' access to information which could induce adoption of SAPs. Perception of climate change is also related positively to the adoption of the cereal-legume diversification only ($V_0C_0D_1$). This result underscores the importance of social capital and information access on the adoption of SAPs.

Risk preference of the household is also an important factor influencing SAPs adoption. Generally, we find that risk preferring households intend to adopt SAPs than the risk-averse households.

Table 3. 6 Household level mixed multinomial logit model estimates of adoption of SAPs in Upper East Region of Ghana (baseline category is non-adopters of any SAPs

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_0D_0$
Household Characteristics						
Age of the household	-0.0353*	-0.0135	-0.00317	-0.0156	-0.0222	-0.0417**
	(0.0186)	(0.0199)	(0.0151)	(0.0172)	(0.0166)	(0.0178)
Gender head	0.717	-0.308	-0.428	-1.352**	0.658	0.330
	(0.668)	(0.703)	(0.519)	(0.684)	(0.696)	(0.679)
Family size	0.0619	0.0758	-0.0165	0.188**	-0.146	-0.0386
	(0.0962)	(0.0984)	(0.0768)	(0.0948)	(0.0934)	(0.0966)
Education of head	0.299**	0.243	0.300**	0.348**	0.200	0.280*
	(0.150)	(0.186)	(0.144)	(0.159)	(0.155)	(0.153)
Resource Constraints and market access						
Distance to forest	-0.000253**	0.000142	-7.85e-05	6.57e-05	5.34e-05	-5.99e-05
	(0.000126)	(9.54e-05)	(8.01e-05)	(9.11e-05)	(8.09e-05)	(9.90e-05)
Distance to (forest) output market	0.00280	0.00192	0.00459*	0.00391	0.00334	-0.00889*
	(0.00339)	(0.00338)	(0.00240)	(0.00284)	(0.00287)	(0.00474)
Distance to input market	-0.00185	-0.00195	0.00217	-0.00435	0.00187	0.000697
	(0.00401)	(0.00367)	(0.00256)	(0.00401)	(0.00370)	(0.00328)
Credit constrained	-1.130*	-0.272	-2.476***	-3.056***	-0.273	-1.521**
	(0.636)	(0.566)	(0.581)	(0.831)	(0.587)	(0.630)
Assets value (log)	0.285	0.0315	0.410	0.402	0.539*	0.173
	(0.312)	(0.308)	(0.257)	(0.379)	(0.281)	(0.310)
Total livestock holdings	0.133***	0.111**	0.0486	-0.00354	0.116**	0.177***
	(0.0487)	(0.0473)	(0.0564)	(0.0693)	(0.0490)	(0.0472)
Total cultivated land (log)	-0.635	-0.176	-0.164	-0.0467	0.121	0.846*
	(0.498)	(0.515)	(0.383)	(0.498)	(0.437)	(0.462)
Death shock	0.0842	1.107*	-0.0689	-0.0164	0.779	0.443
	(0.527)	(0.649)	(0.418)	(0.560)	(0.499)	(0.523)

Table 3.6 Continued

VARIABLES	**(1)** **$V_1C_0D_0$**	**(2)** **$V_0C_1D_0$**	**(3)** **$V_0C_0D_1$**	**(4)** **$V_1C_1D_0$/ $V_0C_1D_1$**	**(5)** **$V_1C_0D_1$**	**(6)** **$V_1C_1D_1$**
Social Capital and Information						
Group membership	0.629	-0.0704	0.240	0.262	1.357**	1.496***
	(0.496)	(0.642)	(0.471)	(0.575)	(0.552)	(0.529)
Village kinship	0.0977*	-0.0325	-0.0543	-0.0906	-0.0573	0.0820
	(0.0582)	(0.0581)	(0.0558)	(0.0633)	(0.0722)	(0.0617)
Non-village kinship	-0.0664	0.106	0.161***	0.175***	0.123*	0.0520
	(0.0867)	(0.0667)	(0.0547)	(0.0614)	(0.0686)	(0.0628)
Extension contact	0.345	1.179*	-0.0664	0.951	0.297	-0.500
	(0.601)	(0.658)	(0.490)	(0.615)	(0.547)	(0.597)
Climate change awareness	0.530	1.133	1.254	1.711	0.729	1.731*
	(0.778)	(0.954)	(0.803)	(1.188)	(0.870)	(0.980)
Risk Preference						
Severe risk averse (RA)	-0.895	-0.792	0.222	0.0680	-0.0482	1.815**
	(0.865)	(0.925)	(0.581)	(0.821)	(0.783)	(0.781)
Moderate RA	0.0555	-2.478**	-0.102	0.409	-1.024	1.516*
	(0.899)	(1.212)	(0.704)	(0.908)	(0.916)	(0.801)
Intermediate RA	-0.327	-0.249	-0.434	0.404	-0.765	0.635
	(0.769)	(0.769)	(0.578)	(0.814)	(0.790)	(0.854)
Slight to neutral RA	1.552	0.734	2.383**	2.575**	1.462	2.918**
	(1.107)	(1.092)	(1.002)	(1.039)	(1.089)	(1.149)
Neutral to preferring RA	1.044	1.162	1.461**	2.400***	1.439*	3.488***
	(0.870)	(0.943)	(0.694)	(0.857)	(0.858)	(0.896)
Instrumental Variable						
SAPs information/training	2.251***	1.488**	0.436	0.805	1.736***	2.299***
	(0.618)	(0.746)	(0.484)	(0.644)	(0.547)	(0.616)
Constant	-3.222	-6.207**	-5.220**	-9.294***	-7.848***	-8.593***
	(2.308)	(2.691)	(2.084)	(2.960)	(2.423)	(2.419)
District Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	**421**	**421**	**421**	**421**	**421**	**421**

$\chi^2 = 458.66***$. ***<0.01, **<0.05, *<0.1. Robust standard errors in parenthesis. District controls are included but not reported.

3.4.6 Impacts of SAPs on environmental reliance

Table 3.7 presents the results of the effects of the adoption of different combinations of SAPs[24] on households' reliance on environmental resources estimated using the multinomial treatment effect model. The outcome variables of interest are absolute and relative measures of environmental products reliance i.e. annual environmental income per capita and share of environmental income to the total household income.

The model generates interesting results which contribute to the better understanding of the relationship between SAPs adoption and environmental reliance outcomes. It also provides an additional important insight into the few studies that examined the relationship between interventions that improve households' income, except environmental income, and environmental reliance outcomes. Previous works by Illukpitiya and Yanagida, (2008) and Wei et al., (2016) show how forest reliance relates to income diversification of households. The authors show that household's engagement in different forms of income activities reduces their reliance on environmental products. Similarly, Illukpitiya and Yanagida, (2010), estimated the effects of technical efficiency of households in agriculture on forest reliance and found that an increase in technical efficiency reduces extraction of non-timber forest products. Furthermore, Fischer and Shively, (2005) show how income shocks due to technology assistance programme related to forest pressure in Malawi and found that technology assistance program reduces forest pressure. López-Feldmana & Chávezb (2017) estimated the effects of remittances from the United States to Mexico and found that remittances reduce household's extraction of environmental resources. Our study complements these studies but from a different perspective i.e. adoption and use of different combinations of SAPs and their impact on environmental products reliance.

The results of the study point to the possibilities of reducing households' annual environmental income per capita through the use of the different combinations of SAPs. A measure of the absolute environmental income, annual environmental income per capita, shows that environmental reliance decreases with the adoption and use of the SAPs. We find a significant impact of SAPs in reducing environmental reliance, except when soil and water conservation is adopted in isolation. We find that the adoption of improved maize seed varieties only ($V_1C_0D_0$), ceteris paribus, reduces annual environmental income per capita by about 7%. Similarly, the causal impact of cereal-legume diversification ($V_0C_0D_1$),

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[24] Other variable determinants of environmental reliance are presented in Table 3A.2 in the appendix

when other factors are held constant, is about 6.8% in reducing environmental income per capita as compared to the base category. The study did not find a significant statistical evidence of the impact of soil & water conservation when it is implemented in isolation in reducing environmental income per capita. However, the study found a positive and slightly higher effect when SAPs are adopted in some form of combinations, as compared to when they are adopted in isolation. Specifically, the causal impact of the SAP soil & water conservation with improved maize seed varieties or cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$) is around 9.4% in reducing environmental income per capita. Similarly, the effect of improved maize seed varieties with cereal-legume diversification ($V_1C_0D_1$) is about 9.7% in reducing environmental income as compared to the base category. Most importantly, results show that a higher impact on environmental resources reliance is obtained when the three SAPs are adopted altogether by the households. In quantitative terms, the causal impact of the adoption of improved maize varieties, soil and water conservation and cereal-legume diversification ($V_1C_1D_1$) together, leads to a reduction of 15.2% in environmental income per capita than the non-adopter category of households. The slightly higher effects of SAPS as one moves from the adoption of a single strategy, to double, and then to all three shows that there is a synergistic effect of the SAPs in reducing the environmental reliance of households on environmental products.

Results of the relative measure of environmental reliance, i.e., share of environmental income to total household income, also generate comparable results with the absolute measure of environmental reliance in terms of statistical significance. However, the effect of the change is much higher in the case of relative environmental reliance measure as compared with the absolute environmental reliance outcome measure.

The results show that ceteris paribus, when improved maize seed varieties are adopted in isolation, it reduces the proportion of environmental income to the total household income by about 22%. The results did not show any significant reduction of the share of environmental income to total household income when soil & water conservation ($V_0C_1D_0$) and cereal-legume diversification ($V_0C_0D_1$) are adopted in isolation. It is found instead that these SAPs are effective in reducing the share of environmental income to total household income when they are adopted in combination among themselves and with the third SAP i.e. improved maize seed varieties. In quantitative terms, the findings show that adoption of soil & water conservation with improved maize varieties or with cereal-legume diversification ($V_1C_1D_0/V_0C_1D_1$) reduces the share of environmental income to total household income by about 30%. Similarly, the results show that when improved maize varieties and cereal-legume diversification are combined they lead to a reduction of the share of environmental income to total household income by about 48%. Similar to the estimated effects for the absolute environmental reliance measure, it is found that the three SAPs considered are more effective when jointly adopted because they result in a reduction of the share of environmental income to total household income by about 75.3%, which is the highest reduction among the SAP categories. This again confirms that there is a synergistic effect among the adopted SAPs in reducing environmental resources extraction.

In addition, most of the factor loading (λ) show evidence of positive selection bias indicating that unobserved factors that increase the likelihood of adopting SAPs are associated with higher levels of environmental dependence than those expected under a random assignment of SAPs adoption status. A negative selection bias is also observed in the soil & water conservation only $(V_0C_1D_0)$ SAP in the environmental income per capita equation, suggesting that unobserved explanatory variables reducing the likelihood of adopting $V_0C_1D_0$ are associated with lower levels of environmental income per capita than those expected under a random assignment of $V_0C_1D_0$.

Table 3. 7 Impacts of SAPs on environmental reliance

SAPs	(1) Environmental income per capita(log)	(2) Share of environmental income to total household income
$V_1C_0D_0$	-0.0711**	-0.224**
	(0.0300)	(0.0889)
$V_0C_1D_0$	0.00700	-0.108
	(0.0273)	(0.0924)
$V_0C_0D_1$	-0.0686**	-0.115
	(0.0308)	(0.0716)
$V_1C_1D_0$/ $V_0C_1D_1$	-0.0941***	-0.300***
	(0.0310)	(0.102)
$V_1C_0D_1$	-0.0969***	-0.480***
	(0.0268)	(0.102)
$V_1C_1D_1$	-0.152***	-0.753***
	(0.0288)	(0.100)
Selection Terms (λ)		
$V_1C_0D_0$	0.0252	-0.176
	(0.0422)	(0.0267)
$V_0C_1D_0$	-0.0276**	0.0441*
	(0.0135)	(0.0259)
$V_0C_0D_1$	0.0173	-0.0334
	(0.0240)	(0.0265)
$V_1C_1D_0$/ $V_0C_1D_1$	0.0252	0.0417
	(0.0204)	(0.0304)
$V_1C_0D_1$	0.0460***	0.0417
	(0.0133)	(0.0304)
$V_1C_1D_1$	0.0061	0.0886**
	(0.0225)	(0.0444)
Sigma	4.348***	1.393***
	(0.202)	(0.0759)
Other Variables	Yes	Yes
Observations	**421**	**421**

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

3.5 Conclusions

Farm households in developing countries; make their livelihoods from different livelihood sources such as crop production, animal husbandry, off-farm income and extraction of environmental resources. This chapter investigates the level of dependences of rural households on environmental resources as a livelihood strategy and estimates the impact of the adoption of different combinations of SAPs on environmental reliance measured in absolute and relative terms. SAPs have been endorsed for their 'climate-smart' roles due to their multiple welfare and environmental related benefits including increasing crop production, reducing crop production variability under extreme weather events and changing climate, reducing greenhouse gas emission from agriculture by absorbing carbon through fixation, reducing soil erosion and increasing rainfall infiltration. By doing so, SAPs can contribute to increasing food security and poverty reduction in rural areas, through maintaining and enhancing agricultural productivity and resilience of natural and agricultural ecosystem functions (Steenwerth et al. 2014). Such benefits of SAPs on welfare and the environmental benefits can be considered as their on-site benefits.

This chapter tests the hypothesis of whether there is also an ‘off-site’ environmental benefit of SAPs, measured environmental reliance for augmenting livelihoods. Previous literature shows that SAPs leads to increased crop productivity and higher incomes in SSA (Di Falco and Veronesi, 2013; Teklewold, et al, 2013; Manda et al., 2015; Mutenje et al., 2016; Teklewold, et al., 2017; Beyene, et al., 2017). SAPs can also affect the labor allocation decision of households among livelihood strategies. Therefore, both the income from crop productivity and labor allocation decision can affect households’ environmental resources extraction. Using data from 421 randomly selected rural households in the Upper East Region of Ghana, this chapter first shows how rural households depend on environmental resources as a livelihood strategy, and then compares environmental reliance outcomes of non-adopters with the households who adopted SAPs using a multinomial treatment effect model to control for observed and unobserved heterogeneities.

Results show that environmental resources are significant contributors to the total household income of rural households. Quantitatively, on average, environmental products cover about 30% of the total household income among the rural households. The mean share of environmental income increases to 40% when households do not adopt any of the SAPs and it falls to 15% when households adopt the three SAPs together. It is found that adoption of SAPs reduces environmental reliance both on the absolute and relative measures. The effect of SAPs on environmental reliance is higher when SAPs are adopted in combinations than in isolation due to the synergistic effects.

The study complements the literature on the possible pathways to reduce environmental pressure by linking SAPs adoption and environmental reliance outcomes. But the need for future research is indisputable. For example, using panel data that span for several years could produce more robust results. The results indicate very important implications for policies to conserve tropical environmental resources. SAPs can play a role in future climate change mitigations through reducing forest degradation and deforestation. Considering SAPs in future REDD+ initiatives would be a viable option for win-win solutions. That said, however, outcomes will also depend on urban residents dependence on environmental products such as firewood and charcoal. If the urban demand for environmental products remains unchanged, then reducing extraction of environmental products through SAPs will only increase the price of environmental products and raise the opportunity cost forgone to supply the environmental products to the urban areas.

Finally, we would like to recommend some tips for further research. Extending the study to other parts of the developing world, specifically in SSA, over several time periods to have a panel data analysis would contribute to the generalization of the findings. Furthermore, a more than one spot survey in a year for calculating the environmental income would provide better accounts and hence the dependence on the environment. Including other environmental non-pecuniary benefits of environmental sources would also provide better estimates of the dependence on environmental resources.

3.6 Appendix

Table 3A. 1 Household level mixed multinomial logit model estimates of adoption of SAPs in Upper East Region of Ghana (outcome variable in the second stage is share of environmental income to total household income)

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_0D_0$
Household Characteristics						
Age of the household	-0.0328*	-0.0103	-0.00114	-0.0126	-0.0212	-0.0375**
	(0.0185)	(0.0203)	(0.0144)	(0.0173)	(0.0164)	(0.0182)
Gender head	0.666	-0.532	-0.444	-1.560**	0.686	0.470
	(0.681)	(0.712)	(0.510)	(0.689)	(0.697)	(0.774)
Family size	0.0495	0.0869	-0.0165	0.202**	-0.154*	-0.0470
	(0.0966)	(0.0947)	(0.0737)	(0.0942)	(0.0931)	(0.0966)
Education of head	0.299**	0.271	0.316**	0.327**	0.190	0.277*
	(0.150)	(0.181)	(0.145)	(0.164)	(0.154)	(0.156)
Resource Constraints and market access						
Distance to forest	-0.000245*	0.000118	-9.00e-05	6.05e-05	5.16e-05	-6.69e-05
	(0.000133)	(9.48e-05)	(8.05e-05)	(8.89e-05)	(8.17e-05)	(0.000104)
Distance to (forest) output market	0.00199	0.00178	0.00426*	0.00389	0.00317	-0.00860*
	(0.00369)	(0.00336)	(0.00239)	(0.00281)	(0.00279)	(0.00509)
Distance to input market	-0.00139	-0.00228	0.00309	-0.00358	0.00242	-2.92e-05
	(0.00404)	(0.00368)	(0.00266)	(0.00375)	(0.00371)	(0.00337)
Credit constrained	-1.149*	-0.363	-2.566***	-3.096***	-0.176	-1.636**
	(0.622)	(0.557)	(0.591)	(0.791)	(0.562)	(0.654)
Assets value (log)	0.312	0.112	0.479*	0.433	0.619**	0.268
	(0.306)	(0.314)	(0.253)	(0.371)	(0.297)	(0.339)
Total livestock holdings	0.134***	0.103**	0.0545	0.00351	0.113**	0.176***
	(0.0496)	(0.0484)	(0.0607)	(0.0689)	(0.0501)	(0.0472)
Total cultivated land (log)	-0.649	-0.261	-0.229	-0.0545	0.0828	0.734
	(0.482)	(0.523)	(0.380)	(0.496)	(0.426)	(0.452)
Death shock	0.172	1.253*	-0.0168	0.0171	0.650	0.300
	(0.517)	(0.643)	(0.415)	(0.569)	(0.496)	(0.537)

Table 3A.1 continued

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_1D_1$
Social Capital and Information						
Group membership	0.690	-0.116	0.302	0.246	1.267**	1.540***
	(0.498)	(0.632)	(0.471)	(0.581)	(0.552)	(0.527)
Village kinship	0.0844	-0.0158	-0.0542	-0.0886	-0.0587	0.0815
	(0.0585)	(0.0580)	(0.0546)	(0.0632)	(0.0730)	(0.0607)
Non-village kinship	-0.0565	0.100	0.161***	0.170***	0.117*	0.0526
	(0.0814)	(0.0640)	(0.0518)	(0.0581)	(0.0666)	(0.0615)
Extension contact	0.477	1.151*	-0.130	0.839	0.282	-0.405
	(0.585)	(0.621)	(0.489)	(0.597)	(0.567)	(0.593)
Climate change awareness	0.566	0.923	1.145	1.675	0.980	1.552
	(0.790)	(0.980)	(0.786)	(1.210)	(0.864)	(1.121)
Risk Preference						
Severe risk averse (RA)	-0.802	-0.645	0.308	-0.0108	0.0884	1.997**
	(0.826)	(0.933)	(0.571)	(0.801)	(0.756)	(0.792)
Moderate RA	0.122	-2.114*	0.0264	0.368	-0.990	1.368
	(0.906)	(1.214)	(0.705)	(0.890)	(0.929)	(0.835)
Intermediate RA	-0.136	-0.110	-0.322	0.119	-0.598	0.657
	(0.762)	(0.775)	(0.589)	(0.849)	(0.768)	(0.896)
Slight to neutral RA	1.514	0.787	2.396**	2.508**	1.638	2.900**
	(1.100)	(1.037)	(0.957)	(1.030)	(1.051)	(1.168)
Neutral to preferring RA	1.178	1.220	1.430**	2.113**	1.572*	3.533***
	(0.855)	(0.940)	(0.683)	(0.836)	(0.835)	(0.896)
Instrumental Variable						
SAPs information/training	2.092***	1.503**	0.488	0.918	1.781***	2.161***
	(0.598)	(0.683)	(0.482)	(0.605)	(0.566)	(0.598)
Constant	-3.533	-6.646**	-5.800***	-9.476***	-8.552***	-8.824***
	(2.294)	(2.919)	(2.002)	(2.911)	(2.440)	(2.623)
District Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	421	421	421	421	421	421

$\chi^2 = 1220.4^{***}$. ***<0.01, **<0.05, *<0.1. Robust standard errors in parenthesis. District controls are included but not reported.

Table 3A. 2 Other variables of the second stage determinates of environmental reliance

VARIABLES	Environmental income per capita (log)	Share of environmental income
Household Characteristics		
Age of the household	-0.000767	0.000866
	(0.000517)	(0.00186)
Gender head	0.000356	0.0497
	(0.0173)	(0.0667)
Family size	-0.0131***	0.0189*
	(0.00252)	(0.00986)
Education of head	-0.00393*	-0.0212***
	(0.00208)	(0.00819)
Resource Constraints and market access		
Distance to forest	-2.14e-06	7.68e-06
	(2.54e-06)	(8.72e-06)
Distance to (forest) output market	0.000114	0.000133
	(7.49e-05)	(0.000255)
Distance to input market	0.000105	0.000822**
	(0.000103)	(0.000345)
Credit constrained	0.0105	-0.00159
	(0.0186)	(0.0718)
Assets value (log)	0.0156	-0.0287
	(0.00976)	(0.0310)
Total livestock holdings	-0.000597	-0.0207***
	(0.00142)	(0.00458)
Total cultivated land (log)	-0.0361***	-0.308***
	(0.0139)	(0.0507)
Death shock	0.0155	0.0878*
	(0.0139)	(0.0518)
Social Capital and Information		
Group membership	0.0525***	0.0830
	(0.0146)	(0.0562)
Village kinship	0.00393***	0.0144***
	(0.00118)	(0.00497)
Non-village kinship	-0.00165	-0.00576
	(0.00108)	(0.00588)
Extension contact	0.00575	0.0906*

Table 3A.2 Continued

VARIABLES	**Environmental income per capita (log)**	**Share of environmental income**
Climate change awareness	-0.0729***	-0.270***
	(0.0194)	(0.0798)
Risk Preference		
Severe risk averse (RA)	0.0191	0.146*
	(0.0205)	(0.0778)
Moderate RA	0.000933	0.0224
	(0.0234)	(0.0862)
Intermediate RA	-0.0170	-0.0234
	(0.0227)	(0.0792)
Slight to neutral RA	-0.0176	-0.0609
	(0.0260)	(0.0994)
Neutral to preferring RA	0.0265	0.0699
	(0.0213)	(0.0789)
Constant	-2.475***	-1.761***
	(0.199)	(0.283)
Observations	421	421
District dummies	Yes	Yes

Robust tandard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3A. 3 Test on the validity of instrumental variable

VARIABLES	Environmental income per capita (log)	Share of environmental income
Household Characteristics		
Age of the household	-0.00298	0.000835
	(0.00425)	(0.00113)
Gender head	0.0935	0.0350
	(0.161)	(0.0427)
Family size	-0.0958***	0.00196
	(0.0282)	(0.00748)
Education of head	-0.0474	-0.00883
	(0.0439)	(0.0116)
Resource Constraints and market access		
Distance to forest	-2.23e-05	-5.76e-06
	(2.63e-05)	(6.97e-06)
Distance to (forest) output market	-0.000948	-6.19e-06
	(0.00110)	(0.000292)
Distance to input market	0.000545	0.000608**
	(0.000937)	(0.000249)
Credit constrained	0.0255	-0.0853**
	(0.156)	(0.0414)
Assets value (log)	0.0306	-0.00636
	(0.0928)	(0.0246)
Total livestock holdings	0.0449**	-0.000968
	(0.0212)	(0.00562)
Total cultivated land (log)	-0.294*	-0.0720*
	(0.152)	(0.0403)
Death shock	-0.0314	0.0323
	(0.146)	(0.0387)
Social Capital and Information		
Group membership	0.123	0.0160
	(0.153)	(0.0406)
Village kinship	0.0313*	-0.00138
	(0.0176)	(0.00468)
Non-village kinship	0.0263	0.0103
	(0.0242)	(0.00641)
Extension contact	0.0506	0.0277
	(0.132)	(0.0349)
Climate change awareness	-0.316	-0.0229
	(0.203)	(0.0539)

Table 3A.3 continued

VARIABLES	**Environmental income per capita (log)**	**Share of environmental income**
Risk Preference		
Severe risk averse (RA)	0.199	0.0426
	(0.169)	(0.0448)
Moderate RA	-0.227	-0.0742
	(0.197)	(0.0524)
Intermediate RA	0.123	-0.0208
	(0.178)	(0.0473)
Slight to neutral RA	0.578*	-0.0600
	(0.336)	(0.0893)
Neutral to preferring RA	0.474*	0.0464
	(0.239)	0.0426
Instrumental Variable		
SAP_Info	**-0.0118**	**-0.0436**
	(0.142)	**(0.0376)**
Constant	-2.475***	0.415**
	(0.199)	(0.173)
Observations	96	96
District dummies	Yes	Yes
R-squared	0.495	0.343

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Chapter 4

Do SAPs encourage agricultural land expansion into forest areas? Empirical evidence from Northern Ghana

Gebrelibanos Gebremariam[1] and Tobias Wünscher[1,2]

[1] Center for development research (ZEF), University of Bonn

[2] EARTH University, San José, Costa Rica.

Abstract

Recent studies in Sub-Saharan Africa (SSA) indicate that the adoption of combinations of Sustainable Agricultural Practices (SAPs) improve households welfare through increasing land productivity. The positive effects of SAPs can encourage or discourage households' decision to expand cropland into forest areas. Using micro cross-sectional household survey data from 421 households, we test whether SAPs encourage or discourage cropland expansion into the forest and other virgin lands. We considered the three most common SAPs in the study area i.e, improved maize varieties, soil & water conservation measures and cereal-legume diversification and their different combinations as treatment variables. Our findings show that about 20% of the households have expanded their cropland within 12 months prior to the survey date and have cleared around 0.21 acres, on average. A two-stage churdel double hurdle model regression analysis does not reveal direct evidence of SAPs induced cropland expansion into forest areas.

Keywords: SAPs, Crop land expansion, Ghana

JEL Classification: O12, O13, Q32, Q55, Q57

4.1 Introduction

Due to the relevant role of tropical forests as one of the species-rich habitats on earth, deforestation of such forests has negative effects on biodiversity conservation, and lead to global warming, water cycle disruption, and biological diversity loss (Joppa and Pfaff, 2011; Pimm et al., 2001 Carrero & Fearnside, 2011). Deforestation in tropical countries remains at alarming rates (Davidar et al., 2010). For example in Africa, 34–41 thousand km2 forest areas were lost per year between the 1990s and 2000s (FAO, 2010). Specifically, in Ghana, deforestation is still a major challenge, which contributes to desertification and habitat loss. Estimates show that an average of 125,400 ha or 1.68 % of forest cover in Ghana was lost per year between 1990 and 2010, totaling approximately 2,508,000 ha or 33.7% of the country's forest cover over the period (Ghana Common Country Assessment (CCA), 2016). The determinants of tropical deforestation vary immensely among different countries and perhaps also in similar locations over time (Carrero & Fearnside, 2011). Many variables are responsible for global forest cover change rather than a single key variable. Multiple synergies between proximate causes and underlying driving forces best explain tropical forest cover losses worldwide (Geist and Lambin 2001, 2002). Some studies indicated that agriculture is one of the main determinants of tropical deforestation (Gibbs et al., 2010). Barraclough and Ghimire, (2000) show that smallholder farmers' decision to expand cropland into tropical forests accounts for at least 50% of deforestation in the region. Therefore, understanding how smallholder farmers make the agricultural investment and cropland expansion decisions is essential if policymakers wish to halt tropical deforestation while increasing crop production.

Sub-Saharan African (SSA) agriculture needs to transform and grow to feed the increasing population which is expected to double by 2050 (FAO, 2015). However, agricultural production in SSA has been affected by erratic and aberrant climatic conditions which expose farm households to pervasive production risks. These risks translate into low food production, income, and consumption (Dercon et al., 2005; Di Falco & Chavas, 2009). Farming households adopt various innovations to mitigate the implications of production and consumption risks arising from climate change and variability. Improving agricultural production is widely regarded as a major objective through which the widespread lack of food security and poverty in Africa can be tackled and even eradicated (Future Agricultures, 2010). At the same time, natural ecosystems need to be protected for environmental regulation and to mitigate the adverse effects of climate change. This is because most of the poor and food insecure households in SSA depend on agriculture for their livelihood (Darko and Ricker-Gilbert, 2013). Unfortunately, agricultural production in SSA has been low and this aggravates deforestation due to agricultural expansion into forest areas. The sustainable intensification of production through a technological and institutional change in agriculture has been suggested as a key solution to the competition for land between agriculture and other land uses such as forests (Strassburg et al. 2014). However, the degree to which agricultural intensification can help to alleviate tropical deforestation remains unclear (Angelsen & Kaimowitz 2001), especially at the local scale.

Technological change in agriculture normally defined as an increase in total factor productivity (Angelsen and Kutzens, 2001) - is expected to intensify agricultural production on available agricultural land and has been suggested as a key solution to the conflict between expanding agriculture and the conservation of natural ecosystems. It has been shown that it is possible to increase agricultural production through agricultural intensification without deforesting more lands (e.g. Godoy et al., 1997; Shively, 2001; Shively & Pagiola 2004; Green et al. 2005; Phalan et al. 2013; Herrero et al. 2010; Illukpitiya and Yanagida, 2010). Other studies (e.g. Herrero et al. 2010; Tilman et al. 2002; Lapola et al. 2010; Burney, et al. 2010) also indicate that agricultural intensification helps mitigate greenhouse gases (GHG) emissions through resource conservation and improvements in land management. This effect of agricultural intensification on forest conservation is known as the “Borlaug hypothesis” after the seminal work of Norman Borlaug (2007) who claimed that the Green Revolution technologies, partly as a result of cereal intensification, had saved over one billion hectares of land from being brought into agricultural production (Villoria et al. 2014).

Another strand of the literature demonstrated that technologies that intensify agricultural production can also aggravate deforestation (Lambin and Meyfroid, 2011; Angelsen et al. 2001; Rudel et al. 2009). This is because of the rebound-effect, a classic economic effect which, due to the increase in productivity through new technologies, makes agriculture more attractive in comparison to alternative land uses (such as forestry), thereby encouraging expansion of the agricultural frontier (Strassburg, at al. 2014; Villoria, et al. 2014; Angelsen et al. 2001). In addition, the capital accumulated from agricultural profits can also increase the capacity of farmers to clear more forest. This outcome has been mentioned as an example of Jevons' paradox (Villoria, et al. 2014; Rudel et al. 2009; Lambin and Meyfroidt 2011) due to its similarity to the situation described by Jevons, who find that an increase in the efficiency of coal utilization could lead to an aggregate increase in demand (Alcott 2005).

Despite their economic importance in improving livelihoods, agricultural intensification technologies such as SAPs remain one of the main controversies in research particularly on their effect on pressure on forests (Maertens, 2006). Evidence on the link between technological change and land use has been reviewed recently by Villoria et al., (2014). The authors' review is based on three categories: local and country-specific studies, across countries studies and global assessments. At the global level, a handful studies have been conducted using different models (Evenson and Rosegrant, 2003; Havlik et al., 2013; Lobell, et al., 2013; Villoria et al., 2013). However, these global studies are based on simulation and projections and their global aggregates often hide important spatial shifts in production that may involve major land use changes in ecologically sensitive areas because they are based on scenarios and their results should be taken with caution (Villoria, et al, 2014; Beyerlee, et al, 2014; Ngoma and Angelsen, 2017). They are also criticized for their methodological flaws. 'Some (including Borlaug's) are simply 'back of the envelope calculations' (Hertel, 2012).

There is few empirical local and country-specific studies that estimated the effect of technologies and policies that boost agricultural production on deforestation. For example, Fisher and Shively (2007) analyzed the effect of an agricultural assistance program (providing farmers with packs of free improved seed and fertilizer) on agricultural expansion and forest product extraction in Malawi using cross-sectional household survey data. The authors find no link between the assistance program and land expansion for agriculture but they find beneficiaries of the program to depend on less on commercial forest products. Yangger and Reardon (2001) evaluate the impact of an introduced kudyu-improved fallow (a leguminous manure crop) on deforestation in the Amazon basin and find that adopting the technology increases secondary forest clearing but reduces the clearing of primary forests. Garrett, Lambin, and Naylor, (2013) estimated the effect of soybean yield on deforestation in Brazil using an instrumental variable method and they found a positive link between the soybean technology and deforestation. Other empirical works in Mexico and Asia (Deininger and Minten, 1999; Shively, 2001; Shively and Martinez, 2001) indicated that use of irrigation technologies reduces deforestation. Ngoma and Angelsen (2017), estimated the effect of one of the components of conservation agriculture (CA), minimum tillage (MT) on cropland expansion in Zambia. The authors found MT did not reduce significantly deforestation. The findings from the empirical works indicated that the link between technologies and policies that can boost agricultural production and deforestation are ambiguous and further empirical work is essential.

Therefore, while this paper adds to the growing literature on the effect of SAPs on deforestation, our first contribution is the investigation of the cross-impact of packages of SAPs, which are sustainable and environmentally friendly technologies, on deforestation. Many agricultural technologies, including some technologies of the green revolution, have been based on technologies that have been unsustainable on their own. For example, the green revolution was implemented by mass distribution of improved varieties and agro-chemicals such as pesticides and chemical fertilizer. Previous empirical works show that different packages of SAP's (Teklewold, et al., 2013; Kassie, et al., 2014; Manda, et al., 2015) increase crop income and contribute to households' welfare in SSA. SAP's are strategies that can increase productivity in a sustainable way in terms of nitrogen fixation, carbon sequestration and reducing soil disturbance, in the farm areas. However, due to their positive effect on farm income and productivity of farm households, they might lead to the Borlaug-Jevons trap of agricultural change and expansion of croplands. As discussed earlier, the potential positive effects of SAPs on the ecosystem in areas where SAPs are adopted is well understood, but their effect on forest land expansion for agricultural production is something which has been missing in the literature. Understanding their effect on the conversion of forest land into agriculture is crucial to have an overall view of SAPs especially with respect to climate change mitigation.

The rest of the chapter is organized as follows. Section two presents the theoretical framework used in the study. Section three presents the data and methodology used. Section four presents and discusses the results. Finally, section five concludes the main findings.

4.2 Theoretical framework

We integrate two distinct but coexistent streams of the theoretical literature. The theoretical framework for this paper follows a non-recursive agricultural household model (Singh et al., 1986; Taylor & Adelman, 2003) and cropland expansion models of (Angelsen 1999; Maertens et al. 2006; Ngoma and Angelsen, 2017) by complementing a new technology (SAPs)[25]. A household is assumed to maximize utility from consumption goods, leisure, production decisions and household's decisions to expand cropland into the forest and other land use systems. We assume that agricultural land expansion is homogeneous across households and it can be accessible at a cost $d(A-A_0)$. Households' production function is given by $Y = f(l^a, A, S; X)$. The determinates of the production function are family labor $\left(l^a\right)$, total agricultural land cultivated $\left(A\right)$[26], Sustainable Agricultural Practices (S) adopted and other variable inputs (X). For ease of calculation, the labor market is assumed to be missing such that leisure plus working time cannot exceed the household's total available time (*T*). For calculations simplicity, the variable inputs X is assumed to be fixed. Land, labor, and S are assumed to be complementary so that agricultural land expansion and S adoption would have implications for the demand for family labor.

A given household maximizes utility which is a function of consumptive goods (c), leisure time (l) and a vector of exogenous household demographics (h). In addition to the accessibility cost of clearing land, $d(A-A_0)$, a household also faces additional cost of clearing, reflecting, for example, increasing cost with distance from the homestead as crop area expanded: $t(A-A_0)^r, t > 0$ and $r > 1$.

A representative farm household solves the following problem:

$$\underset{c, l^a, A, S}{Max U} = U(c, l; h) \tag{4.1}$$

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[25] We used the word S in this theoretical framework to represent SAPs for simplicity to fit in the equation

[26] A includes the recently converted land from forest areas

Subject to

$$c = p_y f(l^a, SAP, A; X) - vS - d(A - A_0) - p_x X + w\overset{=}{l}^{O} + E \tag{4.2}$$

$$T = l + t(A - A_0)^r + l^a + \bar{l}^0 \tag{4.3}$$

$$c, A, l^a > 0; SAP \geq 0; r. > 1; t > 0; A \geq A_0$$

The households utility (U) is a positive but diminishing marginal utility of both consumption and leisure. The cross partial derivatives of the variables of interest are assumed to be zero for the sake of simplicity: $U_c, U_l > 0; U_{cc}, U_{ll} < 0; U_{cl}, U_{lc} = 0$. The budget constraint is presented in equation (4.2) that overall consumption is equal to incomes in a single production season basically it is also assumed that what is produced is consumed in one season period. Py is output price, and v is the farm level input and capital cost of implementing S. Px is the per unit variable input costs X, which, is fixed. E captures all other exogenous income such as income from environmental resources, remittances, and transfers to the household. Eq 4.3 is the households' time constraint. Total households time T equals leisure time l, time spent working in the farm l^a, clearing new agricultural land $t(A - A_0)^r$ and off the farm l^o.

Considering the interior solution case where there are a positive deforestation $(A - A_0)$ and one of the possible combinations of SAPs adopted $(S > 0)$, we can write the Lagrangian for the problem as:

$$\begin{aligned} L = {} & U(c, l) + \mu\left[c - p_y f(l^a, SAP, A; X) + vM + d(A - A_0) + p_x X - wl^0 - E\right] \\ & + \lambda\left[T - l - t(A - A_0)^r - l^a - l^0\right] \end{aligned} \tag{4.4}$$

Solving the above equation and after some mathematical steps, the first order conditions FOCs for the choice variables $l, c, S, and \quad A$ are given by

$$p_y f_{l^a} = z \tag{4.5}$$

$$p_y f_A = d + zrt(A - A_0)^{r-1} \tag{4.6}$$

$$p_y f_{SAP} = v \tag{4.7}$$

Where

$$z = \frac{U_l(c,l)}{U_c(c,l)} \tag{4.8}$$

The shadow wage (z) which is the marginal rate of substitution between consumption and leisure is presented in equation (4.8). Equation (4.5) also show that the marginal productivity of agricultural labor (or leisure) is equal to z. Equation (4.6) shows that marginal productivity condition which indicates that households will expand into forest areas until the marginal productivity of land equals the combination of cash and labor costs of land expansion. Finally, equation (4.7) states that the different combinations of SAPs are profitable given the condition that their marginal benefits are equal to the cost of implementing them.

4.3 Methodology

4.3.1Data and Study area

We used a cross-sectional data collected from 421 households collected from April to July 2015 in the Upper East Region of Ghana. Our study is part of the West African Science Service Center for Climate Change and Adaptive Land Use (WASCAL) project which has been implemented in ten West African countries. Sampling proceeded at three levels. First, we identified seven districts from the 13 districts available in the Upper East Region of Ghana mainly based on agricultural productivity and availability of forest areas. Second, we randomly selected Bongo, Bwaku West, Kassena Nankana East and Bluilsa South districts from the seven districts selected before. Third, we selected six to seven communities from each district using the most recent community list in each district. Fourth, we randomly selected households from each community based on the proportion to the total number of households in the communities. This gave a sub-sample of 110 from Bongo district, 101 Bwaku West, 105 from Kassena Nankana East and Builsa South districts, and 421 households in total.

In this study, three of the most common SAPs in the study area and their combinations were considered as treatment variables. The SAPs are (1) Improved maize seed varieties (V), (2) soil & water conservation (C) and (3) cereal-legume diversification (D). The households were categorized into eight groups based on their adoption status : (1) those that adopted any of the three SAPs (a control group); (2) those that adopted improved maize seed varieties only ($V_1C_0D_0$); (3) those that adopted soil & water conservation structures only ($V_0C_1D_0$); (4) those that adopted cereal-legume diversification only ($V_0C_0D_1$); (5) those that adopted improved maize seed varieties and soil & water conservation technologies only ($V_1C_1D_0$); (6) those that adopted soil & water conservation structures and cereal-legume diversification only ($V_1C_0D_0$); (7) those that adopted improved maize seed varieties and cereal-legume diversification ($V_1C_0D_1$); and (8) those that adopted improved maize seed varieties, soil & water conservation structure and cereal-legume diversification ($V_1C_1D_1$). But, since the SAP category improved maize varieties and soil & water conservation only ($V_1C_1D_0$) was adopted by only eight households, i.e we have got too few observations in this category such that treating it separately would make the model not to converge due to the negative degrees of freedom. Hence, we have combined this category with the soil & water conservation and cereal-legume diversification only ($V_1C_1D_0$) category[27]. This leads us to have seven SAPs categories. The distribution of SAPs among households[28] is presented in Table 1.

Table 4. 1Distribution of SAPs packages at household level

SAP Categories	**Frequency**	**Percent (%)**	**Cum.**
$V_0C_0D_0$	96	22.8	22.8
$V_1C_0D_0$	42	9.98	32.78
$V_0C_1D_0$	31	7.36	40.14
$V_0C_0D_1$	102	24.23	64.37
$V_1C_1D_0$ & $V_0C_1D_1$	40	9.5	73.87
$V_1C_0D_1$	51	12.11	85.99
$V_1C_1D_1$	59	14.01	100
Total	**421**	**100**	

Source: Authors calculation based on survey data

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[27] This method of combining different packages in the case of few observation in certain packages have been used in the literature. For example, see Mutenje, et al., 2016 and Di Falco and Verona, 2013

[28] We consider household as an adopter if the household adopts a specific SAP at least in one of his plots

4.3.2 Empirical Strategy

We used a two-step instrumental variable regression in assessing the effects of the different combinations of SAPs on forest clearing in the past twelve months prior to the data collection period. As we have multiple combinations of SAPs, we used multinomial logistic regression (MNL) to predict the probabilities of adoption of the SAPs, in the first stage of the regression. We used the churel double hurdle craggit model to assess the effects of SAPs on cropland expansion. From this stage, we have predicted the probabilities of households to adopt the seven possible categories. The multinomial logit model was specified as below

$$SAP_i^j = \beta_0 + \beta_1 Z_i + \beta_2 H_i + \beta_3 P_i + \beta_4 R_i + D_i + \varepsilon_i \tag{4.9}$$

Where SAP_i^j is the dependent variable that indicates the adoption of SAP category j by a household i and ε_i represents the random error terms. The vector Z_i constitutes observed exogenous socio-economic variables that are responsible to affect the adoption of combinations of SAPs by households such as the age of the household head, education level of the household, the number of male household members.

The variables in H_i represents for the household's social capital and networks such as the number of kinships in the village and outside village, if the head is relative to the village chief etc. The longer the household had networks, the more likely it would be to adopt SAPs.

Variables in P_i include wealth-related factors such as total asset value, TLU and total cultivated land holdings. R_i represents the risk preference of households which were elicited using an experimental game and D_i represents the district dummies.

SAPs could be endogenous and therefore they might be correlated with the error terms. Furthermore, households self-select into SAPs adoption decisions and adopters might have different unobservable characteristics than non-adopters, which may also influence their agricultural land expansion decisions. Therefore, for a proper identification of the forest clearing equation and to take care of the problem of endogeneity, an exclusion restriction variable (instrumental variable) is needed. That is, at least one variable which appears in the MNL equation should not enter the forest clearing equation. Finding a variable that affects the SAPs adoption but did not affect the forest clearing variable is a challenge. We used former training and|or information about SAPs as an instrumental variable. We assume that former training or information about SAPs is likely to affect the current SAPs adoption decisions but not agricultural land expansion decisions except through the SAPs adopted.

The determinants of the decision to clear forest area and extent of forest clearing were identified in the second stage of the regression. Many specification and models were considered for the second stage. For example, an Ordinary Least Square (OLS) regression is inappropriate for the second stage regression (Chibwana et al., 2012), as our dependent variable was significantly censored at zero because of the fact that many households did not clear forest. One suggested solution for censored data is the use of the one-tailed Tobit model. The main assumption of the Tobit model is that factors that affect the probability of forest clearing decision and extent of forest clearing are the same. Another model that can be suggested for censored data is the Cragg's (1971) double hurdle model, which uses a probit model for the forest clearing decision model and a truncated normal regression for the extent of forest clearing decision. One of the advantages of the double hurdle model is that it allows the variables to affect the decision and extent of forest clearing separately. We, therefore, used a churdle Cragg double hurdle model to analyze the effects of SAPs and other covariates on the decision and extent of forest clearing. The churdle extends the usual cragg double hurdle models by allowing the conditional heteroskedasticity of the random errors. We have also estimated the average marginal effect of each of the covariates.

Double hurdle models are characterized by the relationship $A_i = D_i A_i^*$, where A_i is the observed value of the dependent variable, the total area cleared in the past 12 months prior to the survey date, in our case.

The selection variable D_i is 1 if the dependent variable is not bounded and 0 otherwise. In our Cragg model, the lower limit that binds the outcome variable is 0 so the selection model is given by

$$D_i = \begin{cases} 1 & if \quad Z_i\gamma + \varepsilon_i > 0 \\ 0 & Otherwise \end{cases} \tag{4.10}$$

Where Z_i is a vector of explanatory variables, γ is a vector of the respected coefficients, and ε_i is the standard normal error term

The continuous latent variable A^*_i is observed only if $D_i = 1$. Following the theoretical framework presented in the above section, we can develop the second stage equation (reduced form of the land clearing equation) as:

$$\overset{*}{A} = \overset{*}{A}(\hat{S}_j, p_y, X, S_f, A_0, R, D, z, h) + \varepsilon,_i \tag{4.11}$$

Where $\overset{*}{A}$ is the size of the expanded cropland, $\hat{S}_j$ are the predicted probabilities of the different combinations of SAPs adopted by a given farm household. A_0 is the initial amount of land (total farm size) controlled by the household. The vector of socioeconomic and demographic characteristics and other exogenous variables which are supposed to affect the decision to participate in cropland expansion and the size of expanded land are represented by h. Py[29] is a community level average price of maize which is used a proxy for output price. It captures the financial incentives for expanding agricultural lands into forest areas. Previous literature indicated that higher output prices stimulate agricultural expansion into forest areas (Elnagheeb & Bromley, 1994; Bagachwa et al. 1995; Barbier & Burgess 1996; Angelsen et al., 1999). Sf is the community level share of forest area. X represents the distance to the forest area.

Households shadow wage (z) was estimated using the following equation following Jacoby (1993).

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[29] The households in the communities grow many crops and maize is one of the main crops. However, about 25% of the households did not grow maize in the survey year. Therefore, household level price of maize would have reduced our sample significantly. We then decided to take a community level price for maize. We assume there would be same trend in terms of output prices for the other crops grown too.

$$z = \beta \frac{P}{L} \qquad (4.12)$$

To determine β, we first estimate a Cobb Douglas production function. β is, therefore, the parameter estimate in the Cobb Douglas production function associated with labor. L is total labor input used by the household and P is the predicted values of the Cobb Douglas production function.

4.4 Results and discussion

4.4.1 Descriptive Statistics

The description and descriptive statistics of the dependent variable and explanatory variables are presented below. A set of explanatory variables have been considered based on available empirical studies related to our objectives.

4.4.1.1 Cropland expanded among the SAPs categories

In this section, we provide the descriptive statistics of the dependent variable. Our dependent variable is cropland expansion into forest areas measured in acres in the past 12 months prior to the survey. We did a simple comparison test between the adopters of SAPs and the control group. As can be seen from Table 4.2, there is not a much significant difference in cropland expansion between the comparison group (non-adopters of any SAP) and the adopters except the SAP category of ($V_1C_1D_0/V_0C_1D_0$), which is significant at 10%. The total average cropland expansion into forest areas is estimated at 0.2137 acres.

Table 4. 2 Distribution of cropland expansion into forest among the different categories

SAP Categories	Mean cropland expanded	Difference	t
$V_0C_0D_0$	0.251		
$V_1C_0D_0$	0.289	0.0377	0.721
$V_0C_1D_0$	0.2129	-0.0386	0.7518
$V_0C_0D_1$	0.2215	-0.03	0.7538
$V_1C_1D_0/V_0C_1D_0$	0.0775	-0.1741*	0.0683
$V_1C_0D_1$	0.2186	-0.0329	0.7299
$V_1C_1D_1$	0.1729	-0.0787	0.3739
Overall mean	0.2137		

4.4.1.2 The explanatory variables

The inclusion of other explanatory variables[30] than the treatment variables of our interest (SAPs) in the empirical model is based on a review of theoretical work and previous empirical studies on the determinants of forest clearing. In Table 4. 3 below, we present the simple statistical test of the explanatory variables included as the determinants of cropland expansion into forest among the adopters of different combination of SAPs against the non-adopters.

Table 3 shows some of the descriptive statistics of the explanatory variables. The proportion of households who revealed that they have some relative (local chief, community leaders, and government position) in a leadership position in the community is about 24%. Looking at the different categories of households based on their SAPs adoption, those who have adopted soil & water conservation only reveal that 32.3 % of them have relatives in leadership positions in their respective communities. Similarly, 31.4% of the households who adopted improved maize varieties with cereal-legume diversification indicate that they have relatives who are in leadership positions in their communities. These findings are significantly different at less than 10% significance level from as compared to the non-adopter categories who indicated that only 21% of them have relatives in leadership positions.

The shadow wage of the household is estimated to be 0.53 GH¢. The share of forest area from the total land is reported to cover about 44% in the communities. Table 4.4 shows that about 93% of the plots under the households have a secured land ownership at least in the timeframe of the households head. The average community level price for maize is estimated to be 1.49 GH¢. Other socioeconomic variables such as age of the household head, gender of the household head (male=1), Adult equivalent of the household, Education level of head of the household, value of assets owned by the household (log), total livestock units holding (TLU) and total cultivated land net recently expanded cropland are 53.76 years, 83.1%, 5.4 units, 1.78 years, 7.46, 4.84 units and 6.35 acres, respectively. As can be seen in Table 3, there are some significant differences across the SAP categories as compared to the comparison group. Other variables included in the model are variables related to shocks on crop failure and the risk

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[30] We present the descriptive statistics for the explanatory variables included only in the second stage equation as the explanatory variables in the first equation are already discussed in the previous chapters.

preferences of households which were elicited using an experimental game with real payoffs. The summary statistics are presented in the same table.

Table 4. 3 Summary statistics of the variables used in the second stage regression model

Explanatory Variables	$V_0C_0D_0$	$V_1C_0D_0$	$V_0C_1D_0$	$V_0C_0D_1$	$V_1C_1D_0$	$V_1C_0D_1$	$V_1C_1D_1$	mean
Relative in leadership (yes=1)	0.21	0.286	0.323*	0.206	0.15	0.314*	0.228	0.24
Shadow wage	0.50	0.519	0.525	0.56***	0.535*	0.535**	0.528*	0.53
Share of community forest area	0.46	0.52*	0.38**	0.422	0.36***	0.476	0.437	0.44
Average distance to plots (ln)	6.2	6.38	6.28	5.89	5.93	6.31	6.11	6.12
Average land tenure of plots	0.90	0.9	0.908	0.945*	0.954*	0.905	0.915	0.93
Output price per kg	1.5	1.49	1.42*	1.48	1.37***	1.53	1.49	1.47
Age of head	56.5	50.69**	53.64	55.04	54.2	50.45**	51.88*	53.7
Gender of head (Male=1)	0.76	0.881*	0.774	0.833	0.75	0.902**	0.9***	0.83
Adult Equivalent	5.28	5.76	5.69	5.23	6.01*	5.06	5.33	5.4
Education head (years)	0.46	3.04***	1.68***	1.92***	1.72***	2.31***	2.4***	1.78
Distance to forest reserve	3326	2397*	4503**	3296	3829	3815	3384	3428
Value of assets (ln)	7.27	7.58*	7.62*	7.63***	7.66**	8.04***	7.9***	7.64
Total livestock units (TLU)	3.19	5.86***	4.59*	4.15	3.79	6.57***	7.3***	4.84
Cultivated land, net expansion	5.49	6.67**	5.71	6.22*	6.23*	7.00***	7.6***	6.35
Shock crop failure	0.77	0.4***	0.6***	0.732*	0.7	0.706	0.814	0.70
Sever risk averse	0.20	0.095	0.13	0.176	0.125	0.157	0.169	0.16
Moderate risk averse	0.13	0.214	0.032*	0.88	0.125	0.137	0.186	0.13
Intermediate risk averse	0.24	0.19	0.29	0.127**	0.125*	0.157	0.085*	0.16
Slightly risk averse	0.03	0.2***	0.097*	0.2***	0.18***	0.18***	0.10*	0.13
Neutral risk averse	0.07	0.167*	0.194*	0.19**	0.25***	0.23***	0.39***	0.2
Bongo district (yes=1)	0.28	0.12**	0.258	0.314	0.35	0.06***	0.35	0.26
Bawaku west district (yes=1)	0.20	0.07**	0.323*	0.264	0.25	0.392**	0.254	0.25
Kassena nankana east (yes=1)	0.17	0.285*	0.323*	0.186	0.35**	0.275*	0.254	0.24
Number of Observations	96	42	31	102	40	51	59	421

4.4.2 Determinants of SAPs Adoption

Table 4.4 below presents the results of the MNL of the determinants of the seven SAPs categories in which the non-adopters of any SAP serves as a base category. The main objective of the multinomial logit model was to provide an appropriate instrumented version of the SAPs adoption pathways to be used as a treatment variable in the cropland expansion regression model. The various test of goodness-of-fit indicates that the selected explanatory variables provide a good estimate of the conditional density of adoption of SAPs. For example, the Wald χ^2 test statistic (392.79) indicates that explanatory variables are jointly statistically significant ($P < 0.01$) in explaining the SAPs adoption categories.

As expected older households were found to be less likely to adopt the SAP category $V_1C_1D_1$. This finding is consistent with other empirical works that have found age to have limited the probabilities of technologies adoption (Kassie, et al., 2015; Nidritu, et al., 2014; Teklewold, et al., 2013). This could be associated with the fact that risk aversion behavior increases with age and could limit the likelihood of adopting technologies which are characterized by high risk-high return trade-offs. We find that male-headed households are less likely to adopt ($V_1C_1D_0/V_0C_1D_1$). We find that family size to positively affect the adoption of SAP which includes soil & water conservation ($V_1C_0D_1/V_0C_1D_1$). This could not be surprising as soil & water conservation structures are labor intensive hence bigger households are more likely to adopt more than smaller households. Our results are in accordance with (Abdul-Hanan, et al., 2014) from Ghana. However, family size is negatively and significantly associated with $V_1C_0D_1$. Unsurprisingly, education level of the head of the household has a positive correlation with most of the SAP categories. Education of the head is positively associated with the SAPs $V_1C_0D_0$, $V_0C_0D_1$, $V_1C_1D_0$/ $V_0C_1D_1$ and $V_1C_1D_1$. The possible explanation could be because more educated households could understand and information that facilitates adoption. Wainaina, et al., (2016) further argued that more educated households have more well-paid income streams and thus fewer capital constraints to invest in innovative technologies.

One of the indicators of location and distance variables, distance to market, is positively associated with $V_0C_0D_1$. This finding is against the come-sense intuition that distance from the market should limit technology adoption. However, distance from the market could stimulate the adoption of cereal-legume diversification as households may take it as a strategy for self-sufficiency within their own farm. We find that credit constraint is a bottleneck for most of the SAPs adoption. This is because most of the rural farmers in developing countries are credit constrained. Credit constraint is negatively associated with the adoption of $V_1C_0D_0$,$V_0C_0D_1$ $V_1C_1D_0$/ $V_0C_1D_1$,$V_1C_0D_{0,}$ and our findings are in accordance with those found by Teklewold, et al., (2013) who found that credit constraint is a significant limiting factor in the adoption of SAPs in Ethiopia. This study suggests that, in order to facilitate the SAPs adoption, local financial institutions and governmental institutions need to provide credit opportunities for the local farmers. On the other hand, ownership of more asset significantly improves the probability of adoption of $V_0C_0D_1$ and $V_1C_0D_1$. Similarly, we found that livestock ownership increased the likelihood of the adoption of $V_1C_0D_0$,$V_0C_1D_0$, $V_1C_0D_{1,}$ and $V_1C_1D_{1.}$ Livestock ownership can be seen as an indicator of wealth. Livestock also generates income that can be invested in agricultural technologies. This finding corroborates those in Nidritu, et al., 2014, who find that livestock ownership increases the adoption of SAPs in Kenya. To our surprise, having experienced a death of a household member in the past five years is positively associated with $V_0C_1D_0$.

Looking at the variables related to association membership and social networks, we find that group membership stimulates the adoption of $V_1C_0D_1$ and $V_1C_1D_1$. This is due to the fact that group membership makes access and bargaining power to adopt improved technologies easy. This finding is backed by other empirical works (Mutenje, et al., 2016; Wainaina, et al., 2016; Nidirtu, et al, 2014; Teklewold, et al., 2013). We also analyze whether village level and non-village level kinship affect the adoption of SAPs. We considered the number of relatives and non-relatives that the household depends as the time of need as an indicator of kinship level both at the village and non-village separately. Our findings show that non-village kinship significantly affects the adoption of $V_0C_0D_1$, $V_1C_1D_0$/ $V_1C_0D_{1,}$ and $V_1C_0D_1$. The relationship between kinship and adoption are mixed in the literature. For example, Kassie, et al., (2015) reported that kinship to have reduced the probability to invest in chemical fertilizer in Malawi and Tanzania and water conservation in Malawi. Similarly, Di Falco and Bulte (2013) also found a negative relationship between kinship and water conservation technologies in Ethiopia.

However, kinship is found to stimulate the adoption of agricultural innovations. Kassie, et al., (2015) found that kinship inspires the adoption of minimum tillage in Ethiopia, soil and water conservation in Kenya and rotation in Malawi. We found that extension service positively associates with the adoption of $V_0C_1D_0$.

We found important district level difference in the adoption of SAPs. We found that farmers found in the Bongo district were more to adopt $V_0C_0D_1$, $V_1C_1D_0$/ $V_0C_1D_1$, and $V_1C_1D_1$ but less likely to adopt $V_1C_0D_1$ than the base category, Bulilsa district. Similarly, households from the Bwaku West district were found to have adopted $V_0C_1D_0$, $V_1C_0D_1$/ $V_0C_1D_1$, $V_1C_0D_1$ and $V_1C_1D_1$ than those in the Bulilsa district. Kassana Nankana East was found to adopt more $V_1C_0D_1$ and less of $V_0C_0D_1$, $V_0C_1D_0$, $V_1C_0D_1$/ $V_0C_1D_1$ and $V_1C_1D_1$, as compared to the farmers in Bulilsa district.

Table 4. 4 Multinomial logit model results of determinants of SAPs

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	$V_1C_0D_0$	$V_0C_1D_0$	$V_0C_0D_1$	$V_1C_1D_0$/ $V_0C_1D_1$	$V_1C_0D_1$	$V_1C_0D_0$
Household Characteristics						
Age of the household	-0.0268	-0.0120	-0.000857	-0.0118	-0.0204	-0.0321*
	(0.0171)	(0.0189)	(0.0131)	(0.0157)	(0.0155)	(0.0165)
Gender head	0.558	-0.301	-0.371	-1.279**	0.650	0.300
	(0.610)	(0.667)	(0.478)	(0.624)	(0.658)	(0.693)
Family size	0.0830	0.0586	-0.0132	0.178**	-0.145*	-0.0315
	(0.0874)	(0.0887)	(0.0685)	(0.0882)	(0.0875)	(0.0872)
Education of head	0.274*	0.251	0.289**	0.319**	0.204	0.266*
	(0.143)	(0.171)	(0.138)	(0.151)	(0.147)	(0.147)
Resource Constraints and market access						
Distance to input market	-1.102*	-0.300	-2.222***	-2.724***	-0.256	-1.507***
	(0.596)	(0.508)	(0.542)	(0.769)	(0.503)	(0.573)
Credit constrained	0.171	0.183	0.402*	0.438	0.562**	0.225
	(0.273)	(0.291)	(0.230)	(0.324)	(0.254)	(0.295)
Assets value (log)	0.116**	0.0887**	0.0414	-0.00130	0.111**	0.150***
	(0.0491)	(0.0428)	(0.0599)	(0.0615)	(0.0477)	(0.0447)
Total livestock holdings	-0.539	-0.285	-0.122	-0.163	0.0310	0.669*
	(0.446)	(0.486)	(0.350)	(0.440)	(0.397)	(0.405)
Total cultivated land (log)	0.0666	1.170**	-0.0573	0.0901	0.725	0.293
	(0.489)	(0.587)	(0.367)	(0.510)	(0.442)	(0.482)
Death shock	-1.102*	-0.300	-2.222***	-2.724***	-0.256	-1.507***
	(0.596)	(0.508)	(0.542)	(0.769)	(0.503)	(0.573)
Social Capital and Information						
Group membership	0.680	-0.0642	0.297	0.237	1.157**	1.458***
	(0.477)	(0.568)	(0.433)	(0.527)	(0.505)	(0.496)
Village kinship	0.0657	-0.0135	-0.0487	-0.0797	-0.0581	0.0619
	(0.0539)	(0.0546)	(0.0501)	(0.0587)	(0.0674)	(0.0581)
Non-village kinship	-0.0405	0.0921	0.144***	0.159***	0.111*	0.0598
	(0.0756)	(0.0630)	(0.0499)	(0.0566)	(0.0646)	(0.0600)

Table 4.4 Continued

VARIABLES	(1) $V_1C_0D_0$	(2) $V_0C_1D_0$	(3) $V_0C_0D_1$	(4) $V_1C_1D_0$/ $V_0C_1D_1$	(5) $V_1C_0D_1$	(6) $V_1C_1D_1$
Extension contact	0.405	1.134**	-0.0399	0.739	0.240	-0.388
	(0.567)	(0.559)	(0.432)	(0.563)	(0.517)	(0.542)
Climate change awareness	0.494	0.897	1.143	1.552	0.971	1.400
	(0.720)	(0.880)	(0.761)	(1.190)	(0.783)	(1.032)
Risk Preference						
Severe risk averse (RA)	-0.564	-0.584	0.327	0.0717	-0.0167	1.577**
	(0.790)	(0.852)	(0.513)	(0.742)	(0.681)	(0.732)
Moderate RA	0.245	-2.022*	0.0181	0.324	-0.947	1.216
	(0.825)	(1.149)	(0.664)	(0.811)	(0.813)	(0.775)
Intermediate RA	0.0266	-0.0216	-0.195	0.166	-0.469	0.701
	(0.700)	(0.700)	(0.534)	(0.739)	(0.687)	(0.838)
Slight to neutral RA	1.798*	0.762	2.261**	2.353**	1.609*	2.646**
	(1.001)	(0.989)	(0.908)	(0.974)	(0.976)	(1.098)
Neutral to preferring RA	1.423*	1.109	1.443**	2.073***	1.371*	3.199***
	(0.805)	(0.854)	(0.623)	(0.767)	(0.782)	(0.816)
Bongo	-1.207	0.913	1.064*	2.777***	-1.668**	1.661**
	(0.747)	(0.870)	(0.561)	(1.011)	(0.744)	(0.732)
Bwaku West	0.0241	2.022**	0.635	2.766***	1.046*	1.416**
	(0.604)	(0.888)	(0.513)	(0.963)	(0.631)	(0.717)
Kassenna Nankana East	-1.997**	1.413*	0.635	2.306**	0.322	1.239*
	(0.894)	(0.829)	(0.536)	(1.002)	(0.576)	(0.743)
Instrumental Variable						
SAPs information/training	2.063***	1.327**	0.537	0.840	1.597***	2.048***
	(0.579)	(0.624)	(0.434)	(0.568)	(0.522)	(0.552)
Constant	-3.305	-5.968**	-5.397***	-8.526***	-7.378***	-7.938***
	(2.089)	(2.656)	(1.857)	(2.718)	(2.173)	(2.416)

Number of Observations=421; Wald $\chi^2 = 392.79$***

Note: SE is robust standard errors. $V_0C_0D_0$ is the control category (non-adoption). ***, ** & * represents significance level at 1%, 5% & 10% statistical significance levels

4.4.3 Cropland expansion, why and for which crops

Of the 421 households included in the study, 85 households have expanded their cropland into uncultivated forest, wetland and grassland and shrubs between the 2014 and 2015 years. Therefore, we defined deforestation as households decision to expand cropland into virgin forest lands, wetlands and grass and shrublands.

Table 5 below shows the amount of acres households expanded into forest areas farm household adaptation strategy. On average, households have expanded their cropland by 0.21 acres in the past 12 months prior to the survey. Results from Table 4.5 show that households who adopted the SAP category of improved maize only ($V_1C_0D_0$) has the highest level of cropland expansion of 0.289 acres while households in the group that adopts improved maize varieties with soil & water conservation or Soil & water conservation with cereal-legume diversification, ($V_1C_1D_0/V_0C_1D_0$) have the lowest cropland expansion rate having expanded only around 0.0775 acres. We did a simple statistical test of the mean of cropland expansion among the SAPs adopters and non-adopters. Almost all combinations (except the adoption of improved maize varieties with soil & water conservation or Soil & water conservation with cereal-legume diversification, ($V_1C_1D_0/V_0C_1D_0$)) do have a significant effect on cropland expansion as compared to the non-adopters.

However, the problem with the above simple statistical test methods is that they are simple comparisons among the SAP categories and hence, that does not account for both observed and unobserved covariates that may influence cropland expansion. Variation in cropland expansion among the groups may be strongly influenced by observed and unobservable characteristics of the farm households, such as their innate behavior. Therefore, to find the exact impacts of SAPs on cropland expansion other observable variables must be included with a robust methodology to control for unobservables. We follow the theoretical and empirical methodologies presented in sections 4.2 and 4.3 and presented the impacts of SAPs on cropland expansion in the sub-section 4.4.4.

Table 4. 5 Cropland expansion by SAPs adoption status

SAP Categories	Mean cropland expanded	Difference	t
$V_0C_0D_0$	0.251		
$V_1C_0D_0$	0.289	0.0377	0.721
$V_0C_1D_0$	0.2129	-0.0386	0.7518
$V_0C_0D_1$	0.2215	-0.03	0.7538
$V_1C_1D_0/V_0C_1D_0$	0.0775	-0.1741*	0.0683
$V_1C_0D_1$	0.2186	-0.0329	0.7299
$V_1C_1D_1$	0.1729	-0.0787	0.3739

4.4.3.1 Why do households' expand their cropland?

We have asked the sample respondents the reason why they had to expand their cropland. As can be seen in Figure 4.1, the main reason for their decision to expand their land into forest areas is to meet their households demand for food (81%). The next reason to expand into forest areas is for marketed surplus (12%). Other reasons mentioned for expanding into forest areas were, improved accessibility of inputs, availability of good virgin lands, reduced soil fertility in other plots and to secure land. However, these reasons were less mentioned by the households and only covers between 1 and 2%.

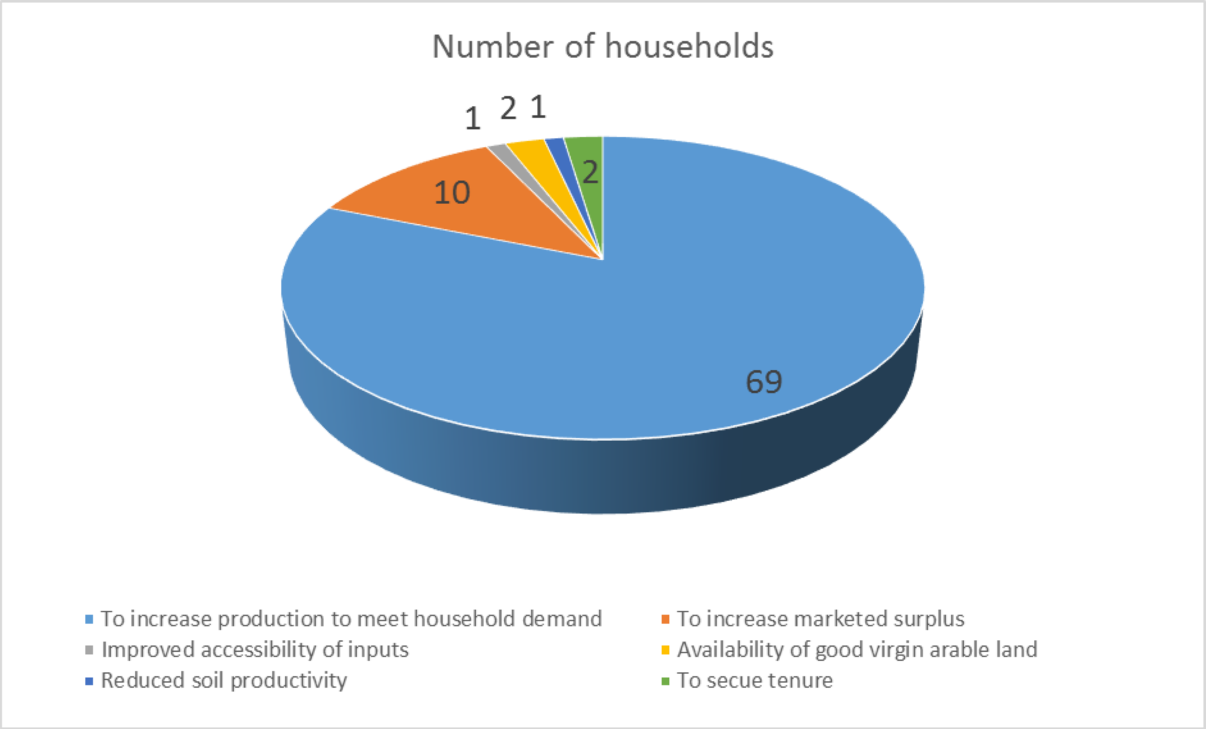

Figure 4. 1 Reasons why households had to expand into forest areas

4.4.3.2 Cropland expansion for which crops?

We also asked the farmers who already expanded to which crop they did so. The results in Figure 4. 2 revealed that most farmers expanded into forest areas for maize production (48%). This finding is in accordance with those in Babigumira, et al., (2014) and Ngoma & Angelsone, (2017), who indicated that most of croplands expansion into forests in Africa is for maize production. Ngoma & Angelsone, (2017), specifically show that about 79% of the households who expanded into forest areas cover their expanded land by maize in Zambia. Millet was used by 24% of the households in expanded lands. Other crops like sorghum, rice Cowpea Groundnut tomato.

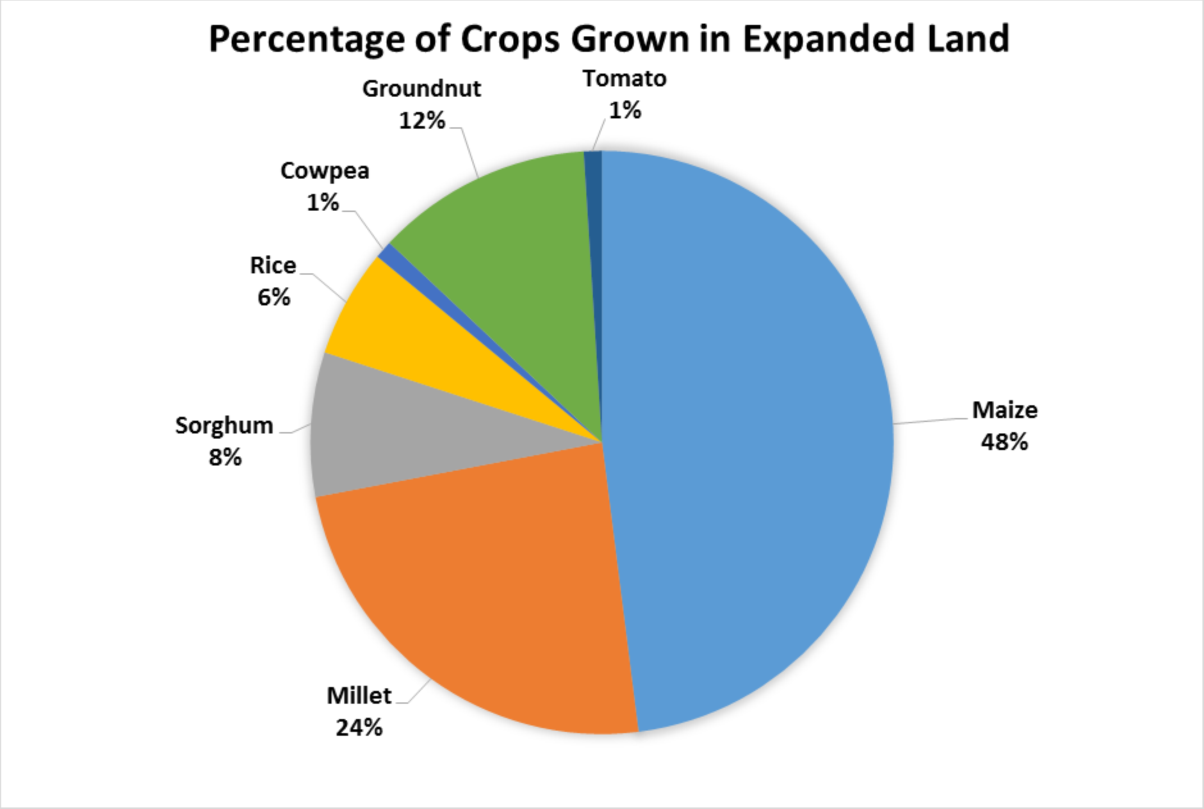

Figure 4. 2 Crops grown in expanded lands

4.4.4 SAPs and forest clearing

There is a substantial difference in the literature concerning the effect of technological change in agriculture and deforestation. Researchers such as Norman Borlaug (1997) argue that agricultural intensification reduces global deforestation. This is due to the fact that intensification allows producing more output with the same land thereby reduces the aspiration to expand agricultural land into forest margins. On the other hand, other researchers argue that technological change in agriculture accelerates deforestation due to the profitability effects of agricultural production. On their extensive deforestation literature review, Kaimowitz and Angelsen (1998) reported a scarcity of empirical works on the dynamics of technological change in agriculture and deforestation. The Authors' conclude that the impact of technological change in agriculture on deforestation depends on the characteristics of both the agricultural technologies and the spatial location of the studies. The variables of policy interest in this study are the different combinations of SAPs adopted by the household. We used the churdle craggit model in estimating the determinants of the decision to clear and extent of cropland expansion into forest. We then estimate the average marginal effects following the double hurdle model. The churdle cragit model estimates are given in Table A4.1 in the appendix. The F-statistics of the model shows that the variables are jointly significant in determining the cropland expansion into forest outcome variable. As direct coefficient estimates of churdle cragit model are not directly interpretable, we presented the average marginal effects[31] below and discuss the results accordingly.

As can be seen in Table 4.6, the main finding of this study is that adoption of combinations of SAPs does not significantly affect deforestation. Our results are in accordance with Byerlee, et al., (2014), who indicated that agricultural intensification may not reduce cropland expansion into forest areas without other measures such as improving policies for forest resources governance and Payment for Ecosystem Services (PES) incentives to preserve forest areas. Ngoma and Angelsen, (2017), have also reported similar results from Zambia but they found MT to have reduced cropland expansion into forest areas among those who already decided to expand their cropland households.

4.4.5 Other drivers of deforestation

In addition to the combinations of SAPs, we included other covariates as factors of deforestation guided by previous literature on cropland expansion. Contrary to economic theory and our expectation, we find shadow wage (opportunity cost of labor) to have positively associated with cropland expansion into forest. Ngoma and Angelson (2017) have reported similar results from Zambia. In quantitative terms, our findings show that each

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[31] We use the margins command in stata to produce the average marginal effects.

additional unit of shadow wage is associated with 0.63 acres of forest land converted to crop production. Some explanations can be given to this contrary result of shadow wage on cropland expansion. Ngoma and Angelson (2017), narrates this unparalleled result to the fact the mechanisms that the shadow wages are calculated. The authors claim that the formula of Eq. (10) includes total agricultural production; a high shadow wage may, therefore, reflect that the household has certain characteristics (including unobservables) that increase productivity also from the recently expanded land. On top of that, it could be due to the fact that the labor markets are missing or imperfect as in most developing country situation. It might also indicate that household labor is an important factor in agricultural production, including cropland expansion, and households might decide to employ more labor into agriculture than elsewhere such as off-farm income (Ngoma and Angelsen, 2017). Furthermore, due to the inclusion of crop income from the expanded forest in the production function in calculating the shadow wage and the potential unobservables, there could be a potential endogeneity problem. Therefore, caution is needed when interpreting the shadow wage effect results.

Results show that having a relative in the leadership community is associated with stimulating cropland expansion. This could be due to the fact that the social networks and that can lead to a better access to resources such as land. For example, households who are close to local chief might get a permission to expand their lands into the forest.

The average distance to plots is found to be positively and significantly affect cropland expansion into forests. This finding is also contrary to the economic theory and intuition. But this could be due to the fact that households normally expand their cropland nearer to the already existing plots which are normally found at the edge of communities near the forest lands. Due to that, as the household holds a plot that is far away in the forest areas, the probability of expanding increases.

We calculate the average tenure security of all plots as an indicator for tenure security. Tenure security can have contradictory effects on the likelihood of cropland expansion due to the following reasons. On the one hand, having a higher level of tenure security could induce investment in the existing plots and could help making intensification more attractive against expansion. For example, studies suggest that tenure security stimulates farm-level investments in Ethiopia (Kassie, et al., 2009; Kassie et al., 2015), Kenya (Wainaina, et al., 2016; Ndiritu, et al., 2014), in Malawi (Kassie et al., 2015), which could reduce for further expanding cropland. Ngoma and Angelsen (2017), found a negative relationship between tenure security and cropland expansion in Zambia. On the other hand, farmers may clear forest land to claim tenure titles, therefore, the presence of tenure security might escalate forest clearing for crop production (Ngoma and Angelsen, 2017; Angelsen 1999). Our result goes with the second argument because we found a positive relationship between tenure security and forest clearing.

We did not find a relationship between output price and forest clearing. This could be, however, due to the short run nature of our study. Some studies suggest that, in the long run, higher prices could be associated with cropland expansion into forests (Elnagheeb and Bromley, 1994; Monela, 1995; Bagachwa et al., 1995; Barbier and Burgess, 1996; Angelsen & Kaimowitz, 1999; Angelsen, 1999). Our study area is also spatially limited that there could not be much variations in the price variable itself across households which could make it difficult to identify the effect on clearing with the cross-sectional data that we have for this study.

We find a positive relationship between crop failures a year before the data collection and forest clearing. Declining soil fertility is considered as the main reason for crop failures (Etongo wt al., 2015; Morton et al., 2006), therefore, farmers may wish clearing new forest areas abandoning the unfertile once.

Table 4. 6 Partial Marginal effects of drivers of deforestation

Variable Description	**dy/dx**	**se**
$V_1C_0D_0$	-0.0241	0.0376
$V_0C_1D_0$	-0.0084	0.0468
$V_0C_0D_1$	-0.0557	0.0637
$V_1C_1D_0/V_0C_1D_1$	0.0592	0.0564
$V_1C_0D_1$	0.0036	0.0496
$V_1C_1D_1$	0.0336	0.0301
Relative in leadership (yes=1)	0.2803***	0.0614
Shadow wage	0.6291*	0.3305
Share of community forest area	-1.061**	0.5057
Average distance to plots (ln)	0.04***	0.01487
Average land tenure of plots	0.2293*	0.1368
Output price per kg	0.3029	0.2019
Age of head	-0.0008	0.0021
Gender of head (Male=1)	0.1148	0.0949
Adult Equivalent	0.0173	0.0161
Education head (years)	-0.0215	0.0148
Distance to forest reserve	-3.16E-07	0.000001
Value of assets (ln)	0.0252	0.042
Total livestock units (TLU)	-0.0004	0.0071
Cultivated land, net expansion	-0.0327***	0.0101
Shock crop failure	0.0636*	0.0382
Sever risk averse	-0.2677***	0.1045
Moderate risk averse	-0.03569	0.1276
Intermediate risk averse	-0.1267	0.0929
Slightly risk averse	-0.1192	0.1089
Neutral risk averse	-0.1468	0.1035
Bongo district (yes=1)	-0.7408***	0.2488
Bawaku west district (yes=1)	-0.6581***	0.2037
Kassena nankana east (yes=1)	-0.5993***	0.2084
Number of Observations	**421**	

4.5 Conclusion

We analyzed the effect of different combinations of SAPs on forest clearing in the Upper East Region of Ghana. Our estimates were derived from a cross-sectional farm household survey collected from 421 sample households from Bongo, Bwaku West, Kassena Nankana East and Bluilsa South districts. Our results suggested that about 20% of the households have expanded their cropland into forest areas clearing on average 0.21 acres of land. We did not find any significant association between deforestation and adoption of SAPs. However, we find other factors that affect deforestation. We concluded that at least in the short run, SAPs do not appear to be the main drivers of deforestation. However, due to the limitation that our data are cross-sectional, cautions must be taken in interoperating our findings. Future research should apply panel data to establish a reliable and strong causality between adoption of SAPs and deforestation.

4.6 Appendix

Table 4A. 1 First stage estimates of the churel double hardel model

	(1)	(2)
VARIABLES	Probit	Truncreg
$V_1C_0D_0^*$	0.318	-0.245**
	(0.203)	(0.115)
$V_0C_1D_0^*$	0.236	-0.144
	(0.244)	(0.144)
$V_0C_0D_1^*$	0.673**	-0.536***
	(0.338)	(0.206)
$V_1C_1D_0 / V_0C_1D_1^*$	-0.339	0.391**
	(0.268)	(0.187)
$V_1C_0D_1^*$	-0.415	0.210
	(0.267)	(0.149)
$V_1C_1D_1^*$	0.0560	0.105
	(0.169)	(0.0868)
Relative_Leadership_position	1.086***	0.580***
	(0.264)	(0.175)
Shadow wage (z)	6.022***	-0.393
	(1.895)	(0.871)
Share of Forest area (fs)	-2.357	-3.027*
	(2.471)	(1.563)
Log of average distance of plots (LP_DIS)	0.0135	0.150***
	(0.0769)	(0.0470)
Average tenure security (AP_TEENURE)	0.424	0.695
	(0.687)	(0.423)
Maize price (Py)	0.748	0.829
	(0.953)	(0.637)
Age of head (AGE)	6.65e-05	-0.00328
	(0.0108)	(0.00663)
Gender Head MHEAD	-0.326	0.603**
	(0.496)	(0.297)
Adult equivalent AE	0.0403	0.0486
	(0.0724)	(0.0528)
Education Head EDUHEAD	-0.223***	0.0215
	(0.0829)	(0.0419)
Distance to forest DISFOREST	-7.86e-05	3.60e-05
	(5.88e-05)	(3.24e-05)
Log value asset Ln_ASSET	-0.206	0.196
	(0.225)	(0.130)
Total livestock units TLU	-0.00434	0.000311
	(0.0360)	(0.0218)
Crop land net expansion NCLA	-0.0663	-0.0967***
	(0.0481)	(0.0315)
Shock_crop_failure	0.271	0.120
	(0.179)	(0.119)

SEV_RP	-1.119**	-0.516*
	(0.518)	(0.306)
MOD_RP	-0.109	-0.0877
	(0.651)	(0.391)
INT_RP	-0.0998	-0.448
	(0.474)	(0.288)
SLI_RP	-0.942*	-0.0195
	(0.521)	(0.343)
NEU_RP	-0.983*	-0.108
	(0.527)	(0.310)
B	-1.600	-2.135***
	(1.236)	(0.750)
BW	-1.540	-1.841***
	(0.978)	(0.621)
KNE	-0.723	-1.998***
	(1.040)	(0.646)
Constant	0.221	-1.972
	(2.290)	(1.459)
Sigma ()	-0.330***	
	(0.119)	
LR chi2(29)	134.16***	
Observations	421	421

Table 4A. 2 Cobb Douglas production function estimates

VARIABLES	(1) Log of net crop income
Log total cultivated land	0.701***
	(0.0686)
Log fertilizer used	0.0511***
	(0.0161)
Log seed cost	0.102***
	(0.0337)
Log labor used	0.169*
	(0.0988)
Age of head	-0.00468*
	(0.00254)
Gender of head	0.212**
	(0.0953)
Education of head	0.00664
	(0.0115)
Bongo district	-0.111
	(0.105)
Bwaku West district	0.00414
	(0.112)
Kassena Nankana East district	0.0720
	(0.110)
Constant	5.280***
	(0.295)
Observations	421
R-squared	0.390

Robust standard errors in parenthesis. ***, ** & * represents significance level at 1%, 5% & 10% statistical significance levels

Chapter 5

Summary and Conclusions

Agriculture is the main source of income, food security and employment for a majority of people, especially the poor, and thus directly supports human development (UNDP, 2012). Agricultural productivity growth is recognized as an important driver of structural transformation and economic development for developing countries (Gollin, et al., 2002). However, agriculture contributes to negative environmental impacts through two channels, i.e, through expansion of croplands and pastures into new areas, replacing natural ecosystems and through intensification (when technologies such as fertilizer and pesticides are used in existing croplands) which leads to producing toxic elements and emits greenhouse gases. Therefore, agriculture has had tremendous impacts on habitats, biodiversity, carbon storage and soil conditions (Tilman, et al., 2002; Foley, et al., 2005; Foley, et al., 2011). Estimates show that agriculture contributes between 30 and 35% of greenhouse gas emissions from global deforestation and nitrous oxide emissions from pintsized and fertilized soils (DeFries and Rosenzweig 2010; Galforda et al., 2010; Foley, et al., 2011).

Furthermore, with the increasing population, producing more food in the coming decades, while at the same time maintaining ecosystem services and combating the adverse effects of climate change will be a primary encounter facing agriculture (Garrity, et al., 2010). Previous literature shows that SAPs can help to increase crop production while reducing environmental footprints. However, most of the studies in SSA on the adoption and impacts of new agricultural technologies in general and SAPs, in particular, have mainly focused on the analysis of single agricultural innovations, despite the fact that rural households use multiple innovations (Dorfman, 1996; Khanna, 2001; Teklewold, et al., 2013; Manda, et al., 2016). Households adapt multiple technologies because of their synergies to enhance crop output, reduce soil erosion, and reduce the damage from pests and diseases, among others (Teklewold et al., 2013). Furthermore, previous studies focused mainly on the adoption and impacts of SAPs on household's welfare outcomes. In this dissertation, while contributing to the analysis of SAPs effects to households' welfare, the thesis extends the previous literature by analyzing the effects of SAPs on measures of environmental outcomes (reliance on environmental resources as a livelihood strategy and agricultural land expansion into natural forest areas). This analysis helps us to understand if there are positive or negative 'indirect environmental benefits' of SAPs to the already known biophysical and economic benefits at the farm and household levels.

This thesis, therefore, addresses three objectives. (1) to estimate the determinants and the impacts of different combinations of SAPs on farm households welfare, (2) to investigate the impacts of the different combinations of SAPs on farm households reliance on environmental resources, (3) to assess the impacts of the SAPs on farm households decision on cropland expansion into forest areas. Primary data obtained from 421 smallholder farmers in the Bongo, Kassena Nankana East, Bawku West and Bulisa South districts of the Upper East Region of Ghana is used for the analysis. The study gives a special emphasis in collecting income from environmental products from uncultivated areas in addition to the socioeconomic variables which are common in other socio-economic surveys. Additional community-level data were also collected through expertise and focus group discussions.

In most of previous literature adoption and impact of interventions that can help to reduce food insecurity and poverty are frequently modeled separately using single equation models. In this study, however, three of the most common SAPs in the study area (improved maize varieties, soil & water conservation measures and cereal-legume diversification) were considered. The adoption and impacts of the combinations of the three SAPs were modeled in a multinomial setting that helps to analyze the synergistic effects of the different combinations of SAPs on households' welfare measures and environmental outcomes.

Using multinomial endogenous treatment effect model, which controls for self-selection bias and other observable and unobservable heterogeneities, the thesis estimated the adoption and impacts of different combinations of SAPs on households' welfare measured in crop income per acre and consumption expenditure per capita. The results suggest that variables related with household characteristics, resources constraint and market access, social capital and information, plot level characteristics and risk aversion levels of the household are found to be the determinant factors in the adoption of the different combinations of SAPs. Looking at the welfare impacts of SAPs, generally, it is found that SAPs have positive effects on households' welfare (on crop income per acre and consumption expenditure per capita). Furthermore, due to the synergistic effects of SAPs, the effects of SAPs on the welfare measures are higher when SAPs are adopted in combinations than in isolation. For example, adopting all the three SAPs together (improved maize varieties, soil & water conservation measures and crop-legume diversifications), leads to about 20% higher in crop income per acre, while only adopting improved maize varieties leads to only 8% increase on crop income. The results are consistent with, other few empirical works in SSA that have found positive effects of SAPs on welfare outcomes. For example, Teklewold et al. (2017)

analyzed the adoption and impacts of three SAPs (fertilizer, improved maize seed, and water management) and they find that higher income is obtained when all the three SAPs are adopted. In Malawi, Kassie et al. (2014), found that higher incomes are realized when farmers adopt improved maize varieties with minimum tillage than when they adopt these two SAPs in isolation. On the other hand, Manda, et al., (2016), analyzed the adoption and impacts of three SAPs (improved maize varieties, maize-legume rotation and residue retention) in Zambia. Contrary, to the prior studies, the authors found that higher incomes are realized when improved maize varieties are adopted in isolation than in any combinations.

The thesis also analyzed if the positive agricultural income change due to the adoption of SAPs translates into environmental reliance of households as their livelihood strategies. Absolute and relative measures of environmental reliance were estimated. The thesis defined environmental income, *inter alia*, Sjaastad et al. (2005) and Angelsen et al. (2014), as income obtained by directly consuming, using or selling environmental resources which comes from the natural environment (whose original stock is not as a consequence of farming or a human productive process). The importance of environmental income to households' livelihood has been overlooked from most of the socio-economic surveys. In the last two decades, however, there have been some studies that incorporated environmental income into the household income accounting. The contribution of environmental income to total household income ranges between 15 to 60% (Vedeld et al. 2007; Mamo et al. 2007; Paumgarten and Shackleton, 2009; Kamanga et al. 2009; Thondhlana and Muchapondwa, 2014; Angelsen et al. 2014). This thesis tested the hypothesis that whether SAPs, which increase crop income, have positive or negative effects on environmental reliance. The concept of who depends more on the environmental income is ambiguous by itself. While there is a general consensus that poorer households depend more on environmental products than better off households, there is also evidence that poorer households utilize more environmental resources than better off households in relative terms, while richer households use greater quantities of these resources in absolute terms (Cavendish, 2000; Shackleton and Shackleton, 2006; Mamo et al. 2007).

The study found that the rural households generate about 30% of their income from environmental resources, on average. This share of environmental income to total household income ranges between 15 and 40% among the rural households who adopted different combinations of SAPs. The results from the absolute measure of environmental dependence show that SAPs generally reduce households' dependence on the environmental resources. Same as the welfare effects of SAPs analysis, the environmental dependence effects of SAPs is higher when SAPs are adopted in combination than in isolation. For example, households that adopted improved maize varieties only ($V_1C_0D_0$) reduces their environmental reliance by about 7%, while households that adopted all the three SAPs ($V_1C_1D_1$) are found to be 15% less on environmental reliance, in absolute terms. Results of the relative measure of environmental dependence are also in accordance with the absolute measures, except the estimated coefficients are higher. Quantitatively, households that adopted improved maize varieties only ($V_1C_0D_0$) reduces their environmental reliance by about 22%, while households that adopted all the three SAPs ($V_1C_1D_1$) are found to be 75% less on environmental reliance, in relative terms. Therefore, the thesis found that SAPs are important not only for improving households' welfare but also can save environmental resources degradation as households who adopted SAPs reduce their reliance on environmental resources as their livelihood strategies.

The thesis also analyzed the effects of the different combinations of SAPs on households' cropland expansion into forest areas. Results show that 85 (20.1%) households from the sampled 421, have expanded their cropland into forest areas within the past 12 months prior to the survey date. The average expanded crop area into forest areas is estimated about 0.21 acres. Households were asked why they had to expand their cropland and 81% of the households they did expand their cropland into forest areas to increase their crop production to meet their household demands while only 12% did so for marketed crop surplus. Results also show that 48% of the area expanded into the forest is used for maize production while millet takes 24%. The study found that there is no SAPs driven cropland expansion into forest areas.

Important implications can be taken from the welfare and environmental outcome impacts of SAPs. The results show that there is the high dependence of households on environmental products. Hence, any policies that could be set to protect environmental products might have a significant effect on the welfare of rural households. Therefore, policies and strategies that aim to protect environmental resources should look at the potential trade-offs between conservation policies and the livelihood strategies of households. The fact that there are higher percentage point impacts of SAPs on the crop income than the consumption expenditure could be partly because non-adopters depend more on environmental resources and hence it narrows the gap as the environmental resources are included in the consumption expenditure accounts. For example, adopting the three SAPs ($V_1C_1D_1$) increases crop income by about 20% but it only increases consumption expenditure by about 8%. This is backed by some literature that environmental resources have a consumption smoothing and equalizing effects on rural households (Heubach, et al., 2011; Babulo, et al., 2009; Kamanga, et al., 2009).

However, this thesis is not without limitations and some of the major caveats deserve mentioning. The first one is that the results of this thesis are based on cross-sectional data and therefore, although robust methods were used, observed and unobserved heterogeneity might not be controlled well. Therefore, causality based on evidence of correlation might not be inferred perfectly. Further research, should use longitudinal panel data to estimate more robust effects of SAPs on the outcome variables. Others may also question the external validity of the results in this thesis to other parts of the world and other parts of Ghana as they refer to only the Upper East Region of Ghana.

Second, due to small sample size on the SAP category of improved maize varieties and soil & water conservation measures ($V_1C_1D_0$), it had to be merged with another SAP category (soil & water conservation and cereal-legume diversification ($V_0C_1D_1$) package) for ease of estimation. Hence, the independent impact of these two important SAPs is not estimated for the above-mentioned reason. Future studies should have large sample sizes that can allow having enough variations and sample sizes in each SAP categories.

Third, collecting data on environmental resources collection and utilization is a difficult task because most of the environmental resources are seasonal and different members of households collect the environmental resources. Households also use different material units in collecting the environmental resources. Therefore, a one-time survey, like the one used in this thesis, might not fully capture the total value of environmental resources and there might be measurement errors.

This study is based on the notion that environmental resources collection is linked with degradation. However, sometimes there is nothing wrong with consuming environmental resources and therefore not all consumption is considered as degradation. Nonetheless, there is a general trend that ecosystem and environmental resources have been depleted through decades of human consumption. However, future studies should differentiate degradable and non-degradable environmental consumption in order to clearly show the real impacts of SAPs or any other interventions on environmental reliance.

Given these limitations, the overall findings of the thesis demonstrate that SAPs have positive effects on households' welfare. It also shows the importance of using combinations of SAPs than individual effects for higher welfare benefits. Further, the key message of the thesis is that SAPs have positive environmental effects (measured here as the households reliance on environmental resources) in addition to the already known biophysical and economic benefits. Results also show that there is no evidence of SAPs driven cropland expansion into forest areas. Therefore, it is important that the adoption of SAPs to be promoted and supported as it improves households' welfare but also reduces households' reliance on environmental resources which can have positive effects on biodiversity conservation, climate change mitigation and ecosystem services.

Finally, we would like to make some recommendations for further research. First, this study is based on cross-sectional data, which could partly limit the credibility of the findings. Future studies should, therefore, use panel data for more robust findings. In addition, more than one spot survey in a year for calculating the environmental income would provide better accounts and hence the dependence on the environmental resources. Including other environmental non-pecuniary benefits of environmental resources would also provide better estimates of the dependence on environmental resources. Second, other aspects of environmental resources such as nutrition should be investigated. It is known that environmental resources contribute to human nutrition such as protein (e.g wild meat) and vitamins (e.g wild vegetables and fruits). As it is demonstrated in this thesis, SAPs reduce the household's dependence on environmental resources, which can be seen as a positive contribution to the environment. But the less dependence on environmental resources could mean less diversification of the food basket of the household. Therefore, this needs further investigation.

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