ESSAYS ON SUSTAINABLE AGRICULTURAL INTENSIFICATION PRACTICES:

THE CASE OF TWO WEST AFRICAN STATES

by

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B.Sc., University for Development Studies, Ghana, 2004
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AN ABSTRACT OF A DISSERTATION

Submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Abstract

Essay one evaluates two farmer field schools aimed at promoting conservation agricultural practices. The field schools were conducted and offered to approximately 1/3 of all individuals surveyed in a baseline in 2010. These same farmers were resurveyed in 2012 in order to determine whether their knowledge of conservation agriculture practices had changed using a double-difference approach. The approach was also used to determine whether innate perceptions and biases against conservation agriculture have changed over time due to training in the field schools. These findings are supported with enterprise budgets of conservation practices to determine whether knowledge or on-farm economics limit adoption of conservation practices. The data showed that farmer-to-farmer communications are effective tools for raising knowledge.

Essay two examines the interdependence of sustainable agricultural intensification practices (SAIPs) in order to better understand the constraints and incentives for the adoption of components and "packages" of components. The impact of accumulated knowledge score on the adoption of SAIPs was assessed using data from 168 participant and non-participant farm households that completed a survey in 2014 and 2012 from the Upper West region of Ghana. From a three-step regression, our findings show knowledge of participant household improved with evidence of knowledge spillover to non-participant. Participation, age and gender of the head of household and experience were factors impacting farm household knowledge score change on SAIPs. The study found that, knowledge score through the treatment effect impacts adoption of SAIPs which are complementary. Younger household heads and experience in farming are also found to likely impact adoption.

Essay three estimates technical efficiency (TE) scores for millet and sorghum and evaluates the impact of soil and water conservation methods on TE scores. The paper also examines the sensitivity of TE scores on the distributional assumptions of the one-sided error using data from 518 and 754 farm households producing millet and sorghum respectively from a random national household survey in Niger. A Cobb-Douglas stochastic frontier model was used. The mean TE scores range from 52% to 66% and 35% to 60% respectively for adopters and non-adopters of soil and water conservation methods in millet production based on the distributional assumptions of the one-sided error. For sorghum production, the mean TE scores range from 47% to 63% and 39% to 63% respectively for adopters and non-adopters of soil and water conservation methods based on the distributional assumptions of the one-sided error. This suggests inefficiencies in the production of millet and sorghum and hence, the potential to improve output using existing technology. Adopters are relatively more efficient than non-adopters of soil and water conservation methods. The TE score differences in millet production are explained by location of household (rural), educational level and adoption of soil and water conservation. The efficiency score differences in sorghum can be explained by household size, educational level and soil and water conservation adoption. We also found TE scores are sensitive to the distributional assumptions of the one-sided error using the farm household level data.

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Acknowledgements

I would first like to give thanks to the ALMIGHTY ALLAH for my life on earth and will continue to ask for blessings.

I would always be thankful to Dr. Timothy J. Dalton for his sound and critical advice, guidance and mentoring me as I progressed towards completion of my degree. His availability, flexibility and encouragement has provided the motivation to pursue my own research interests with the laxity to work on multiple projects during the period I have been here in the past years. I am really very grateful for the conversations we have had which shaped my perspective in field of research and many other areas. I would like to thank my supervisory committee members, Dr. Jason Bergtold, and Dr. Jeffery Williams and Dr. Vara Prasad, I would like to thank them all for helping me through this process and for their advice in shaping my research.

To all the professors and graduate students in the department of Agricultural economics at Kansas State University, I say “Niikpangmanga” which literally means well done. I would also like to thank Judy Maberry, Deana Foster and Maria Sweet for their readiness to help me get through this studies during my stay here.

I would like to thank my family for their support and prayers during the course of my studies. I wish to thank my parents, Hajia Samata Fuseini and Yahaya Musah of blessed memory, for instilling in me a work ethic comparable to none and for supporting my career decisions. I also want to thank my friends for the encouragement whenever needed. My wife has been of tremendous help throughout my stay in Manhattan for enduring my continuous absence and I could not say anything other than to tell her I am very much grateful and her pain will not go unnoticed. I am especially blessed to have her as a wife and may the almighty bless her.

I will forever be grateful to the director of CSIR-SARI, Dr. S. K Nutstugah and Dr. Jesse B. Naab for their continuous support they have shown me all these years.

This publication was made possible by the United States Agency for International Development (USAID) and the generous support of the American People for the Sustainable Agriculture and Natural Resources Management Collaborative Research Support Program under terms of Cooperative Agreement No. EPP-A-00-04-00013-00

Partial support for this research was made possible by the generous support of the American people through the United States Agency of International Development (USAID) under Cooperative Agreement No. AID-OAA-A-13-00047 for the Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet. The contents do not necessarily reflect the views of USAID or the United States Government.

Dedication

To Maraiama Napari Fuseini, Samata Fuseini, Yahaya Musah (Late) and Rukaya Yahaya (Late).

Chapter 1 - Introduction

1.1 Background

Climate change has generated negative impacts on tropical agricultural production, reducing production levels from 1 to 5% globally (Porter et al. 2014). African production systems are vulnerable since most agriculture is rainfed which is sensitive to climate change variability. According to Morton (2007), smallholder farmers are vulnerable to the effects of climate change because it aggravates food insecurity due to price instability and poverty. Adaptation strategies are therefore important for the sustainability of rainfed food production systems.

Evidence shows that there is potential for sustainable agricultural intensification practices (SAIPs) to reduce the effects of climate variability on smallholders (FAO 2009). According to FAO (2009), SAIPs may involve direct seeding without ploughing, retaining crop residue, planting of cover crops, intercropping or crop rotations with legumes. The reasons for adopting SAIPs include reducing the rate of declining soil fertility, improving soil structure, preventing soil erosion and allowing for sustained soil fertility. The benefits of sustainable agricultural intensification practices include a significant reduction in the cost of production (Dalton et al. 2014) and increased yields (Balota et al. 2004; Bayala et al. 2012; FAO 2009). The unintended benefits may also include increased soil organic matter (Balota et al. 2004; Bayala et al. 2012), a reduction in the pollution of water bodies and carbon dioxide emissions (Steiner 2002).

Resource poor farmers in Niger and the Upper West region of Ghana are dependent on rainfed agriculture and their livelihoods are at stake due to low soil productivity caused by continuous mono-cropping with disking, soil erosion (from wind and water), lack of external inputs and inadequate water for crops. The adoption of SAIPs have the potential to improve soil productivity and improve the use of existing technology generating a reduction in poverty and extreme hunger (FAO 2009).

1.2 The Motivation

The Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP) introduced SAIPs to farm households in the Upper West region of Ghana in 2009. The goal was to improve food security by increasing economic returns to smallholder farming households dependent on rainfed agriculture through the development and dissemination of SAIPs. SAIPs improve soil quality, water capture, water use efficiency, crop productivity, ecosystem services and the efficient use of farm inputs and labor. The research program was implemented through a farmer participatory research approach. The participatory approach was adopted to enhance sustainability of SAIPs through social and human capital development and to facilitate technology impacts (Johnson et al. 2004; Neef & Neubert 2010).

The introduced SAIPs include:

- Zero/no-tillage: This involved the use of herbicides to spray fields in preparation for planting without the use of any form of tillage (hand or mechanical).
- Residue retention: This practice allows farm households to leave crop residue on their fields to provide a permanent soil cover, maintain optimum soil temperature, improve moisture retention and prevent soil erosion. It also decomposes and forms part of the soil organic matter.
- Cereal-legume rotations: This practice involved crop diversification in sequence by alternating the planting of cereals followed by a legume in the second

production period. It improves soil nutrient recycling through a biological processes. It also reduces the effect of plant diseases and pests.

- Fertilizer or nutrient management: This practice involves the use of recommended levels of fertilizer use for cereals and legumes.
- Tied ridges: This practices involves the use of terraces across the slope and creating furrow diking to trap water while reducing soil erosion.

One of the reasons for adopting the farmer participatory research approach is to induce learning through the change in farmer perceptions. Based on an unpublished baseline survey conducted in 2010, farmers' knowledge levels were very low especially on zero/no-tillage practices (Yahaya & Hashim 2010 unpub.).

This dissertation focused on research into the following questions related to knowledge on, the adoption of, and the impact of sustainable agricultural intensification practices:

1. Is there a knowledge change on sustainable agricultural intensification practices since the 2010 baseline when measured again, two years after training?
2. Is the accumulated knowledge change due to the farmer participatory research?
3. If yes to the above, did the knowledge gain have an impact on adoption of SAIPs?
4. Are the adoption of SAIPs complementary or substitutes for each other?
5. Can SAIPs increase household sorghum and millet technical efficiency?

Research on the above questions gave rise to the papers in this dissertation. The first and second essays are intended to analyze the effects of knowledge accumulated through intensive farmer participatory research training on the adoption of new crop and resource management technologies. Most approaches to modelling the adoption of soil and water conservation practices use univariate Probit or Logit models (Sidibé 2005; Adesina et al. 2000; Mugwe et al. 2009). Other studies have examined the multiple adoption of conservation agricultural practices using multinomial logit models (Fuglie 1999; de Herrera & Sain 1999). These studies assume independence on the adoption of SAIP components while evidence of the interdependence of SAIPs components has been shown (see Kassie et al. 2009; Kassie et al. 2012, Dalton et al. 2011; Neill & Lee 2001).

The third essay addresses the fifth question. This paper measures the technical efficiency levels of farm households producing sorghum or millet in Niger using the Living Standards Measurement Survey data from the World Bank group and estimates the impact of SAIPs on technical efficiency scores. The paper evaluates the mean differences in technical efficiency scores between adopters and non-adopters of soil and water conservation practices. The paper also looks at the sensitivity of technical efficiency scores to the distributional assumptions underlying the one-sided error. Variables capturing household adoption of the soil and water conservation practices were included to measure the effect of the technology on technical efficiency scores and policy recommendations are provided based on the results. Other factors influencing household technical efficiency scores were estimated.

1.3 Organization of the dissertation

Figure 1.1 presents the countries and sites where the data for the three papers were collected. The first paper presented in chapter 2 tests knowledge differences between participating and non-participating farm households from SAIP training. The analysis uses datasets from a survey of 168 farm households in 2012 compared to baseline data collected in 2010 prior to the training program. This allowed for evaluation of changes in farmer perceptions and knowledge between the participating and non-participating farm households after two sessions of farmer field schools on SAIPs. The paper also evaluated enterprise budgets of farm households' experimental plots.

The second essay as in chapter 3 tests whether accumulated knowledge from the training affected the adoption of sustainable intensification practices. The paper evaluated the effects of participation in training programs on accumulated knowledge, and the impact of accumulated knowledge on adoption of SAIPs using a three-step regression approach. The analysis uses datasets from farm households surveys conducted in 2014, compared against both the 2012 and 2010 data, to measure the accumulated knowledge change through the training program.

The third essay presented in chapter 4 measures the technical efficiency of millet and sorghum production in Niger and compares the differences of technical efficiency scores between adopters and non-adopters of soil and water conservation practices. After identifying sources of inefficiency, the impact of soil and water conservation adoption on technical efficiency is evaluated and policy recommendations are offered. The paper also evaluates the sensitivity of technical efficiency scores to various distributional assumptions of the one-sided error describing the stochastic inefficiency underlying the production process. The analysis makes use of datasets from the Living Standard Measurement Survey collected by the World Bank in 2010-2011 in Niger. The data consists of a sample of 518 millet and 754 sorghum producing households.

Chapter 5 presents the summary conclusions from the three papers and provides policy recommendations based on the conclusions drawn and proposed future research.

The dissertation will be useful for researchers, economists, policy makers and development partners as it provides information on the design and implementation of agricultural development projects focusing on crop and resource management in low-income countries in

West Africa. It also provides information for the determination of the extent to which millet and sorghum producing households may improve their output by making use of the existing technologies.

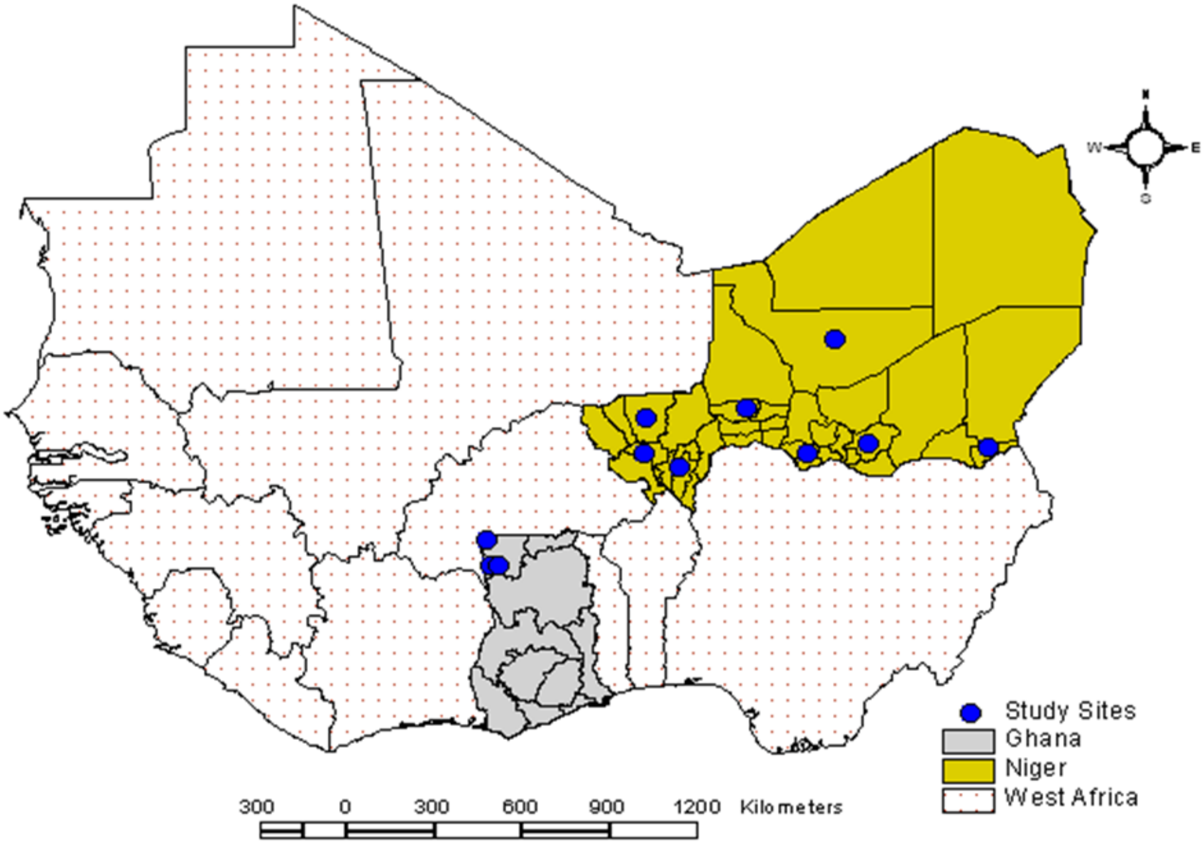

Figure 1.1. A map of West Africa showing study area

References

Adesina, A.A., D. Mbila, G.B. Nkamleu, and D. Endamana "Econometric analysis of the determinants of adoption of alley farming by farmers in the forest zone of southwest Cameroon." Agriculture, Ecosystems & Environment 80 (2000):255-65.

Balota, E.L., A. Colozzi Filho, D.S. Andrade, and R.P. Dick "Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol." Soil and Tillage Research 77 (2004):137-45.

Bayala, J., G. Sileshi, R. Coe, A. Kalinganire, Z. Tchoundjeu, F. Sinclair, and D. Garrity "Cereal yield response to conservation agriculture practices in drylands of West Africa: a quantitative synthesis." Journal of Arid Environments 78 (2012):13-25.

Coelli, T.J. "Recent developments in frontier modelling and efficiency measurement." Australian Journal of Agricultural Economics 39 (1995):219-45.

Dalton, T.J., N.K. Lilja, N. Johnson, and R. Howeler "Farmer participatory research and soil conservation in Southeast Asian cassava systems." World Development 39 (2011):2176-86.

Dalton, T.J., I. Yahaya, and J. Naab "Perceptions and performance of conservation agriculture practices in northwestern Ghana." Agriculture, Ecosystems & Environment 187 (2014):65-71.

de Herrera, A.P., and G. Sain Adoption of maize conservation tillage in Azuero, Panama CIMMYT, 1999.

Fuglie, K.O. "Conservation tillage and pesticide use in the Cornbelt." Journal of Agricultural and Applied Economics 31 (1999):133-48.

http://www.fao.org/ag/ca/ (accessed 02/20/2009).

Johnson, N., N. Lilja, J.A. Ashby, and J.A. Garcia The practice of participatory research and gender analysis in natural resource management. Wiley Online Library, 2004.

Kassie, M., M. Jaleta, B. Shiferaw, F. Mmbando, and M. Mekuria "Interdependence in farmer technology adoption decisions in smallholder systems: Joint estimation of investments in sustainable agricultural practices in rural Tanzania: Paper prepared and selected for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference." Foz do Iguaçu, Brazil (2012):18-24.

Kassie, M., P. Zikhali, K. Manjur, and S. Edwards Adoption of sustainable agriculture practices: Evidence from a semi-arid region of EthiopiaWiley Online Library, 2009.

Morton, J.F. "The impact of climate change on smallholder and subsistence agriculture." Proceedings of the National Academy of Sciences of the United States of America 104 (2007):19680-5.

Mugwe, J., D. Mugendi, M. Mucheru-Muna, R. Merckx, J. Chianu, and B. Vanlauwe "Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya." Experimental Agriculture 45 (2009):61-75.

Neef, A., and D. Neubert "Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making." Agriculture and Human Values 28 (2011):179-94.

Neill, S.P., and D.R. Lee "Explaining the adoption and disadoption of sustainable agriculture: the case of cover crops in Northern Honduras." Economic development and cultural change 49 (2001):793-820.

Oduol, J.B.A., J.N. Binam, L. Olarinde, A. Diagne, and A. Adekunle "Impact of adoption of soil and water conservation technologies on technical efficiency: Insight from smallholder farmers in Sub-Saharan Africa." Journal of Development and Agricultural Economics 3 (2011):655-69.

Porter JR, Xie L, Challinor AJ, Cochrane K, Howden M, Iqbal MM, Lobell DB,Travasso MI. 2014. Chapter 7. Food Security and Food Production Systems. Climate Change 2014: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report. Geneva, Switzerland

Sherlund, S.M., C.B. Barrett, and A.A. Adesina "Smallholder technical efficiency controlling for environmental production conditions." Journal of Development Economics 69 (2002):85-101.

Sidibé, A. "Farm-level adoption of soil and water conservation techniques in northern Burkina Faso." Agricultural Water Management 71 (2005):211-24.

Steiner, K. "Conservation tillage: gateway to food security and sustainable rural development: crop residue management and cover crops." African Conservation Tillage Network, Information (2002):

Chapter 2 - Perceptions and Performance of Conservation Agriculture in Northwestern Ghana

2.1 Introduction

Agriculture in Northwestern Ghana is subsistence in nature with infertile soils due to continuous mono-cropping of cereals with low external input usage (Yahaya et al., 2010 unpublished). Limited fertilizer and other chemical input usage is caused in part by poverty and hence the continuous usage of land without replenishing the soils results in a trap of declining crop yields. After harvest, crop residues are collected and fed to farm animals. This results in the depletion of major plant nutrients that could support plant growth (Rhodes 1995). Erosion is also a common feature of the soils in the upper regions of Ghana (Quansah 1990). The combined effects of these phenomena lead farmers to clear more land to cultivate food crops to feed a growing population.

Conservation agricultural practices were the focus of experiments in the forest areas of Ghana in the early 1980s (Boahen et al. 2007). The practices included: slash-and-mulch without burning, use of cover crops and minimum tillage with herbicides and direct planting. Since the late 1980's, research on conservation agriculture in northern Ghana has been led by the Savanna Agricultural Research Institute (SARI) and NGO's (Boahen et al. 2007). These practices were at the research level and were concentrated in the Northern Region of Ghana. Conservation agriculture (CA) was introduced by the Sustainable Agriculture and Natural Resources Management (SANREM) Collaborative Research Support Program (CRSP) in the northwestern part of Ghana (Upper West Region) as a potential intervention to address the problems of natural resource degradation, declining crop yields and to increase smallholder farmers' incomes and food security. The objective of this paper is to describe the evolution of knowledge between groups of farmers who participated in farmer field schools and those who did not in order to determine whether farmer knowledge or farm economics limits adoption and utilization of conservation agriculture practices.

2.1.1 Knowledge of Conservation Agricultural Practices

Recent studies have shown the agronomic and environmental potential of CA principles worldwide. An area of about 105 million hectares have been estimated to be under CA practices in the world with South America, USA, Canada and Australia accounting for about 96.1% of the total area. The rest of the world accounts for only 3.9% of the area and Africa only 0.3% (Derpsch 2009). The increasing awareness and adoption of CA is due to its agronomic benefits to increase soil productivity, maintenance of optimum soil environment in the top soil, improvement of soil organic matter content and hence the soil structure, reduction in the atmospheric CO_2 levels and other greenhouse gases through reduction in oxidation by releasing soil organic carbon into the soils, and nitrogen mineralization through rotation with legumes (Friedrich et al. 2009 ; Balota et al. 2004; Chivenge et al. 2007; Lal 2009).

Available literature points to the potential of CA practices to stabilize or increase crop yields over time, but the adoption of these practices are very slow or non-existent (Giller et al. 2009). A recent study on the performance of CA includes a quantitative synthesis of CA practices initiated to combat soil degradation in West Africa and shows that CA practices often, but not always, produce a positive yield effect (Bayala et al. 2011). In Malawi, short term maize-legume intercropping systems under conservation agriculture improved yields compared to conventional practices (CP) (Ngwira et al. 2012). Long-term maize-based conservation systems also showed significantly higher yield trends compared to conventional practice in Malawi

(Thierfelder et al. 2013). However, no assessment of the economic benefits or costs were conducted.

Improved yields can be translated into increased revenues, but a net gain in revenue is achieved only if the benefits exceed additional cost (Farrel 2008). However, proponents of CA practices argue that the economic benefits can only be realized in the medium-to long-term. Data from two years of on-farm studies supports cost savings due to reduced labor and machinery time despite an increase in agro-chemical usage (Ribera et al. 2004).

Existing literature shows that CA was introduced in Ghana in the late 1980’s in both the northern and the southern part of the country. Slash-and-mulch without burning, use of cover crops and minimum tillage with direct seeding in southern Ghana was sponsored by the Food and Agriculture Organization of the United Nations, while in the northern part, organizations such as SARI and others introduced direct planting methods. They also reported the benefits of CA practice as improving crop yields, reduction in labor use, weed control and improving farm incomes, but with limited adoption after the project ended (Boahen et al. 2007).

In Ghana, Boahen et al. (2007), found that a lack of cover crop seeds, lack of appropriate equipment and tools, limited promotion and little or no institutional support posed important challenges to the adoption of no-till in the forest zone. Farmers’ knowledge, information and adequate government policies are considered some of the main constraints to adoption of CA practices (Derpsch 2009). Reluctance to reduce plowing and the fear of switching to new production methods also hinder adoption (Srivastava and Meyer 2008). Land tenure systems, the mindset of farmers and lack of farmer cooperatives were also reported as constraints to adopting zero-tillage practices (Ashburner et al. 2002). Overall, two main lines of argument have evolved to explain limited adoption of conservation practices globally and in Ghana: poor knowledge by farmers and limited economic incentive to adopt.

2.1.2 Development of Farmer Field Schools in Northern Ghana

A participatory technology development workshop was organized prior to the implementation of conservation agriculture project in three districts of Upper West Region in Ghana (see table 2.1). These workshops were held in six communities in three districts. The objectives of the workshops were to assess farmer knowledge of conservation practices by gathering farmers' indigenous knowledge on agronomic practices that are commonly used to manage soil fertility and soil quality.

A baseline study was also conducted to gather biophysical and socio-economic characteristics, farming methods practiced and knowledge of conservation agriculture from 210 households prior to the implementation of the project in 2010. Farmers who were interested in participating in experiments self-selected into a group of participants and are subsequently labeled as the "With" group. Farmers who were in the communities who did not want to take part in the research program, but who were introduced to the objectives of the program at the community workshop were also surveyed and were categorized into a group of non-participants and labeled as the "Without" group.

Using this baseline information, new conservation practices were introduced to the participant groups that were consistent with farmer practices. Farmers then indicated their preferences on the integrated conservation practices for adaptation trials that were implemented on their own farms. The combinations of conservation practices were community based in order to suit local practices and also because they were easily adapted to the local agro-ecological environment. Table 2.1 presents the integrated conservation tillage practices selected for adaptation trial by participating farm households. These were compared to the conventional tillage of using tractor at the on-farm level. These on-farm adaptation experiments have been continuously monitored for the past two years and yield and input data were collected and used to develop partial budgets for performance comparison.

Table 2.1 Conservation practices introduced

District	*Community*	*Integrated elements of CA*	*Trial crops*
Wa West	*1. Nyoli* *2. Seiyiri*	*Zero tillage + residue retention Nutrient management (NPK for cereal)*	*1. Maize* *2. Soy beans*
Wa Central	*1. Busa-Tangzu*	*Zero tillage + rotation + residue retention + nutrient management (NPK for cereal and SSP for legume*	*1. Maize* *2. Soybeans*
Nandom	*1. Bu* *2. Puffien* *3. Brutu*	*Tied ridges +grass strips + residue retention + nutrient management*	*1. Maize*

Farmer field schools were organized every year to educate farmers on what other farmers in the district were doing as part of a broader education effort on conservation practices. The facilitator of the field schools for the two year period was a seasoned soil scientist from the Savanna Agricultural Research Institute (SARI), Wa in the Upper West region of Ghana. Knowledge assessment exams were conducted, and the constraints to adoption of the conservation practices, short term benefits and perceptions about the practices were gathered in 2012 from 118 households. More than half of the households were non-participating households with two-thirds of them taking part in the farmer field schools. Data were collected on farmer perceptions of integrated CA practices, knowledge levels prior to and after the implementation of the program and workshops, constraints and benefits of CA. Short-run financial performance data was collected from those with on-farm trials and used in the development of partial budgets.

2.2 Results

The following sections provide evidence on the role of farmer perceptions, knowledge and the perceived constraints to adopting conservation agriculture practices. Characteristics of the household in the survey are presented in Table 2.2. Constraints that these farmers faced were assessed at the baseline in 2010 and at subsequent points in time after the farmer field schools and on-farm experimentation. Difference-in-difference approach was used to assess whether these activities affect knowledge.

Table 2.2 Household demographic structure (N=180)

Category of household	*Variable*	*Mean*	*Standard deviation*	*Sample*
	Age	*40.12*	*9.63*	*49*
With	*Household size*	*9.00*	*3.62*	*49*
	Age	*40.30*	*14.80*	*69*
Without	*Household size*	*8.60*	*4.75*	*69*
Overall sample	*Age*	*40.00*	*12.85*	*118*
	Household size	*8.70*	*4.30*	*118*

2.2.1 Initial Perceptions on Information, Adoption and Perceived Benefit of Conservation Agriculture

Results of farmer perceptions/prejudices about new agricultural technologies are shown in Table 2.3. Farmer perceptions are subjective by definition and misperceptions indicate where knowledge may be improved through the presentation of objective information. Identifying misperceptions is useful for determining where education and extension programming might intervene to reduce knowledge gaps that prevent the adoption of practices. The statements in Table 2.3 were presented to farmers and they were asked if they “Agree” or “Disagree” with the statement. We present results on the percentage of farmers agreeing. Both groups of farmers indicate that they update themselves with information on the current practices and a high percentage indicates that they are cautious about trying new practices. Nearly one third, however, indicated that there was no need to change farming practices and this difference was statistically significant between the "with" and "without" groups, perhaps explaining why the "with" group self-selected for further activities. Furthermore, the "without" group had a higher percentage of farmers agreeing that "traditional ways of farming are the best." Despite these statements, nearly two-thirds indicated that they only experiment with promising practices, indicating that tangible evidence is needed before adopting on-farm, and that evidence from peers is an important source of information.

Table 2.3 Percentage of sample "agreeing" to the perceptions/prejudices on new agricultural technologies

Statement	*With*	*Without*	*Total sample*	*χ2 value (Sig.)*
I update myself with current information on farming practices	97.96%	95.65%	*96.60%*	*0.466 (0.495)*
I am cautious in trying out new framing practices	85.71%	92.75%	*89.80%*	*1.554 (0.213)*
I do not see why I should change my farming practices	22.45%	37.68%	*31.40%*	*3.089* (0.079)*
I only try out promising new practices	63.26%	63.77%	*63.60%*	*0.003 (0.955)*
I check out results from my neighbors field before trying out	46.94%	71.01%	*61.00%*	*6.982*** (0.008)*
Traditional ways of farming are the best	12.25%	27.54%	*21.20%*	*4.012** (0.045)*
Less labor is used in no-till compared to the conventional till	95.92%	92.75%	*94.10%*	*0.514 (0.473)*
Costs of land preparation is less in no-till compared to conventional till	97.96%	95.65%	*96.60%*	*0.466 (0.495)*
Yields from no-till farms are higher or the same from conventional till	81.63%	95.65%	*89.80%*	*6.165** (0.013)*
Net benefit of zero tillage is higher compared to conventional tillage	83.67%	89.86%	*87.30%*	*0.987 (0.321)*
Tied ridging contributes to water retention on the field	34.69%	42.03%	*39.00%*	*2.557 (0.278)*
Erosion through run-off is minimized by tied ridging	59.18%	55.07%	*56.80%*	*0.197 (0.657)*

*Where *, **, *** indicates significance at the 10%, 5% and 1%*

Seventy-one percent of the "without" group indicated that peer evidence is important while only 47% of the "with group" think the same way. The transmission of information through extension service is lacking and hence hinders adoption of new technologies especially CA (Singh et al. 2008; Boahen et al. 2007; Derpsch 2009). Farmer-to-farmer exchange may reduce this inefficiency.

When examining specific practices, both groups agree that less labor is required with no-till as opposed to conventional tillage and that this results in lower cost for land preparation. Interestingly, the “without” group has a higher percentage of farmers who think that yields are higher under no-till and that there is a higher net benefit to no-till than conventional tillage. This difference may indicate that farmers are self-selecting into the experimentation group because they are seeking information on no-till instead of already being convinced of the benefits to no-tillage practices. Overall, we found very low levels of understanding of the benefits of tied-ridging in both groups. Most perceived that no-till required less labor use, has a lower cost of land preparation, higher or indifferent yields and high net returns.

Figure 2.1 presents the bar graph on the stated benefits of CA practices. 354 responses were elicited when farmers were asked to state the three most important benefits of CA practices. The survey identified the three most important benefits of CAPs as 1) yield improvement, 2) time saving and 3) an increase in organic matter content of the soil in the short-run. However, between household categories, there were slight but insignificant differences between the participating and nonparticipating groups. Differences existed in whether they thought that conservation agricultural practices increase organic matter content and reduce land preparation cost. Reduction in labor and improved water holding capacity were other important benefits mentioned by households. These are supported by the performance data described later.

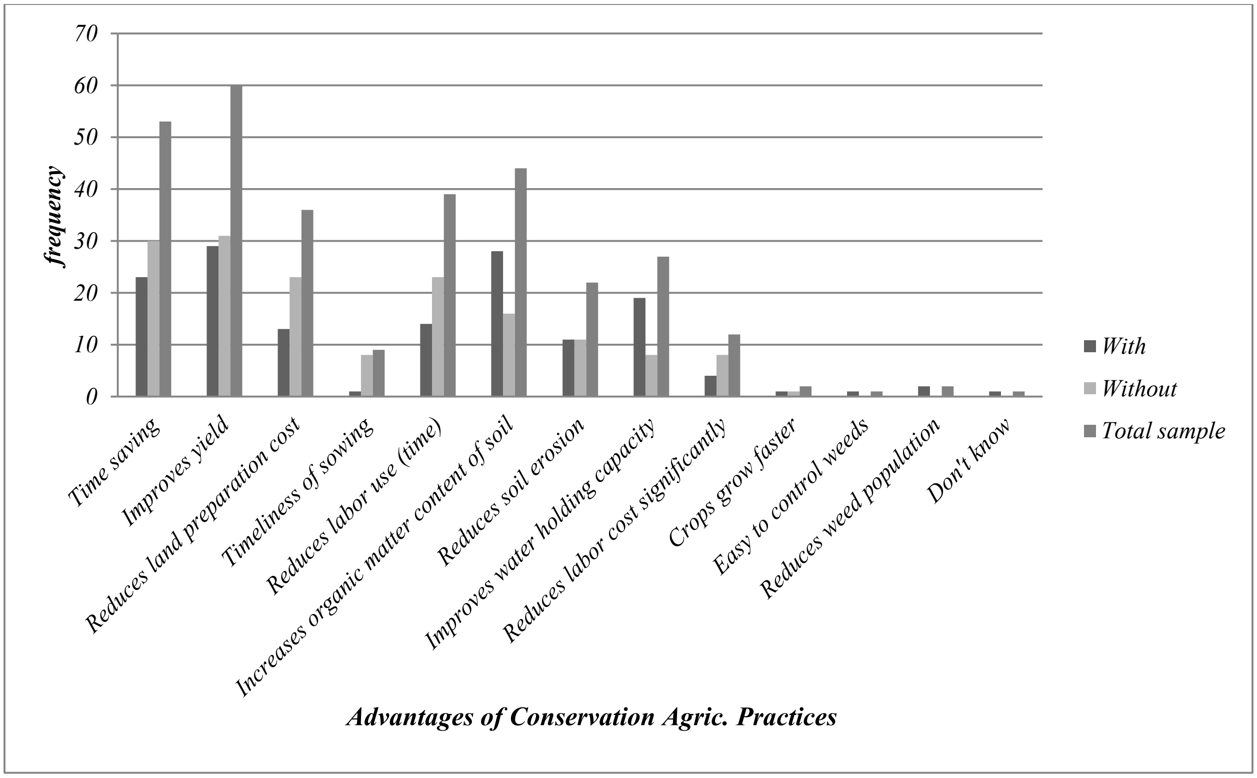

Figure 2.1 Perceived advantages of conservation agriculture practices

2.2.2 Knowledge index of CA practices

Knowledge of specific agronomic principles embedded in the conservation agriculture paradigm was evaluated. These questions were asked at the baseline in 2010, and then again two years into the program to evaluate whether any change in knowledge had taken place. Farmer knowledge was elicited through twelve questions focusing on usage of crop residue, animal manure, tillage, water infiltration, rotations and cover crops (Table 2.4). The double difference approach (DID) was used. The paper used the t-test to evaluate the effectiveness of the farmer field schools and knowledge changes after two years of the adaptation trials. The DID approach measures whether group treatments are different before and after intervention:

$$mean_i(a-b) - mean_j(a-b) = DID$$

Where

i = intervention group (with) and j = non-intervention group (without)

a = after implementation and b = before implementation

Significant differences were observed in the means between the intervention (with) and non-intervention (without) groups before the implementation in several dimensions of CA (see table 2.4). Overall there was a strong congruence between the with and without group on the importance of crop residue as a source of organic matter but the "with" group increased their understanding of its importance through the field schools. Farmers appear to have limited knowledge on the nutrient content of manure. Most believe that it is as concentrated as inorganic sources and the training and field activities appear to have changed knowledge on this topic. In addition, it appears that the role of manure in increasing water retention was also affected through project activities.

Understanding of the agronomic impacts of no tillage changed significantly for both groups. Forty percent and 35% of the with and without groups initially believed that they could plant directly into the soil without tillage and after training and on-farm experimentation this number increased to over 90% for both groups. It is interesting that perceptions on no-till increased dramatically for the without group, which likely reflects the ease that non-participants observed others planting directly into the soil. Other studies have found that crop and resource management practices spread more rapidly between farmers than IPM practices (Dalton et al. 2011).

There is near unanimous agreement that tillage assists in water infiltration, seedbeds improve water holding capacity, rotations prevent plant diseases and cover crops increase soil microbial activities. There were no changes in other knowledge indices. Combined, these results indicate that there is high knowledge of many agronomic practices, reflecting accumulated knowledge over a long period of time. However, farmers' knowledge on direct planting (zero-till) was very low (40% for the intervention group and 34% for the non-intervention group) but higher in the other principles of CA (rotation, residue management and use of cover crops).

Table 2.4 Mean difference before and after and between intervention and non-intervention farmers

Knowledge index	*Category of household*	*2010*	*2012*	*Mean difference*	*DID*
Crop residue are a source of organic matter to the soil	*with*	*0.96*	*1.00*	*0.04**	*0.04**
	without	*1*	*1*	*na*	
High soil organic matter content improves water holding capacity	*with*	*0.94*	*0.96*	*0.02*	*0.00*
	without	*0.95*	*0.97*	*0.02*	
Manure is strong as purchased fertilizer	*with*	*0.80*	*0.64*	*-0.16***	*-0.09**
	without	*0.85*	*0.78*	*-0.07*	
Manure improves water holding capacity of soil	*with*	*0.80*	*0.98*	*0.18****	*0.10***
	without	*0.85*	*0.93*	*0.08**	
One can plant directly without tilling the soil	*with*	*0.40*	*0.92*	*0.52****	*-0.07**
	without	*0.35*	*0.94*	*0.59****	
Tillage assists in water infiltration	*with*	*0.90*	*0.92*	*0.02*	*-0.20****
	without	*0.74*	*0.97*	*0.22****	
Seed bed improves water holding capacity	*with*	*0.84*	*0.96*	*0.12***	*0.17****
	without	*0.94*	*0.88*	*-0.05*	
Seed bed improves aeration in the soil	*with*	*0.94*	*0.90*	*-0.04*	*0.01*
	without	*0.97*	*0.93*	*-0.05*	
Rotating cereals and legumes improves soil fertility	*with*	*0.96*	*0.94*	*-0.02*	*0.02*
	without	*0.98*	*0.94*	*-0.04*	
Rotation prevents plant diseases	*with*	*0.88*	*0.98*	*0.10***	*0.13***
	without	*0.97*	*0.94*	*-0.03*	
Cover crops prevent soil erosion	*with*	*0.86*	*0.96*	*0.10***	*0.04**
	without	*0.93*	*0.99*	*0.06**	
Cover crops increase microbial activities in the soil	*with*	*0.82*	*0.90*	*0.08**	*0.03*
	without	*0.91*	*0.96*	*0.05**	

*Where *, **, *** indicates significance at the 10%, 5% and 1%*

The knowledge indices used in the baseline were tested after two years of implementation and after two farmer field schools were held. The results indicate that farmers' knowledge on ability to plant directly without tilling the soil increased to over 90%. Other knowledge indices on conservation practices increased to above 85% compared to the results from the baseline survey. This is an indication that farmers are learning by doing and are increasing their knowledge, which may enhance adoption of the practice (Derpsch 2009).

The results show the effectiveness of the interventions through positive mean differences in the knowledge indices after the implementation of the education program. Effectiveness of the farmer field schools on CA knowledge indices are positive, indicating that learning took place and farmers gained knowledge, which in the long run may factor into the adoption of the practices. However, on planting directly without tilling (no-till), the double difference was negative and significant even though it is positive and highly significant in the intervention group before and after.

2.2.3 Stated constraints and benefits of CA practices

Figure 2.2 presents the bar graph of farmer perceptions on the constraints that hinder adoption of CA practices. The households were asked to elicit the three most important constraints or disadvantages of CAPs and 356 responses were collected. The survey identified lack/high cost of drilling tools for planting as one of the major constraints that hinder the adoption of no-till in North-western Ghana consistent with other studies (Boahen et al. 2007; Reganold 2008; Singh et al. 2008). High populations of weeds at the time of planting were also found to be an important constraint that might hinder the adoption of no-till. This finding is also consistent with an increase in labor demand for weeding found elsewhere (Giller et al. 2009). “Financial constraints” was the third most common hindrance to adoption (Reganold et al. 2008). However, in comparison between the intervention and non-intervention farmers, there were no differences in their responses except that a majority of the non-intervention farmers did not know of any specific constraints.

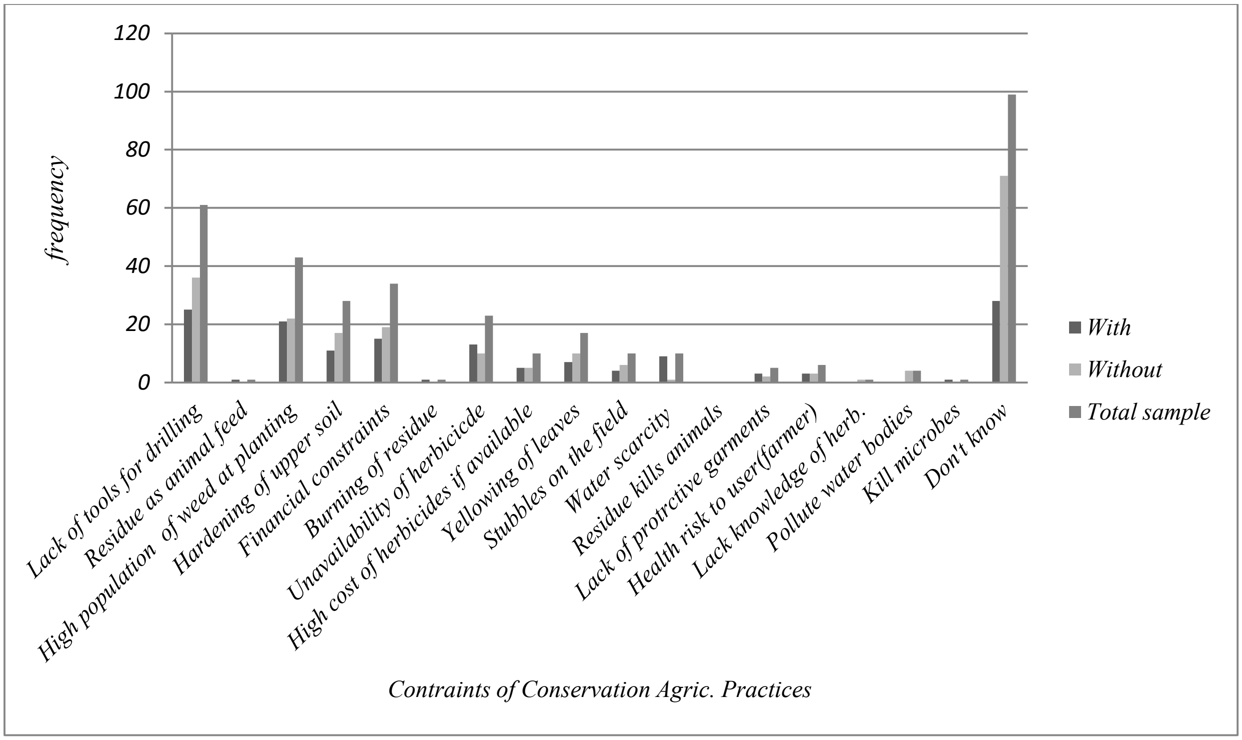

Figure 2.2 Farmer perspective on constraints preventing adoption of CA practices

2.2.4 Short-run enterprise budgets of conservation agriculture practices

Data from the on-farm adaption trials are limited and provide only a limited view on the economic benefits of CA practices. We use two years of data from 40 farmers in five communities implementing the CA practices. The data presented in the enterprise budgets are based on average from all the 40 farmers who implemented the conservation practices. Price information was based on the prevailing market levels for each year presented. Family labor cost was determined using the local wage rate to account for the opportunity cost of time.

Table 2.5 presents the results of no-till (NT) compared to conventional tillage (CT) at Nyoli in the Wa West district. The results indicate farmers saved about half the cost of land preparation due to switching to CA. By comparison, CA had lower labor costs when compared to CT plots in both the soybeans and the maize base plots. However, the mean yield differences between CT and NT in the maize plots were statistically significant and lower while those of soybeans were not statistically different in the 2010 cropping season. Yields in no-till plots were lower in both years. Net returns to land and management were similar when comparing the no-till and tillage plots in 2010 but lower in 2011.

Table 2.5 Enterprise budget CA compared to CT with fertilizer management at Nyoli

Crop type	*Maize*				*Soybeans*			
Season	*2010 season*		*2011 season*		*2010 season*		*2011 season*	
Income per acre	*CT+NPK*	*NT+NPK*	*CT+NPK*	*NT+NPK*	*CT*	*NT*	*CT*	*NT*
a. Yield(kg)/acre	*108.92*	*80.32*	*1278.99*	*795.68*	*447.47*	*404.89*	*1075.11*	*783.43*
b. Price/kg	*0.30*	*0.30*	*0.38*	*0.38*	*0.38*	*0.38*	*0.63*	*0.63*
c. Returns($)/acre	*32.68*	*24.1*	*486.02*	*302.36*	*170.04*	*153.86*	*547.32*	*433.31*
Costs per acre($)								
1. Herbicides	*0.00*	*7.50*	*0.00*	*8.79*	*0.00*	*7.50*	*0.00*	*8.79*
2. Tractor use	*15.62*	*0.00*	*25.00*	*0.00*	*15.62*	*0.00*	*25.00*	*0.00*
3. Labor cost	*22.22*	*19.19*	*104.49*	*52.10*	*41.36*	*39.39*	*105.49*	*51.46*
4. Fertilizer cost	*31.37*	*31.37*	*32.19*	*32.19*	*0.00*	*0.00*	*0.00*	*0.00*
d. Total costs	*69.21*	*58.06*	*161.68*	*93.08*	*56.98*	*46.89*	*130.49*	*60.25*
e Total cost/kg (d/a)	*0.64*	*0.73*	*0.13*	*0.12*	*0.13*	*0.12*	*0.12*	*0.08*
f. Net returns (c-d)	*-36.53*	*-33.96*	*324.34*	*209.28*	*113.06*	*106.97*	*416.83*	*373.06*

Table 2.6 presents the result of no-till compared to CT + fertilizer management in a soybean-maize rotation in Busa-Tangzu. Statistical differences in mean yields were observed between NT+NPK and CT+NPK treatment and the NT+NPK and NT+P treatment for soybeans in the first season. The cost of production was lower by switching from CT to NT even when herbicides were used due to a decrease in labor use. In the second year, significant differences were observed in the mean yield of all the treatments. Even though cost of herbicides increased that year, land preparation costs were reduced by more than half of rented tractor service cost in CT. All the treatments gave positive net returns to land and management in both the first and

second years in the soybeans and maize plots respectively. Conventional tillage produced the highest net returns for maize while the net returns for soybean were similar across treatments.

Table 2.6 Enterprise budget of CA compared to CT with fertilizer management and rotation at Busa-Tangzu

Crop type	*Soybeans*				*Maize*			
Season		*2010 season*				*2011 season*		
Income per acre	*CT+NPK*	*NT-NPK*	*NT+NPK*	*NT+P*	*CT+NPK*	*NT-NPK*	*NT+NPK*	*NT+0.5NPK*
a. Yield(kg)	*383.64*	*248.14*	*343.48*	*328.53*	*1003.6*	*191.5*	*686.19*	*540.08*
b. Price/kg	*0.38*	*0.38*	*0.38*	*0.38*	*0.38*	*0.38*	*0.38*	*0.38*
c. Returns($)	*145.78*	*94.29*	*130.52*	*124.84*	*381.368*	*72.77*	*260.75*	*205.23*
Costs per acre($)								
1. Herbicides	*0.00*	*6.06*	*6.06*	*6.06*	*0.00*	*8.79*	*8.79*	*8.79*
2. Tractor use	*22.73*	*0.00*	*0.00*	*0.00*	*25.00*	*0.00*	*0.00*	*0.00*
3. Labor cost	*46.56*	*44.44*	*43.43*	*43.43*	*100.49*	*46.1*	*51.49*	*50.46*
4. Fertilizer cost	*31.56*	*0.00*	*31.56*	*42.98*	*32.19*	*0.00*	*32.19*	*16.1*
d. Total costs	*100.85*	*50.5*	*81.05*	*92.47*	*157.68*	*54.89*	*92.47*	*75.35*
e Total cost/kg (d/a)	*0.26*	*0.20*	*0.24*	*0.28*	*0.16*	*0.29*	*0.14*	*0.14*
f. Net returns (c-d)	*44.93*	*43.79*	*49.47*	*32.37*	*223.69*	*17.88*	*168.28*	*129.88*

Financial results for water management adaptation trials in three communities at Nandom are presented in Table 2.7. The results indicate no significant differences in the mean yields between treatments in the two seasons (2010 and 2011). However, the yields during the second season are reduced by about 30% on average and are attributed to hot and dry climatic conditions in the 2011 season. The higher production cost under the tied ridges with grass strips is a result of the extra labor required to plant the grasses. The results show positive net returns on all the treatments but that tied ridges with grass strips had a higher positive net return even with a slightly higher cost of production in 2010. There was no difference between tied ridges alone or with grass in 2011.

Table 2.7 Enterprise budget of water management with grass strips

Crop type			*Maize*			
Season		*2010 season*			*2011 season*	
Income per acre	*Flat*	*Tied ridges*	*Tied ridges+ grass*	*Flat*	*Tied ridges*	*Tied ridges+ grass*
a. Yield(kg)	*1105.5*	*916.5*	*1228.5*	*734.82*	*785.78*	*782.22*
b. Price/kg	*0.30*	*0.30*	*0.38*	*0.38*	*0.38*	*0.38*
c. Returns($)	*331.65*	*274.95*	*368.55*	*279.23*	*298.59*	*297.24*
Costs per acre($)						
1. Animal traction	*10.00*	*10.00*	*10.00*	*12.00*	*12.00*	*12.00*
2. Labor cost	*62.80*	*64.40*	*65.40*	*64.00*	*66.00*	*68.00*
3. Fertilizer cost	*31.56*	*31.56*	*31.56*	*32.19*	*32.19*	*32.19*
d. Total costs	*104.36*	*105.96*	*106.96*	*108.19*	*110.19*	*112.19*
e Total cost/kg (d/a)	*0.26*	*0.20*	*0.24*	*0.28*	*0.16*	*0.29*
f. Net returns (c-d)	*227.29*	*168.99*	*261.59*	*171.04*	*188.41*	*185.05*

2.3 Discussion

This research presents farmer perceptions and changes in knowledge along with preliminary evidence on the economic benefits of conservation agriculture practices. Farmers have strong perceptions about their farming practices that can be used to develop intervention strategies. Farmer-to-farmer communication appears to be effective. Farmer field schools have been effective in information delivery and they have changed knowledge on some CA practices. There has been a positive spillover effect on no-till knowledge indicating an additional short term impact of the project on the dissemination of CA practices in northwestern part of Ghana.

The results of the performance indicators show that there is a net reduction in the total cost of production due to reduction in labor and switching to herbicide use from tractor usage at Nyoli and Busa-Tangzu. In the water management plots, there has been an increase in the cost of production from switching from flat-land type production and using the tied ridges with and without grass strips at Nandom area. This cost reduction did not produce statistically significant increases in net farm returns to land and management. Many argue that conservation agricultural benefits are realized only in the medium to long term so we cannot make any conclusions based on the available data. In the short-run, conventional practices appear to be more profitable.

2.4 Conclusions

Training and farmer-to-farmer communication are effective tools for raising knowledge of agricultural and crop management practices. This suggests that knowledge gaps on conservation practices can be filled and do not appear to be an insurmountable obstacle to adoption. By contrast, the short-run net returns to conservation agriculture practices do not appear to be greater than conventional practices. While we have taken care to qualify these results as preliminary and reflective of only two years of data, it does highlight the opportunity costs of transitioning to conservation practices over conventional. More data is therefore required to make conclusions on the overall benefits of the CA practices in northwestern Ghana. If these practices are determined to improve farm income and stabilize production, policy strategies to facilitate the transition to CA will need to be developed to facilitate the transition from traditional production practices to conservation ones.

References

Ashburner J., Friedrich T. and Benites J. (2002): Opportunities and constraints for Conservation agriculture in Africa. Pp 1-5. LEISA, 2002. www.fao.org/corp/google-results/en/?cx (Accessed; 05/15/2012).

Balota, E. L., Colozzi Filho, A., Andrade, D. S., & Dick, R. P. (2004). Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a brazilian oxisol. Soil and Tillage Research, 77(2), 137-145.

Bayala, J., Sileshi, G., Coe, R., Kalinganire, A., Tchoundjeu, Z., Sinclair, F., & Garrity, D. (2011). Cereal yield response to conservation agriculture practices in drylands of west africa: A quantitative synthesis. Journal of Arid Environments,

Boahen P., Dartey A. B., Dogbe D. G, Boadi A. E., Triomphe B., Daamgard-Larsen S. and Ashburner J. (2007): Conservation Agriculture as Practiced in Ghana. Pp 1-71. African Conservation Tillage Network (ACT) publications. www.fao.org/corp/google-results/en/?cx (Accessed; 05/15/2012).

Chivenge, P., Murwira, H., Giller, K., Mapfumo, P., & Six, J. (2007). Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. Soil and Tillage Research, 94(2), 328-337.

Dalton, T. J., Lilja, N. K., Johnson, N., & Howeler, R. (2011). Farmer participatory research and soil conservation in Southeast Asian cassava systems. World Development, 39(12), 2176-2186.

Derpsch, R., & Friedrich, T. (2009). Global overview of conservation agriculture no-till adoption. 4th World Congress on Conservation Agriculture New Delhi, India, 4-7.

Erenstein, O. (2002). Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. Soil and Tillage Research, 67(2), 115-133.

Erenstein, O. (2003). Smallholder conservation farming in the tropics and sub-tropics: A guide to the development and dissemination of mulching with crop residues and cover crops. Agriculture, Ecosystems & Environment, 100(1), 17-37.

FAO, 2009. http://www.fao.org/ag/ca/ (accessed 02/20/2009).

Friedrich, T., Kassam, A., & Shaxson, F. (2009). Conservation agriculture. Agriculture for Developing Countries.Science and Technology Options Assessment (STOA) Project.Karlsruhe, Germany: European Technology Assessment Group,

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in africa: The heretics' view. Field Crops Research, 114(1), 23-34.

Hobbs, P. R. (2007). Conservation agriculture: What is it and why is it important for future sustainable food production? Journal of Agricultural Science-Cambridge-, 145(2), 127.

Hobbs, P. R., Sayre, K., Gupta, R., Hobbs, P. R., Sayre, K., & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1491), 543-555.

Huggins R. D. and Reganold P. J. (2008): No-till: The Quiet Revolution. Scientific American, 2008. Pp 71-77. www.research.wsu.edu/resources/files/no-till.pdf (Accessed; 05/15/2012)

Keating, B. A., Carberry, P. S., Bindraban, P. S., Asseng, S., Meinke, H., & Dixon, J. (2010). Eco-efficient agriculture: Concepts, challenges, and opportunities. Crop Science, 50(Supplement_1), S-109-S-119.

Lal, R. (2009). Challenges and opportunities in soil organic matter research. European Journal of Soil Science, 60(2), 158-169.

Ngwira, A. R., Aune, J. B., & Mkwinda, S. (2012). On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in

Quansah, C. (1990). Soil erosion and conservation in the northern and upper regions of ghana. Topics in Applied Resource Management in the Tropics, 2, 135-157.

Rhodes, E. (1995). Nutrient depletion by food crops in Ghana and soil organic nitrogen management. Agricultural Systems, 48(1), 101-118.

Ribera, L. A., Hons, F., & Richardson, J. W. (2004). An economic comparison between conventional and no-tillage farming systems in Burleson county, texas. Agronomy Journal, 96(2), 415-424.

Scherr, S. J. (1999). Soil degradation: A threat to developing-country food security by 2020? International Food Policy Research Inst.

Singh R., Kumar S., Kumar A., Chand R., and Singh S. (2008): Multi-dimensional Impact Assessment of Zero Tillage Technology. Indian Journal of Agricultural Research. 42(1): 13-18

Srivastava J. and Meyer E. (1998): Is Conservation Tillage a Viable Option in the CIS? siteresources.worldbank.org/.../20431884/conservationandtillage.pdf (Accessed; 05/16/20120.

Thierfelder, C., Chisui, J. L., Gama, M., Cheesman, S., Jere, Z. D., Trent Bunderson, W., . Rusinamhodzi, L. (2013). Maize-based conservation agriculture systems in malawi: Long-term trends in productivity. Field Crops Research, 142, 47-57.

Yahaya I., Hashim I., Naab J. B. Prasad P. V., Dalton T. J. (2010): Knowledge of Households, Cropping Systems and Perceptions on Conservation Agricultural Practices in Upper West Region of Ghana. Unpublished Feasibility study report, SANREM CRSP, 2010

Chapter 3 - Learning, knowledge and imitation in the adoption of Sustainable Agricultural Intensification Practices (SAIPs) in Ghana

3.1 Introduction

Studies on the adoption of crop and resource management technologies have often focused on agronomic or environmental benefits and, to a lesser extent, the economic factors affecting decision strategies about which practices to adopt, where and why. Since these practices vary widely, and suites of practices, such as “conservation agriculture” or “integrated soil fertility management” have emerged, better understanding of the relationship between components is important as each plays a different ecological and economic role in the process of intensification. For example, conservation agriculture requires minimum soil disturbance, crop rotations and a permanent organic soil cover, yet knowledge, investment, recurrent and opportunity costs vary by practice. This may be one explanation for patchy adoption, and the lack of common explanations for persistent adoption, of individual components in conservation agricultural systems (Arslan et al. 2014). Recently, sustainable intensification has become a commonly applied term for improved productivity per unit of input (land, labor or water) while minimizing negative environmental externalities. As consistent with the previously mentioned practices, this concept has received little attention on which factors affect adoption of SAIPs or the relative importance of knowledge and management versus technology attributes (Kassie, Shiferaw and Muricho 2011).

This issue is relevant because adoption of sustainable agricultural intensification practices (SAIPs) in Africa may help curb the effects of climate variability and may increase crop productivity and the performance of improved crop varieties (Morton 2007). Despite the broad proliferation of studies documenting the economic impact of genetic enhancement of modern crop varieties, few studies (outside of integrated pest management) have focused on the relative value of crop husbandry, land management or integrated systems-based approaches to improving agricultural productivity over the past twenty-five years (Abdulai and Huffman 2014;Traxler and Byerlee 1992; Norgaard 1989). Even despite limited availability, literature on SAIPs is often framed around conservation tillage practices. It is estimated that South America leads the rest of the world in the adoption of conservation tillage, with 46.8% of total cultivable land under the practice, while only 0.3% of the total arable land in Africa is estimated to be under similar SAIPs (Derpsch et al. 2010). According to Friedrich and Kassam (2009), the low adoption rate of conservation tillage in Africa is attributed to a number of factors, including the conservativeness and risk averse nature of small-holder farmers, biophysical and technical constraints, as well as financial and policy constraints. One of the main objectives of this study is to determine the interdependence of SAIPs in order to better understand the constraints and incentives to the adoption of components and bundles of components.

Secondly, as these practices are management intensive, a controlled experiment on environmental and agronomic education is developed to assess the impact of accumulated knowledge on the adoption of sustainable intensification practices. This paper contributes to the growing literature on the impact of learning and knowledge generated through participatory training processes on the adoption of new technologies by households. This study is also important for development partners, who promote soil and water sustainable practices to smallholders, to have a holistic look at the training and education relative to the technical attributes of SAIPs and to consider the whole package of soil and water sustainable practices instead of the individual components.

Specifically, the paper seeks to evaluate:

1) The household factors affecting the decision to participate in training on SAIP practices;

2) The impact of training on accumulated economic, agronomic and environmental knowledge about new agricultural practices and technologies;

3) The interdependence and relative importance of accumulated knowledge on the adoption of SAIPs.

The paper is organized as follows. In the second section, a literature review and context is provided. In the third section, a conceptual and empirical models are presented followed by, in the fourth section, empirical results. Discussion and conclusions are presented in the final section.

3.2 Background

Sustainable agricultural intensification practices (SAIPs) were introduced to smallholder farmers who are the most vulnerable to climate change effects in the Upper West region of Ghana in 2009. The goal was to improve food security by increasing economic returns to smallholder farming households dependent on rain-fed agriculture through the development and dissemination of SAIPs. The expected outcomes are improved soil quality, water capture, water use efficiency, crop productivity, ecosystem services and profitability through efficient use of farm inputs and labor in an ecologically integrated manner.

The Upper West region of Ghana is located in both Guinea and Sudan Savanna agro-ecological zones in the South and North respectively. These areas are prone to the effects of climate variability on farm households. The Ministry of Food and Agriculture (MOFA) in Ghana, estimates about 80% of the people in Upper West region of Ghana are employed by agriculture and its related activities with majority being subsistence producers. These resource-poor farmers are dependent on rain-fed agriculture and subject to low soil productivity caused by continuous mono-cropping with disking, erosion (both wind and water) and lack of or inadequate external inputs use. According to Morton (2007), the panacea to improving food security, natural resource management and reduction in poverty, is SAIPs.

Dalton et al. (2014), showed significant improvement in smallholder knowledge about sustainable agricultural practices among participants in agricultural training and non-participant farm households since the SAIPs training implementation in 2010. They also showed that there were no significant differences in the yields on plots of SAIPs compared to farmer practice. SAIPs were found to have the lowest cost of production due to reduced labor time (days) (see also, Ngwira et al. 2011) and reduction in the cost of tractor usage for tillage. Bayala et al. (2011) showed mean yield increases in SAIPs of cereals in West Africa were not statistically different from those produced under traditional practices. Unintended benefits that were not quantified include an increase in soil organic matter (Chivenge et al. 2006; Balota et al. 2003) and reduction in pollution of water bodies and carbon dioxide emissions (Steiner 2002). Despite the benefits and promotion of SAIPs, adoption rates of SAIPs are still insignificant (about 0.3%) among small-holder resource-poor farmers in developing nations and Ghana in particular.

Several approaches have been used to empirically study the adoption decisions of SAIPs. Cameroon, (2011) used the averaged differential of profit as a knowledge variable explaining the adoption decision by farmers in a dynamic model. Other adoption studies on sustainable intensification practices have employed the use of univariate Probit and logit models without considering the interdependence of individual components of SAIPs (Bett 2004; Mugwe et al. 2009; Sidibé 2005). Abdulai and Huffman, (2014) evaluated the impact of soil and water conservation technology adoption on rice yields and net returns in the low-land areas of northern

Ghana using an endogenous switching regression method. Also, Wuepper et al. (2014) evaluated agricultural training through peer-learning and sustainable intensification in southern Ghana by using a control function modelling approach with a panel data. Their study used farmers' profitability and proper usage of an innovation as a measure of knowledge. In a recent study, the correlation of education and training on the adoption of soil and water conservation practices was modeled by using bivariate Probit models (Dalton et al. 2011).

Other recent studies have demonstrated the interdependence of SAIPs adoption by considering the correlations of the disturbance terms of the individual adoption models (Kassie et al. 2009; Kassie et al. 2012). Rather than using a proxy variable for knowledge that is often captured by the number of years of education, this research administers knowledge tests on the benefits of the practices and calculates an individual knowledge score at several stages of the research to test the hypothesis that the adoption decisions of sustainable agricultural intensification practices are not independent and are dependent upon learning and accumulated knowledge. It is important to evaluate the impact of participatory farmer adaptation trials on SAIPs in Ghana because these processes are expensive and the impact must be juxtaposed against the education and investment costs.

3.3 The conceptual model and empirical approach

Estimating the factors affecting the adoption of SAIPs, including targeted training and knowledge, is complicated because it is necessary to control for self-selection and participation in the training, evaluate the effects of household and farm characteristics on knowledge accumulation (as measured by the knowledge score index) and then relate these factors to the adoption of individual SAIP components and systems of components. The first step in estimating the treatment effect is to determine the correlates of participation in order to control for self-selection into the training. Studies have found that training programs often appeal to farmers who may have lower opportunity costs of time and this often points to relatively wealthier households, those with access to labor-saving technologies, and those with greater formal education (Zbinden and Lee 2005; Sanginga et al. 2006).

Consider households that consume a bundle of goods that generate utility (*U)* and some of which are produced on-farm (Q_h) while others off-farm(Q_m) :

$$U = U(Q_h, Q_m) \dots \dots \dots \dots \dots \dots \dots . (1)$$

Households self-select to participate in group training, a consumption good, based upon an expected value calculus that compares the opportunity cost of time invested in training to an expected value of the benefits which may be related to increased productivity, profitability of home produced goods (π) or factors related to overall household system gain, *H*, (for example time management or food security), agricultural system resilience, *R,* or a non-pecuniary environmental service benefit, *E*. This may be viewed as a decision to consume a training service that provides an expected utility (U_p) that contains multiple attributes:

$$U_p = U_p(\pi(p, \tilde{p}), H, R, E) \dots \dots \dots \dots . (2)$$

Agricultural profitability is a function of explicit and implicit factor and output prices, *p* and $\tilde{p}$ respectively. An individual with a greater utility of training over non-participation(U_{np}) would self-select into the treatment group=1:

$$U_p(\pi(p, \tilde{p}), H, R, E) \succ U_{np}(\pi(p, \tilde{p}), H, R, E) \dots (3)$$

Many of the elements that underlie the decision are unobservable and thus a latent approach is followed that allows construction of several hypotheses related to the intrinsic decision to participate including those related to household and farm characteristics. Households in a farmer's organization can decide to participate in the training or not. To control for these endogenous factors leading to self-selection, a univariate Probit model is estimated to evaluate factors affecting the decision.

The concept underlying the model of farmer $i,$ to participate in a sustainable intensification agricultural practices training program is assumed to be a latent variable, P_i^* defined by the following model (Maddala 1983),

$$P_i^* = x_i'\beta + \varepsilon_i \dots\dots\dots\dots\dots (4)$$

$$P_i = \begin{cases} 1\ if\ P_i^* > 0 \\ 0\ otherwise \end{cases} \dots\dots\dots\dots\dots (5)$$

In practice, the latent variable P_i^* captures the unobserved preferences associated with participating in the agricultural training program and P_i is the expected probability that, farmer $i's$ participate in SAIPs training program or not.

Given equations 4 and 5 above, the assumption is that, P_i^* is a linear function of observed vector of farmer and farm characteristics, x_i' and an unobserved iid error term ε_i:

$$Prob(P_i = 1) = \Pr(x_i'\beta + \varepsilon_i > 0)$$

$$= \Pr(-\varepsilon_i < x_i'\beta)$$

$$= F(x_i'\beta) \dots\dots\dots\dots\dots . (6)$$

Where $F(.)$ is the cumulative distribution function of$-\varepsilon_i$. The assumption on ε_i is that, it has a standard normal distribution with mean 0 and variance one and hence a Probit function. The marginal effects are calculated generally using the following as in Green (2003):

$$\frac{\partial [P_i|x_i]}{\partial x_i} = \left\{\frac{\partial F(x_i'\beta)}{\partial (x_i'\beta)}\right\}\beta = f(x_i'\beta)\beta \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Where $f(.)$ is the standard normal probability distribution function.

Included in this model are the covariates that explain the household participation decision to undertake training on SAIPs. The covariates include individual, household and farm characteristics that are related to the utility derived from the participation decision. The model predicts the effects of the covariates on the probability of household participating in SAIPs and the marginal effect are then estimated using equation 7 to provide inferences on opportunities to influence participation for better targeting.

Once factors affecting the decision to participate are established, this information can be used to determine whether training has influenced knowledge about the attributes of sustainable intensification and to control for biases introduced through self-selection. Knowledge about sustainable intensification is assessed through the administration of an exam with questions on multiple attributes of the system benefits and costs.

3.4 Knowledge accumulation

Selected farmers were targeted with education on SAIPs. The participant farmers were involved in the research process from the development to the implementation stages and researchers took local farmers view on the existing practices into consideration in the research design. A “mother-baby” trial approach was adopted to facilitate stakeholder involvement at the implementation stage of the research process (Snapp et al. 2002). The “mother” trial, managed by the researcher, was composed of several treatments of the SAIPs compared to the farmers’ practices whiles the “baby” trials, managed by the farmer, had comparative trials between the farmers’ practices and four SAIPs; nutrient management, zero-tillage, crop rotation and permanent soil cover within maize and soybeans fields. A participatory approach was adopted to enhance sustainability of the practices through social and human capital development and to facilitate technology impacts (Neef and Neubert, 2011; Johnson et al., 2004). An important focus of this research was to determine whether these participatory approaches increased knowledge accumulation.

Knowledge is modeled as a stock accumulation process where the current stock of knowledge in time t, K_t, is dependent upon the stock at the previous period (K_{t-1}) plus any investments, I_t (for example, education or training) net of depreciation (D_t) (e.g. knowledge loss or irrelevance):

$$K_t = K_{t-1} + I_t - D_t \ldots\ldots\ldots\ldots (8)$$

Knowledge has both indirect and direct effect upon the utility of an intervening farmer. Knowledge, in and of itself, may be valued and have unspecified benefits to problem solving. At the same time, knowledge generates a flow of services that can be incorporated into how one farms or manages household resources, builds resiliency or produces an environmental service benefit. Allow the flow of services from accumulated knowledge (F_t) to be affected by the stocks of human (H_t) and knowledge capital(K_t).

$$F_t = F_t(H_t, K_t) \ldots\ldots\ldots\ldots.. (9)$$

The flow of services provided by the stock of knowledge is assumed to be increasing in the stocks of both human capital and knowledge, decreasing in the second derivatives, while the cross products are positive. This flow can be integrated into the utility structure of the participant such that a period's utility is affected by the flow of new knowledge and its impact upon the profit structure of agricultural production, i.e. the relative usage of inputs and production of outputs, its impact upon the employment of household resources and results, production resiliency and the production of environmental goods and services.

$$U_p = U_p\{\pi(p, \tilde{p}, F), H(F), R(F), E(F), F\} \dots\dots\dots.. (10)$$

3.4.1 Knowledge treatment effects

Both participating farmers and those that did not participate were administered knowledge tests prior to the start of training and at intervals following program implementation. The knowledge was subdivided in three subcomponents as:

1. Soil and agronomic improvement knowledge score index. This comprised six out of the twelve questions;
2. Questions on tillage knowledge score index. Involves four out of twelve questions; and
3. Environmental improvement knowledge score index. Involves two out of twelve questions.

Mean differences in the knowledge scores were tested between periods (2010, 2012 and 2014). Dalton et al. (2014), compared the mean difference in knowledge score between 2010 and 2012 and found significant differences between and within participant and non-participant households. These results are updated to compare the 2014 knowledge score to that of the 2012 and 2010 to see if there is a significant impact in knowledge score change in the three areas described above. Table 3.1 presents the questions used to assess knowledge in the three areas.

Table 3.1 Sub-components of Knowledge Score

Questions	*Soil & Agronomic*	*Tillage*	*Environment*
Crop residues are a source of organic matter for soil.	*X*		
Higher soil organic matter content improves water holding capacity.	*X*		
Manure is as strong of a fertilizer as purchased inorganic fertilizer.	*X*		
Manure improves water holding capacity of the soil	*X*		
I can plant directly into the soil without plowing.		*X*	
Tillage assists in water infiltration.		*X*	
Tillage increases soil water holding capacity		*X*	
Tillage improves aeration in the soil		*X*	
Rotating cereals and legumes improves soil fertility	*X*		
Rotating cereals and legumes prevents some plant diseases	*X*		
Rotating cereals and legumes prevents soil erosion			*X*
Rotating cereals and legumes increases the microbes in the soil			*X*

X implies the type of question included

Table 3.2 presents the results of the mean difference in knowledge score for households from 2010 to 2014. Comparisons are made between the 2010, 2012 and 2014 knowledge score levels using the student t-test to measure the mean differences. The results indicate significant difference in the aggregate mean knowledge score between participant and non-participant households in 2014. There is a highly statistical difference in mean knowledge score levels between treated and between 2014 and 2012 for both the treatment group and the control group. The indication is that both participating (treatment) and non-participating (control) households are still engaged in active learning through the accumulation of more knowledge on SAIPs from 2012 to 2014. It is also shown that, between 2012 and 2010 there is a statistically significant difference in the knowledge score change (see also, Dalton et al. 2014). Statistically significant differences in aggregate knowledge score levels are also observed between 2010 and 2014 for the treated and control. On the knowledge components, it is observed that average knowledge on tillage improved for both treated and control groups from 2010 to 2014. There is evidence of knowledge spillover which can partly be attributed to the effect of key informant from the control communities who were mostly involved in the field schools through the project.

Table 3.2 Treatment effects of knowledge score

Period	*Category*	*Aggregate*	*Components* *Soil & agronomic*	*Tillage*	*Environment*
2014	*Treated*	*11.68*	*5.82*	*3.86*	*1.99*
	Control	*11.45*	*5.71*	*3.68*	*1.94*
	Difference	*0.22***	*0.11*	*0.18***	*0.05*
2012	*Treated*	*11.38*	*5.51*	*3.93*	*1.95*
	Control	*11.29*	*5.58*	*3.76*	*1.94*
	Difference	*0.09**	*-0.07*	*0.20****	*0.01*
2010	*Treated*	*10.26*	*5.49*	*3.04*	*1.73*
	Control	*10.35*	*5.62*	*2.92*	*1.81*
	Difference	*-0.09*	*-0.13*	*0.12*	*-0.08*
		Knowledge difference between the categories			
2014-2010	*Treated*	*1.41****	*0.32****	*0.81****	*0.25****
	Control	*1.10****	*0.09**	*0.75****	*0.13****
2014-2012	*Treated*	*0.30****	*0.31****	*0.07*	*0.04*
	Control	*0.16**	*0.13**	*0.08*	*-0.01*
2012-2010	*Treated*	*1.11****	*0.01*	*0.89****	*0.21***
	Control	*0.95****	*-0.04*	*0.84****	*0.14****

*Where ***, **, & * represents 0.01, 0.05 & 0.10 p-levels respectively*

These differences provide some evidence of knowledge change but not conditioned on household factors. To answer that question, a Tobit model is estimated using the change in accumulated knowledge through the participation in SAIPs training to capture knowledge change between at baseline and after training. The main hypothesis to be tested is that household participation decision in SAIPs training has a positive impact on accumulated knowledge score change. The change in accumulated knowledge score is censored from zero for households whose knowledge has not changed to a positive figure between the period, 2012-2014 and hence the use of the Tobit model. Dalton et al. (2014) found a positive knowledge change through participation using simple difference method for two years data (2010-2012).

Testing the hypothesis requires the use of the censored regression model. The model uses the latent variable approach as in Green (2003) and can be expressed as a stochastic model as follows;

$$y_i^* = x_i'\beta + \varepsilon_i \dots\dots\dots\dots\dots (11)$$

where, y_i^* is the unobserved change in knowledge score which captures the unobserved preferences associated with change in knowledge score Δy_i and x_i, is vector of exogenous observed explanatory variables. The observed change in knowledge score, Δy_i is defined as follows;

$$\Delta y_i = \begin{cases} y^* \; if \; y_i^* > K \\ 0 \; if \; y_i^* \leq K \end{cases} \dots\dots\dots\dots\dots (12)$$

The probability that, the change in knowledge score is censored is given by;

$$\Pr(y_i^* \leq K) = \Pr(x_i'\beta + \varepsilon_i \leq K) = F\{(K - x_i'\beta)/\sigma\}$$

where, $F(.)$ is the standard normal cumulative distribution function and $K \geq 0$.

The assumption is that the explanatory variables are not censored and hence, equation (11) is estimated as;

$$E[y_i|x_i, y_i > K] = x_i'\beta + \sigma \frac{f\{(x_i'\beta - K)/\sigma\}}{F\{(K - x_i'\beta)/\sigma\}} \dots\dots (13)$$

where, $f(.)$ is standard normal density function. The above conditional mean is different from $x_i'\beta$ because of the censoring and hence use of the Tobit model. However, the conditional mean is based on the assumption that, $\varepsilon \sim N(0, \sigma^2)$ and the maximization of the log-likelihood function. The question then is what is the effect of the accumulated knowledge on the adoption decision of the households on the SAIP components? To answer the question we use the multivariate Probit model.

3.5 SAIPs adoption

To test the hypotheses of the interdependence of SAIP practices and the positive impact of accumulated knowledge change on SAIPs adoption, multivariate Probit model is used. In analyzing the determinants of adoption of the four components of sustainable intensification agricultural practices examined, a computationally practical form of analysis for multiple binary variables referred to as the multivariate Probit model (MVP) is used. This model accounts for the effects covariates have on the probabilities of adopting sustainable intensification agricultural practices and the interdependence between the practices by allowing the unobserved portions of the model to be freely correlated (Lesaffre and Kaufmann 1992). This framework allows us to test the hypothesis that SAIPs are not adopted singularly but in combinations due to complementarity and heterogeneity related to agricultural production in the tropics. Previous studies employed univariate models without considering the multiplicity and inter-related nature of SAIPs adoption (Kassie et al. 2009).

The multivariate model in this study uses four binary dependent variable $y_{i1}, y_{i2}, y_{i3}\ and\ y_{i4}$, such that;

$$y_{ik}^{*} = x_{ik}'\beta_k + \epsilon_{ik} \quad \forall\ k = 1, 2, 3\ and\ 4 \ \ldots\ldots\ldots\ldots (14)$$

$$y_{ik} = \begin{cases} 1\ if\ y_{ik}^{*} > 0 \\ 0\ otherwise \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (15)$$

The assumption is that, the latent variable y_{ik}^{*} captures the unobserved utilities associated with k^{th} sustainable intensification agricultural practices. It is also assumed to be a linear function of the vector of observed farmer's individual, household and farm characteristics (x_{ik}') as well as the unobserved characteristics captured by a random term (ϵ_{ik}). What is estimated is the vector of β_k, which include the impact of the change in knowledge. The unobserved random error term is assumed to jointly follow a multivariate normal distribution with a zero conditional mean and a covariance matrix, Ω. That is, $\epsilon_{ik} \sim MVN(0, \Omega)$ with

$$\Omega = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} \\ \rho_{13} & \rho_{32} & 1 & \rho_{34} \\ \rho_{14} & \rho_{42} & \rho_{34} & 1 \end{pmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

The off-diagonal elements in the variance-covariance matrix, $\rho_r$represents the correlation between the unobserved random terms for the k^{th} and r^{th} sustainable intensification practices allowing for correlations across the random error terms of the four equations. This allows for the complementarity and substitutability of the SAIPs. Based on the correlation coefficient, the decision to adopt interdependent components can be deduced from the estimates using the signs and statistical significance of the coefficient. However, this does not represent causality.

3.6 Data, research design and empirical results

The data for this study was obtained from 168 households in ten communities from the Upper West Region of Ghana. Figure 3.2 below presents the study area and the study sites. Participating households (the treatment) were purposively sampled while non-participating (non-treated) households were selected based on a prior random sample during a baseline in 2010 and mid-term study in 2012. The conceptual diagram of the sample frame is shown in figure 3.1 (Dalton et al. 2011). We had two main effects, the treatment effect (participating) and control (non-participation). Among the control group, we have households within the participating communities but who are not actually treated, and "without" households who are within 10 kilometers from the participating community. The data was obtained using a structured questionnaire. The summary of the sampled households by gender is presented below in Table 3.3. There was however, a non-response rate of 16%.

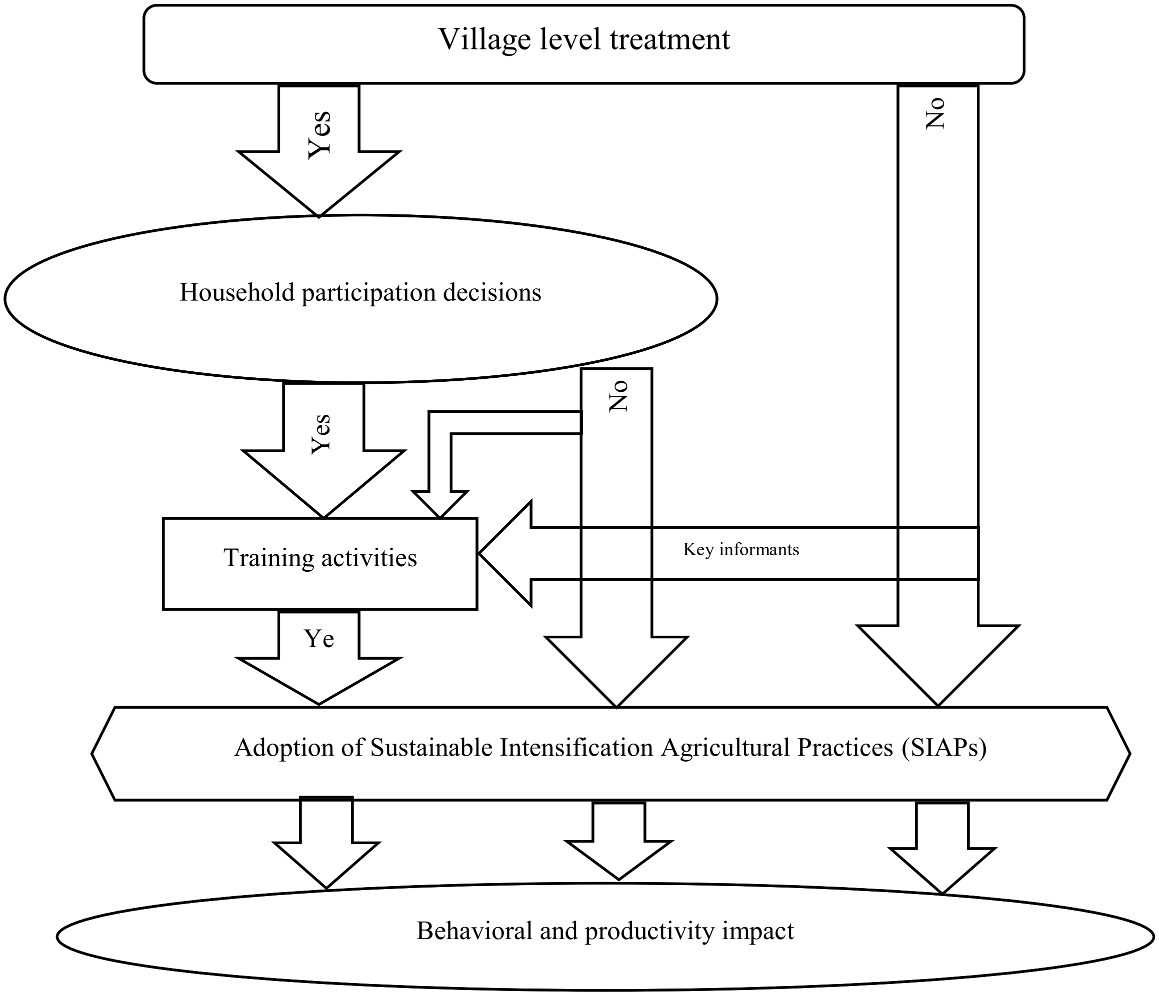

Figure 3.1 Research design (adopted from Dalton et al. 2011 pp 4)

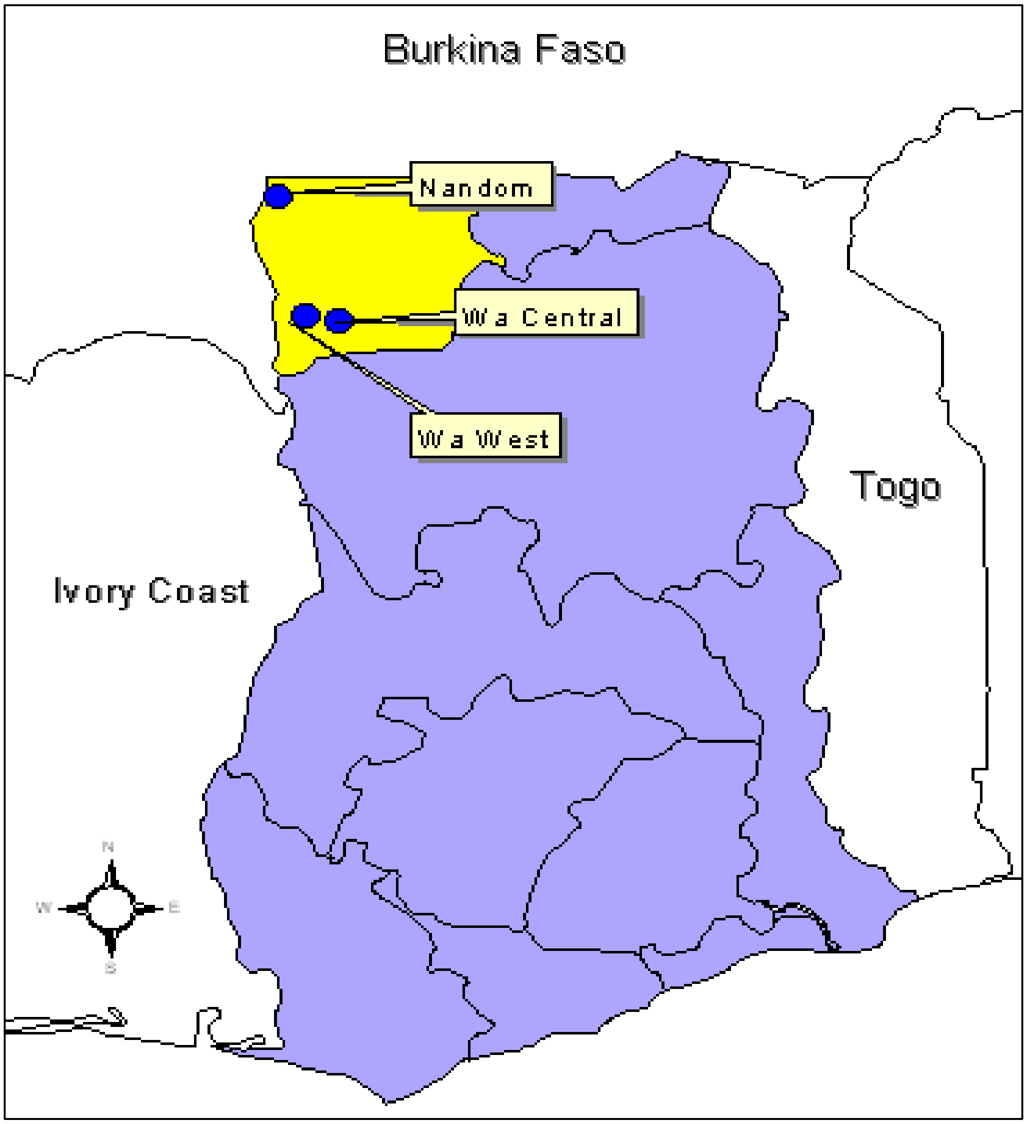

Figure 3.2 Study sites in Ghana

Table 3.3 Sampled households by gender and treatment effects

Category	*Name of Community*	*Male headed households*	*Female headed households*	*Total sample*
Participating (treated)	*Nyoli*	*17*	*7*	*24*
	Seiyiri	*18*	*1*	*19*
	Brutu	*13*	*1*	*14*
	Bu	*14*	*0*	*14*
	Puffien	*16*	*0*	*16*
	Busa-Tangzu	*21*	*2*	*23*
Non-participating (non-treated)	*Biihee*	*19*	*0*	*19*
	Nabugaun	*15*	*0*	*15*
	Kokoyiri	*11*	*0*	*11*
	Ga	*13*	*0*	*13*
	Total	*157*	*11*	*168*

The variables used in the three models are defined with a priori expectations and summary statistics in Table 3.4. Participation refers to the univariate Probit model evaluating the factors influencing the households' participation decision. Knowledge refers to the knowledge score level change which is further categorized into soil and agronomic, tillage and environmental knowledge score changes. Adoption is the multivariate adoption model which simultaneously models adoption decision of households and the interdependence of the different SAIP components.

The participation model is hypothesized to be influenced by both household, individual and farm characteristics. The variables considered to impact household participation decisions in SAIPs training are: age of household head in years, whether household head had some education, experience in farming, gender of the household head, number of children in the household, total household size, ownership of farm land (tenure), household food insecurity access scale, household total income in natural logs, acres of farm land cultivated by household in natural logs, time required to travel to the farm in natural logs and access to credit.

The effects of household, individual and farm characteristics used in the participation model are also hypothesized to influence the household knowledge change score except credit access. However, the main hypothesis to be tested is whether household participation in the training program has positive impact on the knowledge score change. Hence, participation is included in the variables. The predicted participation is however used in the model to take care of the endogeneity problems that may arise due to the use of the participation variable itself (Dalton et al. 2011).

The multivariate Probit model which simultaneously models the interdependence of SAIPs and the probability of household, individual characteristics and farm characteristics on their adoption is hypothesized to be influenced by the variables mentioned above in the knowledge score change model. Included are: access to credit, number of day of family labor used per season, household food insecurity access scale, with a scale measure from 0 being food secure and 25 being food insecure and the predicted knowledge score measure.

Table 3.4 Definition of Variables, a priori expectations and summary statistics

Variable	Description	Expected signs of variables			Total sample		Participant		Non-participant	
		Participation	Knowledge	Adoption	Mean	S. D	Mean	S. D	Mean	S. D
Zetil	Adoption of zero tillage. Dummy dependent variable (adopt=1, otherwise=0)				0.37	0.48	0.56	0.50	0.27	0.45
Rotat	Adoption of rotation. Dummy dependent variable (adopt=1, otherwise=0)				0.51	0.50	0.67	0.47	0.43	0.50
Resid	Adoption of residue retention. Dummy dependent variable (adopt=1, otherwise=0)				0.67	0.47	0.84	0.37	0.58	0.49
Fert	Adoption of chemical fertilizer management. Dummy dependent variable (adopt=1, otherwise=0)				0.45	0.50	0.545	0.50	0.41	0.49
Gender	Gender of the household head. Dummy variable (male=1, female=0)	+	+	-	0.94	0.24	0.89	0.32	0.96	0.19
Educat	Education of household head. Dummy variable(some education=1, otherwise=0)	±	+	+	0.36	0.48	0.51	0.50	0.29	0.46
Age	Age of household head in completed years (completed years)	±	±	±	44.80	14.10	41.20	11.71	46.60	14.86
Exper	Number of years household head has been in crop production (years)	+	+	+	23.57	14.55	20.32	12.44	25.18	15.29
Hhn	Total number of household members (numbers)	±		±	7.69	2.76	6.89	2.36	8.09	2.86
Chn	Number of children in the household (numbers)	±		±	3.00	1.99	2.85	1.73	3.09	2.12
Tenure	Household ownership of plot (s) under cultivation. A dummy variable(owner=1, otherwise=0)	+		+	0.94	0.24	0.95	0.23	0.94	0.24
Hfias	Household food insecurity access scale (scale: 0-25) with zero being food secured	+	+	+	8.74	5.87	7.78	5.62	9.20	5.96
Totacres	Total household land holding in acres (number of acres)			+	8.30	7.45	6.80	4.08	9.05	8.54
Famldy	Total number of family labor days spent during previous season (days/season)			±	20.63	22.40	17.29	23.46	22.26	21.78
Parthat	Predicted participation. Independent variable (continuous variable in numbers)		+		0.33	0.36	0.73	0.24	0.13	0.22
Ttime	Average walking time to the plot (s) (in minutes)			+	45.97	36.88	55.20	42.33	41.48	33.19
Diffkge	knowledge change between 2012 to 2014 (continuous variable in numbers)				0.49	1.07	0.65	1.09	0.41	1.06
Credit	Access to credit. Dummy variable (credit access=1, otherwise=0)	+	+	+	0.21	0.41	0.24	0.43	0.20	0.40
Kngehat	predicted change in knowledge difference (continuous variable in numbers)			+	0.53	0.51	0.69	0.43	0.45	0.52
Diffsimkg	Difference in knowledge levels on soil improvement (2014-2012)(in numbers)				0.36	0.72	0.47	0.74	0.30	0.71
Difftilkg	Difference in knowledge levels on tillage (2014-2012)(in numbers)				0.09	0.66	0.15	0.65	0.06	0.67
Diffenvkg	Difference in knowledge levels on environmental improvement (2014-2012)(in numbers)				0.04	0.32	0.04	0.38	0.04	0.280
lnacre	Natural log of total land holding in cares (number of acres)	-	+		1.86	0.68	1.75	0.59	1.92	0.72
lnincome	Natural log of total household income (Ghana cedis)	+	+	+	6.74	0.97	6.83	1.17	6.69	0.85
lntime	Natural log of average walking time to plot(s) in minutes	±	±		3.47	0.95	3.62	1.05	3.40	0.88
Org.	Household head affiliation to farmer organization. Dummy variable	+			0.50	0.50	0.95	0.23	0.28	0.44

3.7 Factors impacting participation decision

The univariate Probit function is estimated to evaluate the factors hypothesized to impact household's participation decision in SAIPs project activities. This equation is used to control for treatment effects, against households who did not participate in project activities. This approach is to capture the effect of participation separately (Dalton et al. 2011). To predict the factors influencing household's participation decision on the SAIP training, an empirical model was estimated and the results with its marginal effects are presented in Table 3.5. The variables were tested for interaction effects and for possible correlations among them and all were rejected.

Table 3.5 Probit estimates and average marginal effects of participation

	Probability Estimates		*Marginal effects*	
Variable	*Coef.*	*Std. Error*	*AME*	*Std. Error*
Const.	*2.109*	*1.750*		
Age	*-0.042***	*0.021*	*-0.007***	*0.003*
Education	*0.760***	*0.390*	*0.119***	*0.057*
Experience	*0.017*	*0.020*	*0.003*	*0.003*
Gender	*-2.743***	*1.295*	*-0.428***	*0.191*
Number of children	*0.077*	*0.129*	*0.012*	*0.020*
Household number	*-0.106*	*0.098*	*-0.017*	*0.015*
Membership of organization	*3.256****	*0.600*	*0.508****	*0.050*
Tenure	*1.938*	*1.255*	*0.302*	*0.190*
HFIAS	*-0.071***	*0.033*	*-0.011***	*0.005*
Natural log of income	*-0.186*	*0.188*	*-0.029*	*0.029*
Natural log of acres	*-0.810****	*0.290*	*-0.126****	*0.041*
Natural log of travel time	*0.202*	*0.189*	*0.031*	*0.029*
Credit access	*0.712**	*0.423*	*0.111**	*0.063*
Pseudo-R^2	*0.56*			
LR-chi(13)	*106.44****			
LL	*-41.549*			

****, **, & * represents 0.01, 0.05 & 0.10 p-levels respectively*

The results indicate that, age and gender of household head, household food insecurity access score and farm size have a negative and significant relationship to the household participation decision. The implication is that younger and female headed households are more likely to participate in SAIPs activities than older and male household heads. This is consistent with other findings (see Dolisca et al. 2006). Households with small farm sizes are likely to participate in SAIPs training. The implication is that, increasing farm size by unit acre will result in about 12.6% of households not participating in the training program. Also, the positive impact of education and belonging to a farmer group/organization are consistent with other research findings on the household participation decision (Zbinden and Lee 2005). Access to credit has a positive and significant relationship to the decision to participate in SAIPs training. The implication of this is that educated households, belonging to a farmer organization and credit access influences household decision to participate in training with a likely increase in participation by about 11% for having access to credit. The results indicate that, have a formal education will likely increase household participation by SAIPs training by 12%. The results indicate female household heads are more likely to participate in the training program than male household heads. Training participation is likely going to increase more (about 51%) with membership of farmer organization. An increase in the total acres of household cultivable land by a unit will decrease household participation in training by 13% .Finally, households that are more food insecure are less likely to participate in the training. For each increase in the food insecurity access score, there is a 1.1% decrease in the probability of participation.

3.8 Factors impacting knowledge score change

The knowledge score change represents differential change in knowledge on sustainable intensification practices due to the treatment effect. This is an index score calculated linearly using the twelve knowledge questions with weights of 1 for correct and 0 for incorrect answers. The assumption is that farmers' participation in the SAIPs training influences the farmers' change in knowledge score. The participation variable is assumed to be endogenously determined and hence predicted participation, ($\widehat{pt}$), was used to control for the possible endogeneity problem (Dalton et al. 2011). This is to capture the treatment effect on whether active learning by households' is due to the participation. Interaction effects were tested and rejected.

A Tobit model was used to test the hypothesis of households' participation, individual, household and farm characteristics on the change in knowledge score levels. This is used because the knowledge score variable is bounded between zero (0) and a specific maximum knowledge score level. This hypothesis is based on an earlier findings that both participant and non-participant farmers' knowledge on conservation practices significantly improved from 2010 to 2012 (Dalton et al. 2014). The Tobit model used to examine the factors affecting farmers' knowledge index change.

Results of the estimated Tobit model is presented in Table 3.6. The reported coefficients are the same as the marginal effects. The results show the expected positive impact of gender, education, household food insecurity access scale, farm size, income, credit and whether treatment effect (participation) on aggregate knowledge score level change. Experience of household head in farming has an unexpected negative and significant impact on aggregate knowledge score level change. Age of household head and time, which is a proxy for distance to the farmer' field, have positive and negative effects on aggregate knowledge score level change, respectively. Age however, has a significant positive effect on aggregate knowledge score level change which is consistent with other findings (Hussain et al. 1994).

The implication of the results is that, male household heads, participating households and older household heads explains the knowledge acquisition between the periods of 2012-2014. The treatment effect can be explained as households' involvement in active learning due to the direct participation of households in the farmer research training project. The unexpected negative impact of experience may indicate a reticence for new technologies and contradicts the positive effect of age. The reason is that, younger household heads have the desire to learn new technologies compared to the older and the more experience ones.

The results are different for the soil and agronomic, tillage and environmental knowledge score level changes. Even though treatment effect has a positive effect on the sub-components of the knowledge score level changes, the variable is not statistically significant. While age and gender have a positive and significant effect on soil and agronomic knowledge score level change, they are not significant in the tillage and environmental knowledge score level changes. However, experience of farming has a significant negative effect on all the sub-components.

Table 3.6 Factors influencing households' knowledge change (marginal effects)

Variable			*Sub-Components*					
	Aggregate		*Soil and Agronomic*		*Tillage*		*Environmental*	
	Coef.	*S.E*	*Coef*	*S.E*	*Coef*	*S.E*	*Coef*	*S.E*
Constant	*-2.910**	*1.616*	*-1.214*	*1.224*	*-7.685***	*3.502*	*-7.180*	*7.009*
Age	*0.044****	*0.015*	*0.029****	*0.012*	*0.027*	*0.029*	*0.003*	*0.059*
Education	*0.478*	*0.329*	*0.364*	*0.252*	*-0.186*	*0.609*	*-0.279*	*1.363*
Experience	*-0.072****	*0.017*	*-0.040****	*0.012*	*-0.060**	*0.033*	*-0.223**	*0.121*
Gender	*1.187**	*0.650*	*1.019**	*0.535*	*1.939*	*1.397*	*0.345*	*2.179*
Hfias	*0.022*	*0.028*	*-0.001*	*0.021*	*0.069*	*0.055*	*0.063*	*0.111*
Lnincome	*0.186*	*0.170*	*-0.021*	*0.128*	*0.717***	*0.362*	*0.951*	*0.778*
Lnacre	*-0.213*	*0.234*	*-0.070*	*0.180*	*-0.705*	*0.499*	*-0.641*	*0.994*
Lntime	*-0.221*	*0.155*	*-0.085*	*0.117*	*-0.197*	*0.293*	*-0.015*	*0.632*
Credit	*0.210*	*0.360*	*0.250*	*0.284*	*0.054*	*0.720*	*-0.770*	*1.655*
Participation	*0.793**	*0.456*	*0.299*	*0.336*	*0.902*	*0.836*	*0.147*	*1.577*
LL	*-175.100*		*-146.604*		*-87.340*		*-31.828*	
LR-Chi^2	*33.370****		*22.510****		*13.610*		*15.550**	
Pseudo-R^2	*0.089*		*0.070*		*0.070*		*0.21*	

*Where ***, **, & * represents 0.01, 0.05 & 0.10 p-levels respectively*

3.9 Treatment effects on adoption rates of SAIP components

The overall mean adoption rates for the various SAIP components for both treated and non-treated households' combined are 34% for zero-tillage, 51% for residue retention, 67% for crop rotation and 45% for fertilizer management. The results of mean adoption rates based on whether the household engaged in the training or not are shown in table 3.7. The results show that the mean adoption rates of zero-tillage, residue retention, crop rotation and fertilizer management are respectively 56%, 67%, 84% and 54% for the treated households. For non-treated households' the mean adoption rates are 27%, 43%, 58% and 40% respectively for zero-tillage, residue retention, crop rotation and fertilizer management. The results indicate significant mean differences between the treated and the non-treated households.

The impact of the treatment effect was statistically significant for all the SAIP components with fertilizer management being less statistically significant. This might be a result of other educational programs that promote fertilizer management not necessarily the SAIP project impact, as comparable with other studies (Dalton et al. 2011). There is evidence of spillover effects on the adoption of the SIAPs technologies which is evident in the knowledge spillover due to the key informant participation in the field schools.

Table 3.7 Treatment effects of adoption rates

SAIPs components	*Treatment*	*No-treatment*	*Mean difference*	*Overall sample*
Zero-tillage	*0.564*	*0.274*	*0.289****	*0.369*
Residue retention	*0.673*	*0.434*	*0.239****	*0.512*
Crop rotation	*0.836*	*0.584*	*0.252****	*0.667*
Fertilizer management	*0.545*	*0.407*	*0.138**	*0.452*

*Where ***, **, & * represents 0.01, 0.05 & 0.10 p-levels respectively*

3.10 Interdependent adoption of SAIPs

The multivariate Probit model was specified and estimated as a function of predicted knowledge change, the household food insecurity access scale, characteristics about the household head, farm level, and household level characteristics on adoption. Part of the interest in this model is the correlation coefficient of the errors between each practice and the signs of the coefficients of each of the covariates in each model. The estimated results are shown in Table 3.9 below.

The results shown in table 3.8 supports the use of the multivariate Probit model as the correlation coefficients are positive and statistically significant, implying interdependencies between the SAIPs. This shows the random disturbance terms of the models are not independent from each other and hence, the adoption of one component is correlated with the adoption of other components. The SAIPS components are complements to each other as the results indicate positive, high and statistically significant correlations between components in the variance-covariance matrix after the maximum likelihood estimation.

Table 3.8 Correlation matrix between SAIPs components

SAIP	*Zero-till*	*Rotation*	*Residue retention*	*Fertilizer management*
Zero-till	*1*			
Rotation	*0.809*** (-0.064)*	*1*		
Residue retention	*0.860*** (-0.056)*	*0.816*** (-0.064)*	*1*	
Fertilizer management	*0.670*** (-0.068)*	*0.784*** (-0.059)*	*0.859*** (-0.061)*	*1*

*Where ***, **, & * represents 0.01, 0.05 & 0.10 p-levels respectively*

The results of the multivariate Probit measuring show that age, education, experience, having children in the household, household size, land tenure and knowledge score variable. Age has a negative and significant effect on all the SAIPs; zero-tillage (ZT), Rotation (RT), residue retention (RR) and fertilizer management (FM). This result indicates that, younger household heads are more likely to adopt the SAIP components and this is consistent with other findings (Arellanes and Lee, 2003; Mugwe et al. 2009). Education of household head has an unexpected negative effect on the likely adoption of SAIP components. However, except RR, the education variable is significant for ZT, RT and FM. The implication is that, education of household head is not likely to influence adoption of the SAIPs. This results can be explained because, zero/no- tillage is not highly knowledge based compared to other agricultural innovation technologies and hence education level might not seem important. This is consistent with findings that education has a negative impact on legume intercropping and soil and water management (Kassie et al. 2012).

Table 3.9 Estimates of Multivariate Probit model

Variable	*Zero-till (ZT)*		*Rotation (RT)*		*Residue retention(RR)*		*Fertilizer management (FM)*	
	Coef	*S.E*	*Coef*	*S.E*	*Coef*	*S.E*	*Coef*	*S.E*
Constant	*1.392*	*1.260*	*0.139*	*1.262*	*1.389*	*1.239*	*-1.288*	*1.161*
Age	*-0.080****	*0.020*	*-0.082****	*0.021*	*-0.046***	*0.020*	*-0.044****	*0.017*
Education	*-0.697**	*0.375*	*-1.315****	*0.382*	*-0.181*	*0.378*	*-1.059****	*0.345*
Experience	*0.118****	*0.032*	*0.117****	*0.033*	*0.059**	*0.033*	*0.056***	*0.029*
Gender	*-0.588*	*0.581*	*-0.639*	*0.527*	*0.061*	*0.486*	*0.102*	*0.506*
Children	*0.225****	*0.085*	*0.109*	*0.079*	*0.144**	*0.083*	*0.053*	*0.073*
Household size	*-0.180****	*0.066*	*-0.140***	*0.064*	*-0.111**	*0.066*	*-0.081*	*0.057*
Hfias	*-0.031*	*0.023*	*0.031*	*0.021*	*0.023*	*0.020*	*0.022*	*0.020*
Tenure	*-2.461****	*0.795*	*-1.561***	*0.724*	*-0.664*	*0.707*	*-0.854*	*0.699*
Total acres	*0.006*	*0.016*	*0.011*	*0.016*	*0.040***	*0.017*	*0.003*	*0.016*
Famldy	*0.009*	*0.006*	*0.003*	*0.005*	*-0.001*	*0.005*	*0.004*	*0.005*
Ttime	*0.002*	*0.003*	*0.004*	*0.003*	*-0.001*	*0.003*	*0.001*	*0.003*
Lnincome	*0.221*	*0.143*	*0.274***	*0.133*	*-0.057*	*0.128*	*0.320****	*0.123*
Credit.	*0.281*	*0.311*	*-0.148*	*0.296*	*-0.389*	*0.285*	*0.108*	*0.260*
Knowledge.	*2.337****	*0.775*	*3.058****	*0.783*	*1.541***	*0.783*	*1.541***	*0.696*
Log likelihood	*-273.035*							
Wald Chi2(56)	*86.43****							

*Where ***, **, & * represents 0.01, 0.05 & 0.10 p-levels respectively*

The main hypothesis of this research was to evaluate the impact of the knowledge score variable on the likely adoption of SAIPs. The results show positive and significant impact of knowledge score accumulated through the farmer participatory research training on SAIPs. The results confirm the finding that active learning through participation has an impact on the knowledge accumulation and the adoption of sustainable intensification practices in the North-western part of Ghana. This may help improve land productivity in the long-run.

Presence of children in the household has a positive and significant effect on the likely adoption of zero-tillage (ZT) and residue retention (RR) while household size is found to have a negative and significant effect on the likely adoption of ZT, rotation (RT) and RR. The result is inconsistent with other findings that, household size has a positive impact on the adoption of SAIPs due to its labor intensive nature (Kassie et al. 2012). However, this result of the negative impact of household size on the likely adoption of some of the components of SAIP is supported by the findings that, households save on labor when the technology is used (Dalton et al. 2014). Hence, since the finding support an earlier assertion of labor savings, households with children will more likely adopt components of SAIPs.

The land size variable has the expected positive effect on the likely adoption of SAIPs. However, except RR which has a significant effect of land size on the likely adoption, the others are not significant. This finding however contradicts other findings (Adesina et al. 2000) that farmers with bigger farm sizes are more likely to adopt residue retention (RR). Land tenure has a negative effect on the likely adoption of SAIPs. However, it is significant for ZT and RT but not significant for RR and ZT. The implication of this result is that, non-land owners are more likely to adopt ZT and RT than land owners. This results does not sound intuitive, but makes sense based on the land ownership structure existing in the North-western Ghana. The chiefs are the custodians of the land and land for agricultural activities are not owned by households but by the chiefs. Hence the results, which contradicts other findings such as Neill and Lee (2001).

Income has the expected positive impact on the likely adoption of SAIPs, but it is only significant for RT and fertilizer management (FM). This result indicates that richer households are more likely to adopt RT and FM. Fertilizer use in Ghana is dependent on the purchasing ability of the households and hence the findings are consistent with other studies (Adesina et al. 2000). Household food insecurity access scale is not significantly different from zero for any of the models.

3.11 Conclusions and recommendations

The paper looks at farm household participation in SAIPs. The objective is to evaluate the effect of household accumulated knowledge score through the participation on the interdependent adoption of SAIPs. In the modelling the complex effects of participation on knowledge and the effect of knowledge on the independent adoption, a three-step approach was used in the analysis. The first step involved the modeling of household participation decision using a Probit model. The effects of participation on knowledge change score was estimated using a second-step Tobit model. In the third-step model, a multivariate Probit model was used to determine the effects of accumulated knowledge on the interdependent adoption of SAIPs.

The study identified age and gender of household head, education, land size, affiliation to farmer organization, and credit access as factors influencing household decision to participate in SAIPs. The implication of this finding is that, female and younger household heads who have some education and are affiliated to farmer organization are more likely to participate in conservation agricultural practices training. It also show that, smallholder households with previous history of credit access are more likely to participate in SAIPs training research.

The results on the mean knowledge difference between participant and non-participant households is consistent with the other findings that learning through participation has taken place and there is a spillover effect of knowledge on SAIPs to non-participating households. This finding is corroborated by the estimates of the Tobit model. The results show participation to have a positive and significant impact on household aggregate knowledge score change. Other covariates influencing aggregate knowledge change are age of household head, less experience in farming and male of household head.

The knowledge change is found to have a significant impact on the adoption of SAIP components. It is also shown that there is a spillover effect of the impact of the farmer participatory research (FPR) training. This can partly be attributed to the community and family structure system existing in this part of the country. The results also show that the disturbance terms of SAIP components are not independent implying the adoption of SAIP components are dependent on each other. We also found the significant impact of knowledge accumulated through the treatment effect on the likely adoption of SAIPs. Other factors found to influence the likely adoption of all SAIPs components include younger household heads and experience in farming. However, we found variables with different impacts for different components, for example we found no formal education is needed for the likely adoption of ZT, RT and FM whiles household size impacts the likely adoption of ZT, RT and RR. Adoption of ZT and RT are impacted by land tenure and income impacts the likely adoption of RT and FM. RR adoption however, is influenced by total acres owned by household.

Based on the results and the conclusions, we can deduce some recommendations from this study. This confirms the fact that farmer participatory research improves knowledge through the involvement of the beneficiaries in the technology research and training. Hence, governments and development partners in the agricultural innovations should consider the approach the farmer participatory approach since the impacts of any innovation can be measured by its usage for the benefit that comes with it. Future research should focus on how government agricultural policy can influence the likely adoption of SAIPs.

References

Abdulai, A., and W. Huffman "The adoption and impact of soil and water conservation technology: An endogenous switching regression application." *Land Economics* 90 (2014):26-43.

Adesina, A.A., D. Mbila, G.B. Nkamleu, and D. Endamana "Econometric analysis of the determinants of adoption of alley farming by farmers in the forest zone of southwest Cameroon." *Agriculture, Ecosystems & Environment* 80 (2000):255-65.

Arellanes, P., and D.R. Lee *The determinants of adoption of sustainable agriculture technologies: evidence from the hillsides of Honduras (*2003).

Arslan, Aslihan, et al. "Adoption and intensity of adoption of conservation farming practices in Zambia." *Agriculture, Ecosystems & Environment* 187 (2014): 72-86.

Baker, J.M., T.E. Ochsner, R.T. Venterea, and T.J. Griffis "Tillage and soil carbon sequestration—What do we really know?" *Agriculture, Ecosystems & Environment* 118 (2007):1-5.

Balota, E.L., A. Colozzi Filho, D.S. Andrade, and R.P. Dick "Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol." *Soil and Tillage Research* 77 (2004):137-45.

Barr, N., and J. Cary "Influencing improved natural resource management on farms." *Bureau of Rural Sciences, Canberra* (2000):

Bayala, J., G. Sileshi, R. Coe, A. Kalinganire, Z. Tchoundjeu, F. Sinclair, and D. Garrity "Cereal yield response to conservation agriculture practices in drylands of West Africa: a quantitative synthesis." *Journal of Arid Environments* 78 (2012):13-25.

Belderbos, R., M. Carree, B. Diederen, B. Lokshin, and R. Veugelers "Heterogeneity in R&D cooperation strategies." *International Journal of Industrial Organization* 22 (2004):1237-63.

Bett, C. *Farm level adoption decisions of soil and water management technologies in semi-arid Eastern Kenya (*2004).

Bock, R.D., and R.D. Gibbons "High-dimensional multivariate probit analysis." *Biometrics* (1996):1183-94.

Bultena, G.L., and E.O. Hoiberg "Factors affecting farmers' adoption of conservation tillage." *Journal of Soil and Water Conservation* 38 (1983):281-4.

Cameron, L.A. "The importance of learning in the adoption of high-yielding variety seeds." *American Journal of Agricultural Economics* 81 (1999):83-94.

Caviglia, J.L., and J.R. Kahn "Diffusion of Sustainable Agriculture in the Brazilian Tropical Rain Forest: A Discrete Choice Analysis." *Economic Development and Cultural Change* 49 (2001):311-33.

Chib, S., and E. Greenberg "Analysis of multivariate probit models." *Biometrika* 85 (1998):347-61.

Cooper, J.C., and R.W. Keim "Incentive payments to encourage farmer adoption of water quality protection practices." *American Journal of Agricultural Economics* 78 (1996):54-64.

Cullen, R., K.D. Warner, M. Jonsson, and S.D. Wratten "Economics and adoption of conservation biological control." *Biological control* 45 (2008):272-80.

Dalton, T.J., N.K. Lilja, N. Johnson, and R. Howeler "Farmer participatory research and soil conservation in Southeast Asian cassava systems." *World Development* 39 (2011):2176-86.

Dalton, T.J., I. Yahaya, and J. Naab "Perceptions and performance of conservation agriculture practices in northwestern Ghana." *Agriculture, Ecosystems & Environment* 187 (2014):65-71.

de Herrera, A.P., and G. Sain *Adoption of maize conservation tillage in Azuero, Panama*CIMMYT, 1999.

Derpsch, R., and T. Friedrich *Global overview of conservation agriculture no-till adoption* 2009.

Evenson, R.E., and D. Gollin *Crop variety improvement and its effect on productivity: The impact of international agricultural research* Cabi, 2003.

Fernandez-Cornejo, J. "The microeconomic impact of IPM adoption: theory and application." *Agricultural and Resource Economics Review* 25 (1996):149-60.

Fischer, G., M. Shah, F.N. Tubiello, and H. van Velhuizen "Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990-2080." *Philosophical transactions of the Royal Society of London.Series B, Biological sciences* 360 (2005):2067-83.

Friedrich, Theodor, A. H. Kassam, and F. Shaxson. "Conservation agriculture." *Agriculture for Developing Countries. Science and Technology Options Assessment (STOA) project. European Technology Assessment Group, Karlsruhe, Germany* (2009).

Fuglie, K.O. "Conservation tillage and pesticide use in the Cornbelt." *Journal of Agricultural and Applied Economics* 31 (1999):133-48.

Fuglie, K.O., and C.A. Kascak "Adoption and diffusion of natural-resource-conserving agricultural technology." *Review of Agricultural Economics* 23 (2001):386-403.

Gibbons, R.D., and V. Wilcox-Gök "Health service utilization and insurance coverage: a multivariate probit analysis." *Journal of the American Statistical Association* 93 (1998):63-72.

Giller, K.E., E. Witter, M. Corbeels, and P. Tittonell "Conservation agriculture and smallholder farming in Africa: the heretics' view." *Field Crops Research* 114 (2009):23-34.

Gould, B.W., W.E. Saupe, and R.M. Klemme "Conservation tillage: the role of farm and operator characteristics and the perception of soil erosion." *Land Economics* (1989):167-82.

Grizzle, J.E. "317. Note: Multivariate Logit Analysis." *Biometrics* (1971):1057-62.

FAO, 2009. http://www.fao.org/ag/ca/ (accessed 02/20/2009).

Hassan, R., and C. Nhemachena "Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis." *African Journal of Agricultural and Resource Economics* 2 (2008):83-104.

Hill, L., and P. Kau "Application of multivariate probit to a threshold model of grain dryer purchasing decisions." *American Journal of Agricultural Economics* 55 (1973):19-27.

Hobbs, P.R. "Conservation agriculture: what is it and why is it important for future sustainable food production?" *JOURNAL OF AGRICULTURAL SCIENCE-CAMBRIDGE-* 145 (2007):127.

Holland, J. "The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence." *Agriculture, Ecosystems & Environment* 103 (2004):1-25.

Hussain, S.S., D. Byerlee, and P.W. Heisey "Impacts of the training and visit extension system on farmers' knowledge and adoption of technology: Evidence from Pakistan." *Agricultural Economics* 10 (1994):39-47.

Johnson, N., N. Lilja, J.A. Ashby, and J.A. Garcia *The practice of participatory research and gender analysis in natural resource management*Wiley Online Library, 2004.

Kassie, M., M. Jaleta, B. Shiferaw, F. Mmbando, and M. Mekuria "Interdependence in farmer technology adoption decisions in smallholder systems: Joint estimation of investments in sustainable agricultural practices in rural Tanzania: Paper prepared and selected for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference." *Foz do Iguaçu, Brazil* (2012):18-24.

Kassie, M., P. Zikhali, K. Manjur, and S. Edwards *Adoption of sustainable agriculture practices: Evidence from a semi‐arid region of Ethiopia*Wiley Online Library, 2009.

Kiefer, N.M. "Testing for dependence in multivariate probit models." *Biometrika* 69 (1982):161-6.

Kimhi, A. "Quasi maximum likelihood estimation of multivariate probit models: Farm couples' labor participation." *American Journal of Agricultural Economics* 76 (1994):828-35.

Lal, R., and J. Bruce "The potential of world cropland soils to sequester C and mitigate the greenhouse effect." *Environmental Science & Policy* 2 (1999):177-85.

Lee, L.K., and W.H. Stewart "Landownership and the adoption of minimum tillage." *American Journal of Agricultural Economics* 65 (1983):256-64.

Lesaffre, E., and H. Kaufmann "Existence and uniqueness of the maximum likelihood estimator for a multivariate probit model." *Journal of the American statistical Association* 87 (1992):805-11.

Lilja, N., and M. Bellon "Some common questions about participatory research: a review of the literature." *Development in practice* 18 (2008):479-88.

Lilja, N., and J. Dixon "Responding to the challenges of impact assessment of participatory research and gender analysis." *Experimental Agriculture* 44 (2008):3-19.

Madalla, G. "Limited-dependent and qualitative variables in econometricsCambridge University Press." *New York* (1983):

Marra, M., D.J. Pannell, and A. Abadi Ghadim "The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve?" *Agricultural systems* 75 (2003):215-34.

Mazvimavi, K., and S. Twomlow "Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe." *Agricultural Systems* 101 (2009):20-9.

McCarthy, N., L. Lipper, and G. Branca "Climate-smart agriculture: smallholder adoption and implications for climate change adaptation and mitigation." *Mitigation of Climate Change in Agriculture Working Paper* 3 (2011):

MOFA, 2015. http://mofa.gov.gh/site/?page_id=656 (accessed: 03/02/2015)

Morton, J.F. "The impact of climate change on smallholder and subsistence agriculture." *Proceedings of the National Academy of Sciences of the United States of America* 104 (2007):19680-5.

Mugwe, J., D. Mugendi, M. Mucheru-Muna, R. Merckx, J. Chianu, and B. Vanlauwe "Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya." *Experimental Agriculture* 45 (2009):61-75.

Napier, T.L. "Factors affecting acceptance and continued use of soil conservation practices in developing societies: a diffusion perspective." *Agriculture, Ecosystems & Environment* 36 (1991):127-40.

Neef, A., and D. Neubert "Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making." *Agriculture and Human Values* 28 (2011):179-94.

Neill, S.P., and D.R. Lee "Explaining the adoption and disadoption of sustainable agriculture: the case of cover crops in Northern Honduras." *Economic development and cultural change* 49 (2001):793-820.

Norgaard, Richard B. "Three dilemmas of environmental accounting." *Ecological Economics* 1.4 (1989): 303-314.

Ochi, Y., and R.L. Prentice "Likelihood inference in a correlated probit regression model." *Biometrika* 71 (1984):531-43.

Oude Lansink, A., M. van den Berg, and R. Huirne "Analysis of strategic planning of Dutch pig farmers using a multivariate probit model." *Agricultural systems* 78 (2003):73-84.

Pannell, D.J., G.R. Marshall, N. Barr, A. Curtis, F. Vanclay, and R. Wilkinson "Understanding and promoting adoption of conservation practices by rural landholders." *Animal Production Science* 46 (2006):1407-24.

Pannell, D. "Social and economic challenges in the development of complex farming systems." *Agroforestry Systems* 45 (1999):395-411.

Parry, M.L., C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer "Effects of climate change on global food production under SRES emissions and socio-economic scenarios." *Global Environmental Change* 14 (2004):53-67.

Rahm, M.R., and W.E. Huffman "The adoption of reduced tillage: the role of human capital and other variables." *American Journal of Agricultural Economics* 66 (1984):405-13.

Rao, V.R., and F.W. Winter "An application of the multivariate Probit model to market segmentation and product design." *Journal of Marketing Research* (1978):361-8.

Reicosky, D. "Conservation agriculture: Global environmental benefits of soil carbon management." *Conservation Agriculture.* Anonymous pp. 3-12. Springer, 2003.

Sanginga, Pascal C., Jackson Tumwine, and Nina K. Lilja. "Patterns of participation in farmers' research groups: Lessons from the highlands of southwestern Uganda." *Agriculture and Human Values* 23.4 (2006): 501-512.

Schlenker, W., and D.B. Lobell "Robust negative impacts of climate change on African agriculture." *Environmental Research Letters* 5 (2010):014010.

Sidibé, A. "Farm-level adoption of soil and water conservation techniques in northern Burkina Faso." *Agricultural Water Management* 71 (2005):211-24.

Six, J., S.M. Ogle, R.T. Conant, A.R. Mosier, and K. Paustian "The potential to mitigate global warming with no-tillage management is only realized when practised in the long term." *Global Change Biology* 10 (2004):155-60.

Smale, M., P.W. Heisey, and H.D. Leathers "Maize of the ancestors and modern varieties: The microeconomics of high-yielding variety adoption in Malawi." *Economic Development and Cultural Change* (1995):351-68.

Smit, B., and M.W. Skinner "Adaptation options in agriculture to climate change: a typology." *Mitigation and Adaptation Strategies for Global Change* 7 (2002):85-114.

Snapp, S., D. Rohrbach, F. Simtowe, and H. Freeman "Sustainable soil management options for Malawi: can smallholder farmers grow more legumes?" *Agriculture, Ecosystems & Environment* 91 (2002):159-74.

Soule, M.J., A. Tegene, and K.D. Wiebe "Land tenure and the adoption of conservation practices." *American Journal of Agricultural Economics* 82 (2000):993-1005.

Steiner, K. "Conservation tillage: gateway to food security and sustainable rural development: crop residue management and cover crops." *African Conservation Tillage Network, Information* (2002):

Traoré, N., R. Landry, and N. Amara "On-farm adoption of conservation practices: the role of farm and farmer characteristics, perceptions, and health hazards." *Land Economics* (1998):114-27.

Traxler, Greg, and Derek Byerlee. "Economic returns to crop management research in a post-Green Revolution setting." *American Journal of Agricultural Economics* 74.3 (1992): 573-582.

Twomlow, S., D. Love, and S. Walker "The nexus between integrated natural resources management and integrated water resources management in southern Africa." *Physics and Chemistry of the Earth, Parts A/B/C* 33 (2008):889-98.

.Zbinden, S., and D.R. Lee "Paying for environmental services: an analysis of participation in Costa Rica's PSA program." *World Development* 33 (2005):255-72.

Chapter 4 - The impact of soil and water conservation methods on farm households technical efficiency scores: a parametric application to sorghum and millet in Niger

4.1 Introduction

Given the importance of agriculture's contribution to the gross domestic product (GDP) and food security of developing countries, there is the need to study how farmers can improve their output given available inputs and technology. This can be achieved by examining the technical efficiency of production using empirical data.

In studying technical efficiency of firms, two empirical approaches are commonly used: the parametric method that estimates a deterministic or stochastic frontier and non-parametric methods using data envelopment analysis. The parametric methods involve the use of functional forms that describes the production technology, and the non-parametric methods involve the use of linear programming techniques.

The methods are not without their advantages and disadvantages. The advantage of the non-parametric method is that it does not require any functional form for the technology. It is criticized however for its inability to produce parameter estimates of the model and does not easily perform hypothesis tests. The non-parametric model is also criticized for the inability to account for the noise or errors in the data. The parametric method is also criticized for the restrictiveness in the functional form assumed. However, the advantage of the parametric method is that it allows for hypothesis tests involving the model parameters. In the stochastic frontier model in particular, the justification of the distribution of the one-sided error term is important. The stochastic frontier does have the added advantage of accounting for measurement error and missing variables in the data and hence, it is more appropriate for use when using farm household level data (Coelli 1995).

Cross-sectional empirical studies have applied these methods to Africa's agriculture to assess production efficiency. For example some studies used cross-sectional data to study factors affecting technical efficiency of small-holder farmers practicing slash and burn agriculture in Cameroon using the Cobb-Douglas stochastic frontier model (Binam et al. 2003, Binam, Tonye et al. 2004). These studies identified credit, soil fertility, social capital, distance of plot to access road and extension services as explaining efficiency. In small-scale food crop production in Nigeria, both the parametric and non-parametric methods were used to evaluate technical efficiency (Ajibefun 2008). In Ghana, the stochastic profit function was used to study the economic efficiency of rice farmers using cross sectional data (Abdulai and Huffman 2000). The profit function was used to analyze the relative efficiency of women farm managers in Cote d'Ivoire using cross sectional data (Adesina and Djato 1997). Binam et al. (2003), using cross-sectional data among a sample of coffee farmers in Cote d'Ivoire, evaluated the factors affecting technical efficiency (TE). They used the non-parametric approach to estimate TE. They identified family size, membership of farmer's organization and origin of farmer as significant factors influencing inefficiency.

Other studies in the literature span from Asia to developed countries. For example, in a comparative efficiency analysis of wheat farms, both parametric and non-parametric approaches were used in a panel data analysis of Kansas farms (Mo and Featherstone 2010). In China, technical efficiency and technical progress in traditional and modern agriculture was studied with the use of a dual stochastic frontier model using cross sectional data (Xu and Jeffrey 1998). In Paraguay, efficiency of peasant farmers in cassava and cotton production was evaluated using stochastic frontier analysis (Bravo-Ureta and Pinheiro 1993; Bravo-Ureta and Evenson 1994). Rice has been the most studied agricultural crop in the developing world with India receiving the most attention when it comes to technical efficiency analysis (Bravo-Ureta and Pinheiro 1993).

Very few studies have examined sorghum or millet production (see Linton and Miller, 2011). This study will estimate the technical efficiency of millet and sorghum production in Niger using stochastic frontier function decomposition, examining how technical efficiency measures vary among adopters and non-adopters of soil and water conservation practices. This study will also investigate the impact of the technology on TE scores. Other studies have evaluated the effect of soil and water conservation adoption on technical efficiency scores. For example, Oduol et al. (2011) studied the impact of adoption of soil and water conservation methods on technical efficiency by small-holders in Rwanda, Uganda and Democratic Republic of Congo (DRC). They found no significant impact of soil and water conservation practices on TE scores in Rwanda and DRC and a negative impact of soil and water on TE in Uganda and for the pooled sample. Solís et al. (2007), evaluated the TE scores of hillside farmers in Central America using switching regression models. They found that households with above average adoption of soil conservation practices had higher average TE scores compared to lower adopters. These studies however were not targeted to a specific production system. Hence, the current study examines millet and sorghum production systems.

This study uses stochastic frontier analysis because farm household level data is used that might have measurement error or missing variables as well as uncertainties in weather and other climatic factors which cannot be controlled for (Coelli 1995). This study will identify the sources of inefficiencies in sorghum and millet production and prescribe policy and institutional guidelines to minimize them. The study will look at the sensitivity of the technical efficiency measures to the distribution of the one-sided error assumption using farm household level data. Baccouche & Kouki (2002) concluded that inefficiency measures are sensitive to the distributional assumptions postulated about the one-sided error using Tunisian industrial data. Cullinal et al. (2006) also demonstrate the sensitivity of technical efficiency estimates to distributional assumptions of the one-sided error in the analysis of Ports efficiency. Little information is known about the sensitivity of technical efficiency measures using farm household level data. This paper therefore contributes to the existing literature in the efficiency analysis for millet and sorghum production.

The remainder of this paper is organized as follows. Section 4.2 describes the background of Niger's sorghum and millet production and its contribution to food security and the economy. Section 4.3 describes the stochastic frontier model and the distributions of the one-sided error. Section 4.4 describes the data and the empirical estimation methods used. Section 4.5 describes the estimated results of both the stochastic frontier model and the second step models factors influencing inefficiency and section 4.6 presents the summary results, discussion and conclusion.

4.2 Background

Cereals make up about 59% of the food share of people in Niger. Millet and sorghum make up the majority of the calories consumed in the country (FAO 2015). These two cereals are therefore important food security crops in Niger. Production of both millet and sorghum has increased over past years. However, the increasing production is due to increasing crop area (land size). Figure 4.1 shows the relationship between production and land size for both millet and sorghum in Niger. There is a decline in yields on average in Niger for sorghum, but for millet, yield is relatively unchanged, as observed in figures 4.2 and 4.3. The decline in sorghum yield is partly due to an increase in maize yield in the area which is considered as a substitute to sorghum. This can be attributed to the increasing demand in maize in the country. This results might be attributed to the increasing population in the country with an average population growth rate of 3.5% per annum, with 80% of the population living in rural areas and more than half of the population being employed in the agriculture sector. The area is in the semi-arid agro-ecological zone with an average annual rainfall of 300-400 mm per year (FAOSTAT 2015).

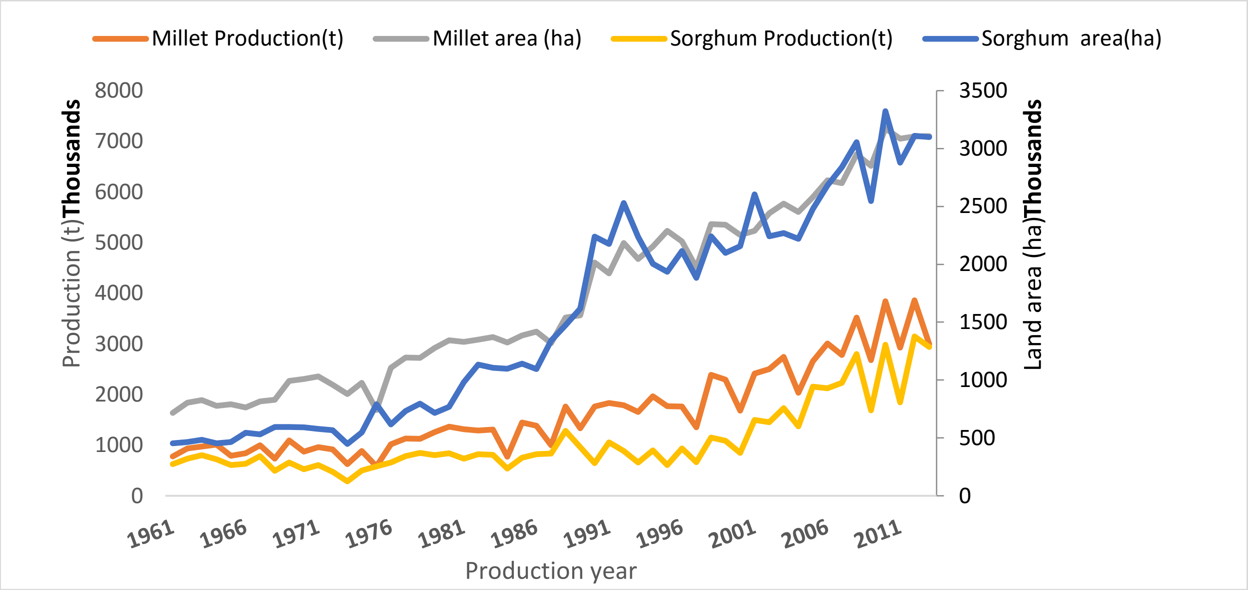

Figure 4.1 Trend of millet and sorghum production and land under cultivation in Niger (Source: FAOSTAT, 2015)

The effect of population growth, climate variability and increasing world food prices requires the use of technology derived from agricultural research to meet increasing food demand. Agriculture is key to the development of Niger as it contributes about 35% to the GDP (FAO 2015). Increasing productivity through efficient use of existing technology will contribute significantly to the development of the country.

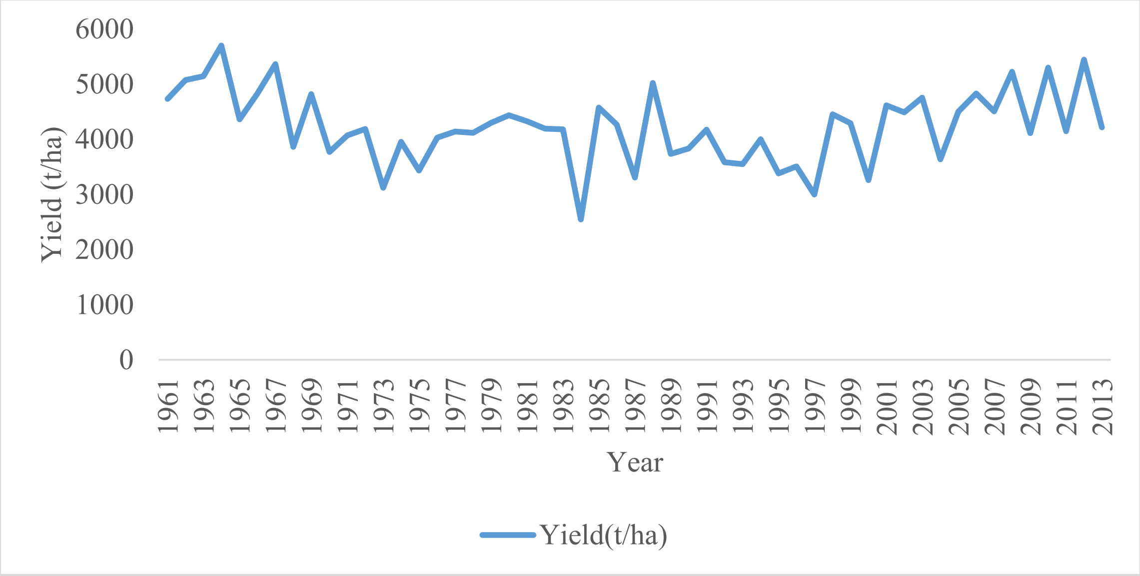

Figure 4.2 Niger millet yield (t/ha) (Source: FAOSTAT 2015)

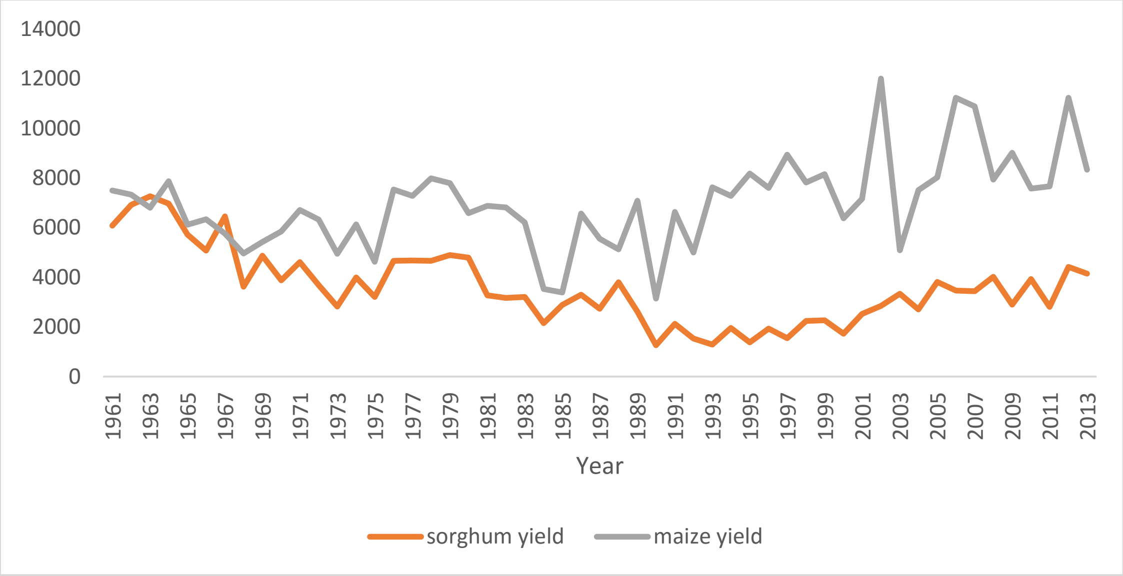

Figure 4.3 Niger sorghum and maize yield (t/ha) (Source: FAOSTAT 2015)

Farm households according to production theory, are either likely risk-averse or risk-neutral expected utility maximizers. These come from the households' objectives that can be constrained by technology, weather, equipment labor availability and finances to purchase some inputs. Farm production decisions are heterogeneous in nature due to the objectives of each farm household. The efficiency of households is likely to be heterogeneous due to heterogeneity in farm decision-making. It is therefore worth investigating the sources of farm household inefficiency and factors influencing them and the impact of soil and water conservation methods on inefficiencies evaluated.

4.3 The stochastic frontier model

Functional forms describing a production technology often has little or no effect on inefficiency estimates (see Baccouche and Kouki 2002; Cakir 2002; Coelli 1998). Coelli (1998), suggests the Cobb-Douglas functional form fits data well, but is very restrictive. The Cobb-Douglas function is used in this study to evaluate measures of inefficiency in millet and sorghum production by farm households.

To estimate farm household $i's$ inefficiency of millet or sorghum production, we follow the stochastic production frontier decomposition proposed by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Suppose household i produces output,q_{ij}, using a vector of k^{th} productive inputs, x_{ijk}, adjusted for technical inefficiency, $u_{ij} \geq 0$. The relationship can be represented as a stochastic frontier model as:

$$q_{ij} = f\left(x_{ijk}, \beta\right) + v_{ij} - u_{ij} \tag{1}$$

where v_{ij} is a two-sided error that accounts for measurement error and the random factors such as missing data and or external factors (e.g. climate and disease effect), that are not under the control of the farmer. The systematic error solves the problem of bounded range which is encountered during the estimation of the deterministic part of the model. The assumption is that,

$v_{ij} \sim N(0, \sigma_v^2)$ and u_{ij} is a one-sided error that accounts for inefficiency. Both v_{ij} and u_{ij} are statistically independent. The one-sided error can be assumed to take on using several distributions. Economically or statistically, there is no *a priori* choice for the distributional assumption of the one-sided error in general. It has been shown that mean efficiency measures can be sensitive to the alternative assumptions made about the distribution of the one-sided error (Baccouche and Kouki 2002). In examining the appropriateness of the assumptions of the various distributions of the one-sided error a Lagrange multiplier test was used (Lee 1981; Schmidt and Lin 1984).

The commonly used distributions in the empirical literature are the half-normal distribution (Aigner et al. 1977) and the normal exponential-normal distribution (Meeusen and van den Broeck 1977). These distributions are described as being less flexible. More flexible forms of the distributions were suggested, but have the additional challenges in the complexity of the estimation procedures. These flexible forms are the normal truncated-normal distributions (Stevenson 1980) and two-parameter gamma models (Green 1990). This study will test the sensitivity of technical efficiency measures to the distributional assumptions of the one-sided error using household level data which has not empirically been tested to the authors knowledge.

Maximizing the likelihood function of model 1, yields the estimators β and λ_{ij}, where β is a vector of coefficients on the k^{th}input vector x_{ijk} for crop j and $\lambda_{ij} = \frac{\sigma_u}{\sigma_v}$, which is defined as the total variation of output from the frontier attributed to technical inefficiency. If $\lambda_{ij} < 1$ the systematic error dominates the composite error and if, $\lambda_{ij} > 1$ then the one-sided error is the dominant source of the composite error. However, if $\lambda_{ij} \rightarrow 0$ then the model collapses to an OLS function without technical inefficiency while $\lambda_{ij} \rightarrow \infty$ implies the model has no noise. Following

Jondrow et al. (1982), the conditional expectation for household specific technical inefficiency based on the distributional assumptions are given as follows:

The half-normal in equation (2)

$$E\left(\mu_{ij}\middle|\epsilon_{ij}\right) = (\sqrt{\sigma_v^2 + \sigma_u^2}) \left\{\frac{f\left(\frac{\epsilon_{ij}\lambda}{\sigma}\right)}{\left[1 - F\left(\frac{\epsilon_{ij}\lambda}{\sigma}\right)\right]}\right\} - (\frac{\epsilon_{ij}\lambda}{\sqrt{\sigma_v^2 + \sigma_u^2}}) \tag{2}$$

where ϵ_{ij} is the composite error term.

Truncated-normal in equation (3)

$$E\left(u_{ij}\middle|\epsilon_{ij}\right) = -\left(\frac{\sigma\lambda}{1 + \lambda^2}\right)\left[\frac{\phi\left(\frac{\epsilon_{ij}\lambda}{\sigma} + \frac{\mu}{\sigma\lambda}\right)}{\Phi\left(-\frac{\epsilon_{ij}\lambda}{\sigma} - \frac{\mu}{\sigma\lambda}\right)} - \left(\frac{\epsilon_{ij}\lambda}{\sigma} + \frac{\mu}{\sigma\lambda}\right)\right] \tag{3}$$

where μ is the mode of the distribution to be estimated together with other distributional parameters, $\sigma^2 and\ \lambda$. The distribution becomes half-normal if $\mu = 0$.

The conditional mean for the exponential-normal distribution assumption of the one-sided error is given by equation (4);

$$E\left(u_{ij}\middle|\epsilon_{ij}\right) = \left\{\frac{\sigma_v\phi\left(\frac{\mu_{*ij}}{\sigma_v}\right)}{\Phi\left(\frac{\mu_{*ij}}{\sigma_v}\right)}\right\} + \mu_{*ij} \tag{4}$$

The conditional mean for the normal-gamma distributional assumption is given as follows;

$$E\left(u_{ij}\middle|\epsilon_{ij}\right) = \frac{q\left(P, \epsilon_{ij}\right)}{q\left(P - 1, \epsilon_{ij}\right)} \tag{5}$$

where $\mu_{*ij} = (\epsilon_{ij} + \theta\sigma_v^2)$ and θ is the exponential distribution parameter estimated, $\epsilon_{ij} = v_{ij} - u_{ij}$ is the composed error term, $f(.) = \phi$ is the standard normal distribution and $F(.) = \Phi$ is the cumulative distribution function.

4.4 Data and Empirical model

The study used data from the Living Standard Measurement Survey established by the Development Research Group of the World Bank. The survey was done in three parts: the agricultural survey, the household survey and the community survey. This study uses the agricultural survey and the household survey data collected in 2011-2012. A total of 4,074 households were randomly sampled and interviewed. However, a sub-sample of 518 households for millet and 754 households for sorghum farmers are used for the study. These sub-samples were obtained after carefully eliminating non-producers of sorghum and millet. Producers with zero outputs for millet and/or sorghum were eliminated from the data sets. The data covers the rural and urban areas, the agricultural producing zones and both agro-pastoral and pastoral zones from eight regions of Niger as shown in figure 4.4. Table 4.1 presents the variables, the definitions and units of measurement in the stochastic frontier analysis. The inputs used are allocable to the crop type for example millet or sorghum. The output quantity is the total output from the production of millet or sorghum, measured in kilograms. Land allocate to sorghum or millet production is measured in total acres. Labor variable measures the total number of days worked by both households and hired labor.

The two-step approach is used in this analysis. The first-step involves the use of the production frontier model in estimating the technical efficiency scores and the second-step involves the identification of factors influencing inefficiency in the production of sorghum and millet. While there are other functional forms to use in the estimation of the frontier functions, studies have shown that, functional forms have limited effect on efficiency score measurement empirically (Kopp and Smith 1980; Baccouche and Kouki 2002).

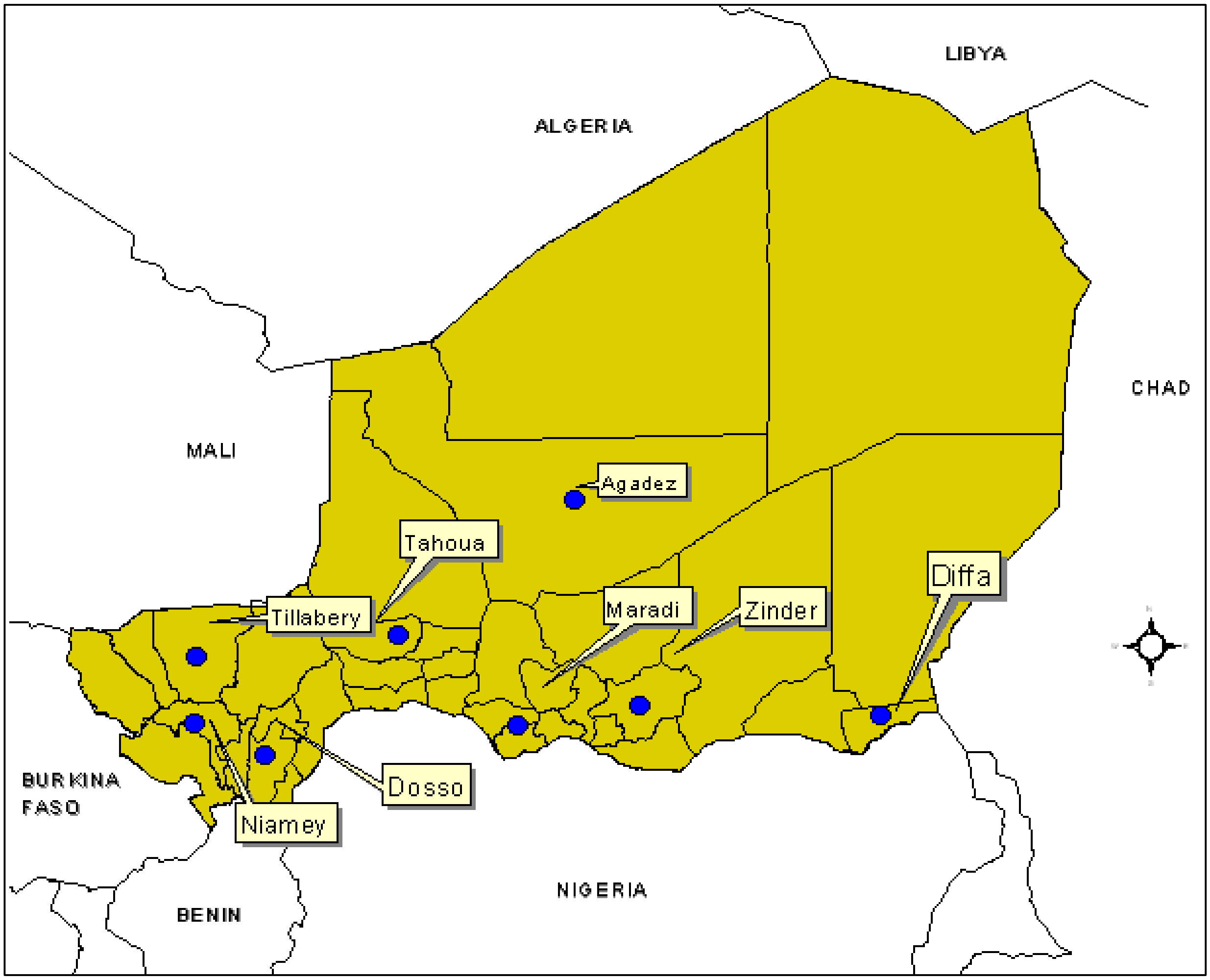

Figure 4.4 Map of Niger showing regional sites used in the study

Table 4.1 Variables, definitions and measure

Variables	*Definition*	*Measure*
Age	*Age of the household head*	*Continuous variable in years*
Education	*Educational level*[1] *of the household head*	*Categorical variable with 0=no education to 5=College education*
Gender	*Gender of the household head*	*Categorical variable with 1= Male and 2=Female.*
Household size	*Household size*	*Continuous in number of people*
Credit	*Access to credit*	*Dummy variable with 0 = no access and 1= access*
Urban	*Whether household is located in an urban of rural area*	*Categorical variable with 1=Urban and 2=Rural.*
Diffa	*Household is located in the Diffa region*	*Dummy variable with 1=located in the region and 0=otherwise*
Dosso	*Household is located in the Dosso region*	*Dummy variable with 1=located in the region and 0=otherwise*
Maradi	*Household is located in the Maradi regio*	*Dummy variable with 1=located in the region and 0=otherwise*
Tahoua	*Household is located in the Tahoua region*	*Dummy variable with 1=located in the region and 0=otherwise*
Zinder	*Household is located in the Zinder region*	*Dummy variable with 1=located in the region and 0=otherwise*
Niamey	*Household is located in the Niamey region*	*Dummy variable with 1=located in the region and 0=otherwise*
Tillaberi	*Household is located in the Tillaberi region*	*Dummy variable with 1=located in the region and 0=otherwise*
Distance	*Distance to farm from household*	*Continuous in number of minutes*
Land	*Household Farm size in acres*	*Continuous variable measured in total acres allotted for crop*
Production	*Total output of crop*	*Continuous variable in Kilograms*
Soil & water	*Adoption of soil & water conservation practices*	*Dummy variable with 0=non-adopter and 1=adopters*
Fertilizer	*Total chemical fertilizer used for crop*	*Continuous variable in Kilogram*
Manure	*Total farmyard manure and compost used*	*Continuous variable in Kilogram*
Other-inputs	*Total other inputs used like herbicides*	*Continuous variable in Kilogram*
Seed	*Total quantity of seed used*	*Continuous variable in Kilogram*
Total-labor	*Total labor use for crop*	*Continuous variable in number of days worked*
Agsector	*Whether the household is located in agric. Region*	*Categorical variable with 1= yes and 2=otherwise.*
Agpastoral	*Whether household is located in agro-pastoral region*	*Categorical variable with 1= yes and 2=otherwise*
Pastoral	*Whether household is located in the pastoral region*	*Categorical variable with 1= yes and 2=otherwise*
Non-agpast	*Whether household is located in neither of the 3 regions*	*Categorical variable with 1= yes and 2=otherwise*

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[1] Educational Levels are: (1) Pre-school (2) Primary (3) Junior secondary (4) Senior secondary/Technical and (5) Post-secondary.

This study uses the Cobb-Douglas functional form to estimate household sorghum and millet technical efficiency. The Cobb-Douglas production function is specified as follows:

$$lnq_{ij} = ln\alpha_j + \sum_i \alpha_{ij} lnx_{ijk} + \sum_k \beta_{ijl} Rgn_{ijl} + \epsilon_{ij} \qquad (6)$$

$$\forall\, i = 1, 2, 3, \dots, N \;and\; \forall\, j = \;Millet\; (N = 518)\; and\; sorghum\; (N = 754)$$

where q_{ij} is the production (output) in kilograms of sorghum or millet, x_{ijk} is the vector of k^{th} production inputs such as land area (acres), labor (days), seed quantity (kilograms), fertilizer quantity (kilograms), manure (kilograms) and other inputs like herbicides and other inputs., Rgn_{ijl} represents regional fixed effects and $\epsilon_{ij} = v_{ij} + u_{ij}$, where these have been defined as above. Estimating the Cobb-Douglas[2] production function for crop $j's$ production yields farm household $i's$ specific technical inefficiency u_{ij} for each of the four distributions; exponential, half normal, truncated normal and gamma-normal. We then estimate the household $i's$ specific technical efficiency as follows;

$$TE_{ij} = \exp[-E(u_{ij}|\epsilon_{ij})] \qquad (7)$$

The technical efficiency measures are segregated based on the various soil and water conservation practices adopted by farm households and compared. The estimation of the efficiency measures will provide little use for producers of sorghum and millet in Niger if the

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[2] *The Cobb-Douglas is used because it fits the data better than Translog, Quadratic and generalized Leontief models. All these models were used in estimating the frontier function. However, it was found that the efficiency estimates had no profound differences.*

factors influencing efficiencies are not identified. Hence, determination of the sources of inefficiency is necessary for policy design. This can be achieved by using specific exogenous variables that characterize the producers and their production environment using the second-step below.

In identifying sources of technical inefficiency of millet and sorghum production in Niger, we use the second-step, where a Tobit model is used to regress technical efficiency on household characteristics and regional fixed effects. The model to be estimated is as shown below;

$$TE_{ij} = \alpha_j + \sum_i \beta_{ij} z_{ij} + \delta_{ij} sc_{ij} + \sum_k \rho_{jl} Rgn_{jl} \tag{8}$$

where; TE_{ij} is the technical efficiency scores of $j's$ production for household i, $z'_{ij}s$ represent household characteristics such as age of household head (years), educational level, household size (number), $sc'_{ij}s$ represent the soil and water conservation practices adopted by households on their sorghum and millet fields and Rgn_{jl} is as defined above.

4.5 Empirical results for millet

Table 4.2 presents the summary statistics for millet data for both the aggregate data (total sample) and soil and water conservation disaggregated data. For the aggregate data, the results indicate an average of 6.4 acres (2.4 ha) was allocated by the households to millet cultivation with an average total output of 408kg. The area allocated for millet production confirms that the households can be considered small-holders. Total fertilizer use on millet was low with an average of 20kg. This represents the low input usage of small-holders in sub-Sahara Africa (FAO 2015). Farm households use farm yard manure to complement the fertilizer usage with an average use of 11kg. Average total labor days was 59 and average total seed quantity used was 6kg. The results indicate that, the majority of the households sampled live in rural areas. About 84% of the total sampled households are headed by males with an average age of 43 years. The household heads have low levels of formal education and have an average household size of 7 persons per household.

On the disaggregated data, adopters of soil and water conservations methods allocated an average of 9 acres (3.6 ha) and non-adopters of the technology allocated an average of 6 acres (2.4 ha) to millet cultivation. The average total output of millet was estimated to be 1100kg (about 1 ton) and 284kg respectively for adopters and non-adopters of soil and water conservation methods. Average of total fertilizer use on millet was found to be 21kg and 20kg respectively for adopters and non-adopters of the technology. The average age of the head of household was estimated to be 46 years for adopters and 43 years for non-adopters of the technology. The mean age difference was highly statistically significant. The implication is that, adopters are relatively older on average compared to non-adopters. The average total labor allocated was higher for adopters, of soil and water conservation methods compared to the non-adopters, which may reflect the labor intensity of the technologies.

4.5.1 The maximum likelihood estimates of Cobb-Douglas stochastic model for Millet

The parameters of the maximum likelihood estimates of the Cobb-Douglas stochastic frontier model is shown in Table A.1 in Appendix A. The log likelihood functions for the exponential-normal, half-normal, truncated-normal and gamma-normal distributional assumptions of the one-sided error do not vary much from each other. The half-normal distributional assumption model has a slightly higher log likelihood value than the rest. The results indicate that the production function is monotonically increasing in all the inputs except manure for the aggregated data and for all the distributional assumptions of the one-sided error.

However, only seed and total labor have statistically significant effects on output. The model estimates are robust to the change in the distributional assumption of the one-sided error. The robustness in the estimates can also be observed in the models for the adopters and non-adopters of soil and water conservation methods

Results on the disaggregated data for adopters of soil and water conservation indicate the log likelihood functions for the various distributional assumptions on the one-sided error do not vary from each other except that of the half-normal distribution which is slightly higher than the rest. The result indicate monotonic increasing functions in inputs except for fertilizer, which is also found not to be significant. Also, in the half-normal model, the function decreases in manure which is not significant. Total seed quantity is found to be statistically significant.

On non-adopters of conservation methods, the log likelihood function of the truncated-normal distribution is higher than that of the other distributional assumptions. The results indicate that, with the exponential-normal distribution assumption, we observe a decreasing output with respect to fertilizer. It was observed that while the function is an increasing function to fertilizer in the half, truncated and gamma distributions, it decreases in land. These results are not statistically significant. The results show that, seed and labor are statistically significant in all the distributional assumptions of the one-sided error.

The variance parameters of the models are shown in table A.2 in appendix A. The result for the aggregate data show that the residual variation in the models are due to inefficiency effects of the one-sided error (u_i) for the half-normal and truncated-normal models. The exponential-normal and normal-gamma models show that the measurement error $(v_i)$is the dominant source of the composite error. These results show the use of the stochastic frontier model is justified for the aggregate data. The results indicate that for both adopters and non-adopters of soil and water conservation methods, the inefficiency effect is the dominant source of the composite error. Indicating that, the one-sided error has the greatest impact.

Table 4.2 Summary statistics for millet

Variable	Soil and water conservation Users (N=102)				Non-users of Soil and water conservation (N=416)				Total sample (N=518)			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Output	1100.00	1586.50	50.00	15000.00	283.60	143.80	3.00	591.00	408.13	791.21	3.00	15000.00[3]
Manure	11.40	16.50	1.41	151.00	10.66	12.56	1.20	151.00	10.80	13.40	1.20	151.00
Fertilizer	20.90	18.84	11.30	165.30	19.90	16.33	11.30	165.30	20.10	16.84	11.30	165.30
Land	9.30	21.55	1.00	214.00	5.70	5.80	1.00	83.63	6.40	10.93	1.00	214.00
Total labor	68.80	55.20	3.00	263.00	56.15	55.41	2.00	284.00	58.63	55.53	2.00	284.00
Seed	9.02	16.50	1.25	100.25	5.20	9.90	1.25	100.25	5.93	11.64	1.25	100.25
Urban	1.90	0.30	1.00	2.00	1.90	0.32	1.00	2.00	1.89	0.32	1.00	2.00
Household size	8.00	6.00	1.00	30.00	7.00	3.00	1.00	30.00	7.00	4.00	1.00	30.00
Age	46.00	13.00	21.00	81.00	43.00	12.00	18.00	81.00	43.00	12.00	18.00	81.00
Gender	1.00	0.22	1.00	2.00	1.00	0.24	1.00	2.00	1.00	0.23	1.00	2.00
Educational level	1.25	0.67	1.00	5.00	1.27	0.62	1.00	5.00	1.27	0.63	1.00	5.00
Diffa	0.18	0.38	0.00	1.00	0.06	0.23	0.00	1.00	0.08	0.27	0.00	1.00
Dosso	0.13	0.34	0.00	1.00	0.26	0.44	0.00	1.00	0.23	0.42	0.00	1.00
Maradi	0.06	0.23	0.00	1.00	0.30	0.46	0.00	1.00	0.25	0.44	0.00	1.00
Tahoua	0.14	0.35	0.00	1.00	0.10	0.29	0.00	1.00	0.10	0.31	0.00	1.00
Tillaberi	0.16	0.37	0.00	1.00	0.09	0.28	0.00	1.00	0.10	0.30	0.00	1.00
Zinder	0.29	0.46	0.00	1.00	0.19	0.40	0.00	1.00	0.21	0.41	0.00	1.00
Niamey	0.05	0.22	0.00	1.00	0.00	0.00	0.00	0.00	0.01	0.10	0.00	1.00
Agsector	1.56	0.50	1.00	2.00	1.50	0.50	1.00	2.00	1.52	0.50	1.00	2.00
Agpastoral	1.60	0.49	1.00	2.00	1.65	0.48	1.00	2.00	1.65	0.48	1.00	2.00
Pastoral	1.94	0.23	1.00	2.00	1.95	0.21	1.00	2.00	1.95	0.21	1.00	2.00
Nonagpastoral	1.90	0.30	1.00	2.00	1.90	0.32	1.00	2.00	1.90	0.31	1.00	2.00

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[3] *The total output level of 15,000kg is translated to 468kg/acre in yield.*

4.5.2 Technical efficiency estimates for millet

Table 4.3 below presents the summary statistics of the technical efficiency (TE) scores of farm households in millet production based on the various distributional assumptions of the one-sided error and for both the aggregate data and soil and water conservation disaggregated data. On the aggregate data, the mean efficiency scores for the exponential-normal, truncated-normal, half-normal and normal-gamma distributions are 63%, 63%, 50% and 69% with respective ranges of 1% to 87%, 2% to 87%, 4% to 85% and 1% to 93%. The results show that for all the distributional assumptions, producers are inefficient. Millet output can potentially be increased from 37%, 37%, 50% and 31% respectively for exponential-normal, truncated-normal, half-normal and the normal-gamma models, without changing the current input mix. The results indicate that, the gamma-normal distribution gave the highest mean TE score of 69% with the half-normal distribution given the lowest mean TE score of 50%. The exponential-normal and truncated-normal distributions gave equivalent mean and maximum TE scores. The results show that existing technologies can be used to increase millet production.

The result for adopters of soil and water conservation methods show mean TE scores of 61%, 61%, 52% and 66% respectively for the exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions of the one-sided error. The results indicate that adopters of soil and water conservation methods are inefficient with a potential for the average household to increase output in the range of 34% to 48% to be on the frontier without changing the existing technology. The half-normal distributional assumption recorded the lowest mean TE scores of 52% and the normal-gamma distributions gave the highest mean TE score of 66%. The mean TE scores of the truncated normal and the exponential-normal distributions are equivalent.

The results indicate that, even the most efficient household among the adopters of soil and water conservation need to improve the use of existing technologies.

Table 4.3 Summary statistics of efficiency scores and mean differences for millet

Sample	*One-sided error Assumption*	*Mean*	*SD*	*Minimum*	*Maximum*
Total (N=518)	*Exponential-normal*	*0.63*	*0.15*	*0.01*	*0.87*
	Truncated-normal	*0.63*	*0.15*	*0.02*	*0.87*
	Half-normal	*0.50*	*0.16*	*0.04*	*0.85*
	Normal-gamma	*0.69*	*0.15*	*0.01*	*0.93*

Mean difference between adopters and non-adopters of Soil & Water methods based on the aggregate frontier	*Exponential-normal*	*0.14****
	Truncated-normal	*0.14****
	Half-normal	*0.14****
	Normal-gamma	*0.19****

Adopters of Soil & Water (N=102)	*Exponential-normal*	*0.61*	*0.20*	*0.02*	*0.90*
	Truncated-normal	*0.61*	*0.20*	*0.08*	*0.90*
	Half-normal	*0.52*	*0.18*	*0.09*	*0.86*
	Normal-gamma	*0.66*	*0.21*	*0.02*	*0.93*

Non-adopters of Soil & Water (N=416)	*Exponential-normal*	*0.60*	*0.21*	*0.01*	*0.88*
	Truncated-normal	*0.52*	*0.20*	*0.31*	*0.92*
	Half-normal	*0.53*	*0.19*	*0.36*	*0.92*
	Normal-gamma	*0.35*	*0.20*	*0.00*	*0.87*

Mean difference between adopters and non-adopters of S & W based on separate frontiers (S&W disaggregated data)	*Exponential-normal*	*0.01*
	Truncated-normal	*0.10***
	Half-normal	*-0.01*
	Normal-gamma	*0.31****

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively*

The results of mean technical efficiency for non-adopters of soil and water conservation methods are also shown in Table 4.3 below. The results indicate the mean technical efficiency scores are 60%, 52%, 53% and 35% respectively for exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumption of the one-sided error. The results also indicate that non-adopters of soil and water conservation methods are inefficient. This result is not consistent with the result obtained by both the aggregate data and that by adopters of soil and water conservation methods, where the normal-gamma gave higher mean technical efficiency and the half-normal gave the lowest mean technical efficiency. A cost-saving of 32%, 44%, 42% and 59% could be realized by the average household in the sample if the millet producing household is to achieve the TE level of the most efficient producer.

The results, based on separate frontier estimates for adopters and non-adopters is shown in the lower part of table 4.3. This was done using the technical efficiency scores obtained by the four distributional assumptions on the one-sided error since we do not have an *a priori* justification for one of them. The result indicate that, except for the half-normal distributional assumption of the one-sided error, all the other models gave positive mean difference in technical efficiency scores obtained from estimating separate frontiers for adopters and non-adopters of soil and water conservation methods. The truncated-normal and normal-gamma distribution assumptions were however significant. The mean TE scores for the aggregate data was segregated into adopters and non-adopters after estimating a common frontier model. The results is shown in the second row of table 4.3 above. The results show significant positive mean TE scores between adopters and non-adopters of soil and water conservation methods. This shows consistency in other findings that, adopters have higher TE scores compared to non-adopters, as in Solis et al. (2007). The results showed consistency in the mean difference of TE scores for the distributional assumption except that of the normal-gamma distribution which is a little higher.

Based on the TE scores of the aggregate and soil and water conservation dis-aggregated data, the TE scores differ for the various distributional assumptions of the one-sided error. Hence we can say that the TE scores vary with the choice of distributional assumption of the one-sided error. This was statistically tested and there was significant mean differences in the mean TE scores obtained from the various distributional assumptions of the one-sided error. Hence with the millet data, the results supports the conclusion of Baccouche and Kouki (2002) that technical efficiency measures are sensitive to the assumption of the one-sided error distribution.

Without any *a priori* justification for the distributional assumptions of the one-sided error, and using the TE scores from the aggregate data, the paper used the Spearman's rank correlation to evaluate the dependence on the technical efficiency scores estimated from the different distributional assumptions (Table 4.4). The results indicate very high correlation coefficient among the technical efficiency scores from the different distributional assumptions of the one-sided error, which ranges from 0.97 to 1.00. This indicates a very high consistency in the technical efficiency scores between the models of the different assumptions on the one-sided error. This is consistent with the findings by Cullinal et al. (2006) when they evaluated the technical efficiency scores of different ports.

Table 4.4 Spearman's rank correlation matrix of TE scores for millet

	TE[4] E-norm	*TE H-norm*	*TE T-norm*	*TE G-norm*
TE E-norm	*1.00*			
TE H-norm	*0.98****	*1.00*		
TE T-norm	*1.00****	*0.98****	*1.00*	
TE G-norm	*0.99****	*0.97****	*0.99****	*1.00*

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively*

4.5.3 Sources of inefficiency in millet production

In identifying the sources of inefficiency in millet production, the Tobit model specified as in equation (8) was estimated. The paper used the aggregate data and the technical efficiencies obtained from that for the Tobit regression model. The paper also used all the models with the four distributional assumptions on the one-sided error which also serves as an evaluation

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[4] *Technical efficiency scores*

on the sensitivity of the technical efficiency scores. The results as in table 4.5 show that, male headed households are less technically efficient compared to their female counterparts even thought it was not found to be statistically significant for all four models. The results showed a mixed effect of head of household age on technical efficiency which is not statistically significant. The result found age of household heads to be decreasing with increasing technical efficiency measure for exponential-normal and truncated-normal models whilst the half-normal and normal-gamma models showed age to be increasing with increasing technical efficiency scores. Empirical findings by Binam et al. (2003), support the assertion that age has positive impact on technical efficiency whilst Ajibefun (2008) found age to have a negative impact on efficiency. Household size is found to have a positive but insignificant effect on technical efficiency scores.

The results show educational levels to have positive and significant effect on households' technical efficiency scores. This results is consistent with other findings (Sherlund et al. 2002; Solís et al. 2007). This was expected as education increases the households' level of awareness and adoption of innovative technologies in agriculture. The result also shows that households located in rural areas have a positive and significant effect on technical efficiency scores for all the distributional assumptions of the one-sided error. This effect of the rural location is reasonable because households located in these areas are mostly small land holders and hence, they are better able to manage their farms productively

Households that adopted soil and water conservation methods have a positive and significant effect on technical efficiency. The findings indicate that, if a household adopts soil and water conservation methods, the TE scores obtained using the exponential-normal, half-normal truncated-normal and normal-gamma distributions are likely to increase by about 17%, 21%, 17% and 16% respectively. The differences in the marginal effects of the soil and water conservation can be attributed to the sensitivity in the TE scores obtained from the various distributional assumptions of the one-sided error. This supports the finding above that households that adopted soil and water conservation methods have higher technical efficiency levels compared to non-adopters. The results is also corroborated by the output levels in the summary statistics with higher maximum total outputs from households who use the technology. This can be explained by using the dry nature of the country with minimal rainfall and hence, conserving water and controlling for erosion will enhance farm productivity. This results is consistent with the findings by Sherlund et al., (2002), that controlling for environmental conditions increases farm technical efficiency scores in based production systems.

The paper controlled for regional fixed effects on the technical efficiency measures since the regional location might have an impact on the households input use in millet production. The regional location variable is positive and significant for the exponential-normal, truncated-normal and normal-gamma assumptions models, except the Niamey region which is not significant. This is because it is the region hosting the capital, which is more urban compared to the other regions. However, the half-normal model shows that, the regional fixed effects have negative and insignificant impacts on technical efficiency. The distance of the household to the millet farms is found to have a negative impact on technical efficiency. This is significant for the half-normal model but not for the other models.

Table 4.5 Tobit estimates of sources of TE scores in millet production

Variables	*E-normal* *Coef* *(S.E.)*	*H-normal* *Coef* *(S.E.)*	*T-normal* *Coef* *(S.E.)*	*G-normal* *Coef* *(S.E.)*
Constant	*0.326**** *(0.112)*	*0.408**** *(0.115)*	*0.324**** *(0.112)*	*0.385**** *(0.116)*
Urban	*0.046*** *(0.021)*	*0.051*** *(0.021)*	*0.046*** *(0.020)*	*0.047*** *(0.021)*
Household size	*0.001* *(0.002)*	*0.001* *(0.002)*	*0.001* *(0.002)*	*0.001* *(0.002)*
Age	*-0.001* *(0.001)*	*0.000* *(0.001)*	*-0.001* *(0.001)*	*0.001* *(0.001)*
Educational level	*0.018** *(0.010)*	*0.019** *(0.011)*	*0.018** *(0.010)*	*0.018** *(0.011)*
Gender	*-0.024* *(0.026)*	*-0.036* *(0.027)*	*-0.024* *(0.026)*	*-0.026* *(0.027)*
Dosso	*0.231*** *(0.094)*	*0.022* *(0.096)*	*0.232*** *(0.094)*	*0.226*** *(0.097)*
Maradi	*0.237*** *(0.094)*	*0.029* *(0.096)*	*0.239*** *(0.094)*	*0.229*** *(0.097)*
Tahoua	*0.190*** *(0.095)*	*-0.030* *(0.098)*	*0.192*** *(0.095)*	*0.186** *(0.098)*
Tillaberi	*0.189*** *(0.095)*	*-0.022* *(0.097)*	*0.191*** *(0.095)*	*0.184** *(0.098)*
Zinder	*0.191*** *(0.094)*	*-0.030* *(0.097)*	*0.192*** *(0.094)*	*0.195*** *(0.097)*
Niamey	*0.077* *(0.113)*	*-0.125* *(0.117)*	*0.078* *(0.113)*	*0.078* *(0.117)*
Diffa	*0.169** *(0.095)*	*-0.061* *(0.098)*	*0.171** *(0.095)*	*0.170** *(0.099)*
Distance	*-0.008* *(0.005)*	*-0.009** *(0.005)*	*-0.008* *(0.005)*	*-0.008* *(0.005)*
Soil & water conservation.	*0.165**** *(0.016)*	*0.214**** *(0.016)*	*0.166**** *(0.016)*	*0.157**** *(0.016)*
Log likelihood	*313.522*	*299.445*	*313.816*	*297.854*

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively*

The percentage distribution of households in the various technical efficiency score ranges is shown in Table 4.6 below. The results of the distributions shed light on the differences in TE scores between adopters and non-adopters of soil and water conservation methods. The results show that, regardless of the distributional assumptions, a relatively high percentage of the households have TE score ≥ 61% for adopters compared to non-adopters. The TE scores obtained by normal-gamma distributional assumption show 3% of households are closer to the f rontier for adopters compared to none for non-adopters. There is however a variation in the percentage distribution of the households for both adopters and non-adopters of soil and water conservations methods and for the different distributional assumptions of the one-sided error. This confirms the findings that, the technical efficiency scores are sensitive to distributional assumptions of the one-sided error. Hence, theoretical consideration are important in selecting the distributional assumption needed.

Table 4.6 Percentage (%) distribution of households TE in millet production

	Adopters of S & W (N=102)				*Non-adopters of S & W (N=416)*			
TE range	*Exponential*	*Gamma*	*Truncated*	*Half*	*Exponential*	*Gamma*	*Truncated*	*Half*
≥ 91	*0*	*3*	*0*	*0*	*0*	*0*	*1*	*1*
81-90	*10*	*16*	*10*	*4*	*14*	*2*	*12*	*10*
71-80	*25*	*38*	*25*	*5*	*26*	*4*	*12*	*11*
61-70	*28*	*21*	*28*	*24*	*14*	*10*	*12*	*12*
51-60	*17*	*4*	*17*	*26*	*14*	*10*	*9*	*8*
41-50	*4*	*3*	*4*	*22*	*11*	*15*	*10*	*11*
31-40	*5*	*5*	*5*	*4*	*10*	*12*	*45*	*47*
21-30	*4*	*4*	*4*	*8*	*5*	*22*	*0*	*0*
11-20	*5*	*4*	*5*	*5*	*3*	*22*	*0*	*0*
≤ 10	*3*	*3*	*3*	*3*	*2*	*8*	*0*	*0*

4.6 Empirical results for sorghum

The summary statistics for households in sorghum production is presented in table 4.7 below. The results present summary statistics for soil and water conservation method disaggregated data and the aggregate data. For the aggregate data, the average total land allocated to sorghum production was estimated at 7 acres (2.8 ha) with output ranging between 2kg to 1640 kg. The allocated area for Sorghum production also confirms that, the households in the sample are small-holders. Total fertilizer use were extremely low with an average of 2kg. The fertilizer usage was complemented by the use of insignificant total mean quantity of manure. The data indicate about 85% of the households are headed by males with an average age of 45 years. About 88% of the households considered themselves as rural dwellers.

On soil and water conservation method disaggregated data, adopters of the technology allocated an average of 10 acres (4ha) of total land for sorghum production, while non-adopters of the technology allocated about 2.4 ha (6 acres). The output for adopters ranges between 12kg and 1640kg, with an average of 311kg, while that of the non-adopters ranges between 2kg and 196kg with an average of 46kg. This indicates high output for adopters compared to non-adopters on average. Among the sample of adopters of soil and water conservation methods, about 89% reside in the rural areas, while about 87% of the non-adopters resided in rural areas. About 85% and 82% of the households are headed by males for non-adopters and adopters, respectively. The average age of household head is estimated at 45 years for both adopters and non-adopters. Household heads in the samples have on average very low educational levels.

Table 4.7 Summary statistics for sorghum

Variable	*Soil and water conservation Users (N=102)*				*Non-users of Soil and water conservation (N=652)*				*Total sample (N=754)*			
	Mean	*SD*	*Min.*	*Max.*	*Mean*	*SD*	*Min.*	*Max.*	*Mean*	*SD*	*Min.*	*Max.*
Output	*311.30*	*260.85*	*12.00*	*1640.00*	*46.46*	*45.51*	*2.00*	*196.00*	*82.29*	*138.32*	*2.00*	*1640.00*
Manure	*16.28*	*24.04*	*6.00*	*156.00*	*11.52*	*11.16*	*1.50*	*106.00*	*12.17*	*13.70*	*6.00*	*156.00*
Fertilizer	*1.86*	*1.21*	*1.50*	*9.50*	*1.98*	*2.26*	*1.50*	*31.50*	*1.96*	*2.15*	*1.50*	*31.50*
Total labor	*63.07*	*50.63*	*1.00*	*240.00*	*51.35*	*62.55*	*1.80*	*184.00*	*53.00*	*61.00*	*1.00*	*240.00*
Seed	*3.37*	*5.78*	*1.60*	*51.60*	*2.00*	*1.60*	*1.60*	*21.60*	*2.20*	*2.63*	*1.60*	*51.60*
Urban	*1.89*	*0.31*	*1.00*	*2.00*	*1.87*	*0.33*	*1.00*	*2.00*	*1.90*	*0.33*	*1.00*	*2.00*
Household size	*7.00*	*3.00*	*1.00*	*17.00*	*7.00*	*3.40*	*1.00*	*30.00*	*7.00*	*3.00*	*1.00*	*30.00*
Age	*45.00*	*13.00*	*22.00*	*80.00*	*45.00*	*13.00*	*23.00*	*85.00*	*45.00*	*13.00*	*22.00*	*85.00*
Gender	*1.00*	*0.27*	*1.00*	*2.00*	*1.00*	*0.27*	*1.00*	*2.00*	*1.00*	*0.27*	*1.00*	*2.00*
Educational level	*1.23*	*0.59*	*1.00*	*5.00*	*1.24*	*0.56*	*1.00*	*5.00*	*1.23*	*0.57*	*1.00*	*5.00*
Diffa	*0.11*	*0.31*	*0.00*	*1.00*	*0.07*	*0.25*	*0.00*	*1.00*	*0.07*	*0.26*	*0.00*	*1.00*
Dosso	*0.12*	*0.32*	*0.00*	*1.00*	*0.11*	*0.31*	*0.00*	*1.00*	*0.11*	*0.32*	*0.00*	*1.00*
Maradi	*0.03*	*0.17*	*0.00*	*1.00*	*0.31*	*0.46*	*0.00*	*1.00*	*0.28*	*0.45*	*0.00*	*1.00*
Tahoua	*0.31*	*0.47*	*0.00*	*1.00*	*0.16*	*0.37*	*0.00*	*1.00*	*0.18*	*0.39*	*0.00*	*1.00*
Tillaberi	*0.10*	*0.30*	*0.00*	*1.00*	*0.06*	*0.24*	*0.00*	*1.00*	*0.07*	*0.25*	*0.00*	*1.00*
Zinder	*0.32*	*0.47*	*0.00*	*1.00*	*0.28*	*0.45*	*0.00*	*1.00*	*0.29*	*0.45*	*0.00*	*1.00*
Naimey	*0.01*	*0.10*	*0.00*	*1.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.06*	*0.00*	*1.00*
Agsector	*1.61*	*0.49*	*1.00*	*2.00*	*1.54*	*0.50*	*1.00*	*2.00*	*1.55*	*0.50*	*1.00*	*2.00*
Agpastoral	*1.60*	*0.49*	*1.00*	*2.00*	*1.63*	*0.48*	*1.00*	*2.00*	*1.62*	*0.49*	*1.00*	*2.00*
Pastoral	*1.90*	*0.30*	*1.00*	*2.00*	*1.96*	*0.21*	*1.00*	*2.00*	*1.95*	*0.22*	*1.00*	*2.00*
Nonagpastoral	*1.90*	*0.31*	*1.00*	*2.00*	*1.90*	*0.33*	*1.00*	*2.00*	*1.90*	*0.32*	*1.00*	*2.00*

4.6.1 The maximum likelihood estimates of Cobb-Douglas model for sorghum

The parameter estimates of the maximum likelihood estimation of the Cobb-Douglas stochastic frontier model for sorghum is shown in Table A.4 in Appendix A. The log likelihood functions for the different distributional assumptions of the one-sided error are similar. The production function is monotonically increasing in all production inputs except fertilizer for the aggregate data and for all the distributional assumptions of the one-sided error. The results show total seed quantity and total land allocated are significant for all the distributional assumptions of the one-sided error. Total labor days is found to be significant at the 0.05 level for exponential-normal and half-normal assumptions models, but not for the other two distributional assumptions of the inefficiency part of the error. Except the Diffa region, the regional fixed effects have a decreasing effect on the function. The Maradi region is significant for the exponential-normal and the normal-gamma distributions models.

The results on the variance parameters of the model is shown in table A.3 in Appendix A. The result show that, for the aggregate data, the residual variation in the models are partly due to inefficiency effects (u_{ij}) for the half-normal, truncated-normal and normal-gamma models even though the dominant source of the variation in the composite error is caused by the systemic error(v_{ij}) as observed in the λ parameter. The use of the stochastic production function in the estimation is therefore justified. For the soil and water disaggregated data, the results indicate the one-sided error dominates the source of variation in the composite error for all the distributional assumptions of the one-sided error for adopters of soil and water conservation methods. The results is however mixed for the non-adopters as the one-sided error dominates the source of variation in the half-normal and truncated-normal distributional assumptions and the systematic dominates for the exponential-normal and normal-gamma distributional assumptions. Hence, justification for the use of the stochastic frontier model.

4.6.2 Technical efficiency (TE) estimates

The summary statistics of the technical efficiency scores for the various distributional assumptions of the one-sided error is shown in table 4.8 below. For the aggregate data in the upper part of the table, the technical efficiency ranges are 86% to 92%, 3% to 92%, 56% to 81% and 15% to 82% with mean technical efficiency scores of 90%, 18%, 71% and 80% respectively for the exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions. The technical efficiency measures on average are consistent with that of African agriculture (see Binam et al. 2004; Sherlund et al. 2001). The results indicate that, an average household is relatively inefficient. Hence, there is still a potential for households to increase their output to get closer to the most efficient counterpart. Relatively, an average household can potentially increase its output levels in the range of 10% to 88% with the use of existing technology based on the distributional assumptions of the one-sided error.

The findings show marked differences in the technical efficiency scores based on the distributional assumptions of the one-sided error. This is consistent with other findings that efficiency scores are sensitive to the assumptions of the one-sided error (see Baccouche and Kouki 2002). The results on the efficiency show that, available resources and or technologies are not being utilized efficiently and there is the need to utilize the resources productively. Hence, households in the sorghum producing areas can improve their productivity through the use of existing technologies.

TE scores for adopters and non-adopters of soil and water conservation were estimated. The results are shown in Table 4.8 below and indicate that the range of technical efficiency for adopters of soil and water conservation are 4% to 87%, 5% to 87%, 6% to 84% and 4% to 92% with averages of 56%, 56%, 47% and 63% respectively for exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions. For non-adopters, the ranges are 15% to 81%, 33% to 92%, 5% to 78% and 15% to 83% with averages of 63%, 39%, 42% and 63% respectively for exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions. These estimates were obtained from estimating separate stochastic frontier models for the adopters and non-adopters. The results indicate that, the adopters of soil and water conservation methods have relatively higher maximum technical efficiency scores compared to non-adopters. The results indicate that both adopters and non-adopters of soil and water conservation methods are inefficient in their current input use. The implication is that, higher output can potentially be achieved with the existing input mix.

Mean differences were evaluated using two-tailed t-tests and the results indicate positive and significant mean difference between adopters and non-adopters of soil and water conservation methods for the truncated-normal and half-normal distributional assumptions while that of the exponential-normal indicate a negative but significant mean difference. We can arguably attribute this differences to sample size bias and different model assumptions but model estimates were obtained independently. The indication of the findings is that, adopters of soil and water conservation methods are more technically efficient than non-adopters of the technology. This can be attributed to the fact that conserving soil and water in a dry area such as Niger improves plant water use efficiency which can be translated into output. This is also consistent with the finding that technical efficiency scores increase if environmental factors are controlled for (Sherlund et al. 2001).

Table 4.8 Summary statistics of efficiency scores and mean differences for sorghum

Sample	*One-sided error Assumption*	*Mean*	*SD*	*Minimum*	*Maximum*
Total (N=754)	*Exponential-normal*	*0.90*	*0.01*	*0.86*	*0.92*
	Truncated-normal	*0.18*	*0.10*	*0.03*	*0.92*
	Half-normal	*0.71*	*0.04*	*0.56*	*0.81*
	Normal-gamma	*0.80*	*0.04*	*0.15*	*0.82*

Mean difference between adopters and non-adopters of S & W methods based on the aggregate frontier	*Exponential-normal*	*0.01****
	Truncated-normal	*0.17****
	Half-normal	*0.05****
	Normal-gamma	*0.05****

Sample	*One-sided error Assumption*	*Mean*	*SD*	*Minimum*	*Maximum*
Adopters of S & W (N=102)	*Exponential-normal*	*0.56*	*0.21*	*0.04*	*0.87*
	Truncated-normal	*0.56*	*0.21*	*0.05*	*0.87*
	Half-normal	*0.47*	*0.18*	*0.06*	*0.84*
	Normal-gamma	*0.63*	*0.23*	*0.04*	*0.92*
Non-adopters of S & W (N=652)	*Exponential-normal*	*0.63*	*0.13*	*0.15*	*0.81*
	Truncated-normal	*0.39*	*0.13*	*0.33*	*0.92*
	Half-normal	*0.42*	*0.18*	*0.05*	*0.78*
	Normal-gamma	*0.63*	*0.13*	*0.15*	*0.83*

Mean difference between adopters and non-adopters of S & W methods based on the separate frontiers on the tech.	*Exponential-normal*	*-0.07****
	Truncated-normal	*0.17****
	Half-normal	*0.05***
	Normal-gamma	*0.00*

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively*

Similar tests were done after estimating the stochastic frontier model of the aggregate data and obtaining the TE score for adopters and non-adopters of the technology. The results is shown in the second row of table 4.8 above. The results show positive and significant mean differences between adopters and non-adopters of the technology for the distributional assumptions. The result is consistent with the conclusion based on estimating separate frontiers from the disaggregated data. Inconsistencies can be observed on the mean differences for the various distributional assumptions of the one-sided error. Significant among them is between exponential-normal (0.01) and truncated-normal distributions (0.17). Consistent mean differences are observed between the half-normal and normal-gamma distributions. The inconsistencies can be attributed to the different distributional assumptions of the one-sided error term.

Based on the four distributional assumptions of the one-sided error, the technical efficiency scores reported vary from each other. A student t-test showed evidence of statistically significant (0.01 level) differences in the mean technical efficiency scores between the distributional assumptions of the one-sided error. However, the Spearman's correlation coefficient (see table 4.9) between the technical efficiency scores of the distributional assumptions range from 0.84 to 0.99 and are significantly different from zero. This indicates that there is a high level of consistency between the technical efficiency estimates from the different distributional assumptions despite the sensitivity in the TE scores.

Table 4.9 Spearman's' rank correlation matrix of TE scores for sorghum

	TE e-normal	*TE h-normal*	*TE t-normal*	*TE g-normal*
TE e-normal	*1.00*			
TE h-normal	*0.84****	*1.00*		
TE t-normal	*0.95****	*0.88****	*1.00*	
TE g-normal	*0.95****	*0.88****	*0.99****	*1.00*

4.5.3 Sources of inefficiency in sorghum production

The Tobit model estimates of factors influencing household technical efficiency scores obtained from the four distributional assumptions of the one-sided error is shown in Table 4.10. The results show size of household, age of head of household, educational level and gender of the head of the household are negatively correlated with technical efficiency scores. The size of household and educational level of household head are statistically significant. The implication is that smaller households are less inefficient compared to the larger ones in the production of sorghum. The smaller households may be able to productively manage their small size effectively compared to their larger counterparts. The level of education of the head of the household is found to have a significant negative impact on technical efficiency of sorghum. This unexpected findings is consistent with findings by Binam et al. (2003).

Adoption of soil and water conservation methods have positive and significant effect on technical efficiency score across the distributional assumptions. The indication is that, the adoption of soil and water conservation technology is likely to increase households TE score. The effect had consistent signs but sharply contrasting marginal effects that can be attributed to the highly sensitive TE scores obtained from the various distributional assumptions of the one-sided error used. This corroborates the findings above, that households that adopted soil and water conservation methods have higher technical efficiency levels compared to non-adopters. This can be explained by considering the dry nature of the country with a limited annual rainfall and hence the ability to conserve water and to control for erosion will enhance farm water use efficiency and hence, productivity. This results is consistent with the findings by Sherlund et al. (2002), that controlling for environmental conditions results in higher farm technical efficiency levels but contradicts the findings of Oduol et al. (2011) where they found soil and water conservation method to have no or negative impact on TE scores. The distance of household to sorghum farms has positive but statistically insignificant effect on TE scores for all the distributional assumptions except for the truncated-normal and the normal-gamma distributions.

Table 4.10 Tobit estimates of sources of inefficiency in sorghum production

Variables	*E-normal*	*H-normal*	*T-normal*	*G-normal*
	Coef (S.E)	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*
Constant	*0.896****	*0.699****	*0.185****	*0.811****
	(0.006)	*(0.028)*	*(0.060)*	*(0.028)*
Urban	*-0.001*	*-0.003*	*-0.110*	*-0.001*
	(0.001)	*(0.005)*	*(0.011)*	*(0.005)*
Household size	*-0.001***	*-0.001***	*-0.001*	*-0.001***
	(0.000)	*(0.000)*	*(0.001)*	*(0.000)*
Age	*-0.001*	*-0.001*	*-0.001*	*-0.001*
	(0.001)	*(0.001)*	*(0.001)*	*(0.001)*
Educational level	*-0.001**	*-0.005**	*-0.013***	*-0.005**
	(0.001)	*(0.003)*	*(0.006)*	*(0.003)*
Gender	*-0.001*	*-0.004*	*-0.003*	*-0.005*
	(0.001)	*(0.006)*	*(0.012)*	*(0.005)*
Dosso	*0.002*	*0.011*	*0.046*	*-0.001*
	(0.005)	*(0.023)*	*(0.050)*	*(0.023)*
Maradi	*0.004*	*0.021*	*0.052*	*0.010*
	(0.005)	*(0.023)*	*(0.050)*	*(0.023)*
Tahoua	*0.001*	*0.005*	*0.023*	*-0.004*
	(0.005)	*(0.023)*	*(0.050)*	*(0.023)*
Tillaberi	*0.002*	*0.010*	*0.028*	*-0.001*
	(0.005)	*(0.024)*	*(0.050)*	*(0.023)*
Zinder	*0.002*	*0.011*	*0.034*	*0.001*
	(0.005)	*(0.023)*	*(0.050)*	*(0.023)*
Diffa	*0.002*	*0.009*	*0.019*	*0.000*
	(0.001)	*(0.024)*	*(0.050)*	*(0.023)*
Distance	*0.000*	*0.001*	*-0.001*	*-0.000*
	(0.000)	*(0.002)*	*(0.004)*	*(0.001)*
S & W cons.	*0.013****	*0.059****	*0.173****	*0.049****
	(0.001)	*(0.004)*	*(0.009)*	*(0.004)*
Agric. sector	*0.001*	*0.003*	*0.004*	*0.002*
	(0.001)	*(0.003)*	*(0.010)*	*(0.003)*
Log Likelihood	*2542.362*	*1377.794*	*806.082*	*1388.788*

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively.*

The results of the percentage distribution of households TE score for the disaggregate data is shown in table 4.11 below. The results indicate that, a relatively high percentage of household have TE scores closer to the frontier ($TE \geq 81\%$) for adopters than non-adopters of soil and water conservation technology for the distributional assumptions of the one-sided error.

It can also be observed that even though the adopters have relative majority of households closer to the frontier, they also have relative majority of households very far from the frontier. The frequency distribution illustrates further the sensitivity of the technical efficiency scores of household based on the distributional assumption of the one-sided error.

Table 4.11 Percent distribution of households' TE scores for sorghum

	Adopters of S & W (N=102)				*Non-adopters of S & W (N=652)*			
TE range	*Exponential*	*Gamma*	*Truncated*	*Half*	*Exponential*	*Gamma*	*Truncated*	*Half*
≥ 91	*0.0*	*1.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
81-90	*7.0*	*17.0*	*7.0*	*2.0*	*0.0*	*1.0*	*2.0*	*0.0*
71-80	*17.0*	*25.0*	*16.0*	*7.0*	*33.0*	*31.0*	*4.0*	*4.0*
61-70	*21.0*	*26.0*	*21.0*	*14.0*	*29.0*	*33.0*	*3.0*	*18.0*
51-60	*28.0*	*13.0*	*29.0*	*15.0*	*22.0*	*19.0*	*5.0*	*15.0*
.041-50	*12.0*	*4.0*	*12.0*	*33.0*	*8.0*	*9.0*	*8.0*	*15.0*
31-40	*1.0*	*0.0*	*1.0*	*14.0*	*5.0*	*5.0*	*79.0*	*17.0*
21-30	*2.0*	*3.0*	*2.0*	*1.0*	*2.0*	*2.0*	*0.0*	*17.0*
20-11	*8.0*	*7.0*	*8.0*	*10.0*	*0.0*	*0.0*	*0.0*	*10.0*
≤ 10	*5.0*	*5.0*	*5.0*	*5.0*	*0.0*	*0.0*	*0.0*	*4.0*

4.7 Conclusions and recommendations

This paper measured technical efficiency scores for a sample households of 518 and 754 millet and sorghum producers from seven regions of Niger. The Cobb-Douglas stochastic frontier model was used to estimates the frontiers of millet and sorghum production and, the TE scores of each of the households. The TE score estimates were obtained using four distributional assumptions of the one-sided error. The analysis was done for the aggregate data and soil and water conservation method disaggregated data for both millet and sorghum productions.

4.7.1 Millet production

The findings from the analysis reveals that, for the aggregate data, the mean TE scores obtained are 63%, 63%, 50% and 69% respectively for exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions of the one-sided error. Similarly, for adopters of soil and water conservation methods, the mean TE scores for millet producers obtained from the analysis are 61%, 61%, 52%, and 66% respectively for exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions of the one-sided error. The mean TE scores for non-adopters of soil and water conservation methods are 60%, 52%, 53% and 35% respectively for exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions of the one-sided error. The results indicate that millet producers are technically inefficient. There are still potential gains in output to be made in the use of current technology available to millet producers and for adopters and non-adopters of soil and water conservation methods. The inefficiencies in millet production results in the loss of average total output in the range of 183kg-408kg based on the distributional assumptions of the one-sided error.

The findings reveal that adopters of the soil and water conservation methods have higher mean TE scores compared to non-adopters. This was tested using the mean difference and the results revealed that, soil and water adopters have significant technical efficiency gains over non-adopters. The suggestion is that, adopters of soil and water conservation methods makes use of the existing technology better than the non-adopters by controlling for environmental effects might aid in preventing leaching and maintaining conducive moisture levels for better utilization inputs.

Generally, the TE scores are relatively different from each other based on the distributional assumptions used for both aggregate and disaggregated data. Hence, we can conclude that even with the household level data, TE scores are sensitive to the distributional assumptions of the one-sided error. However, the TE estimates from the various distributional assumptions were consistent with each other.

Based on the Tobit estimates in the second-step regression for the millet data, rural households exhibited higher TE score than the urban household as evident in the statistical significance of the variable urban. This results suggests that rural households who are mostly subsistence operate on smaller lands and are better able to manage them compared to the urban farmers who are large scale producers. However, the interactions between urban and land size was not statistically significant. The results also suggest that households' heads with higher levels of education exhibit higher TE scores compared to their counterparts with lower education. The result show that, higher education households heads are less conservative and have access to information and are likely to adopt improvements in existing technology compared to their counterparts.

The variable capturing the adoption of soil and water conservation techniques is found to have a positive and statistically significant impact on TE scores. This suggests that households' that adopted soil and water conservation methods exhibit higher TE scores compared to non-adopters. This results confirms the difference in mean TE scores for adopters and non-adapters of soil and water conservation methods. It also supports the idea that controlling for environmental conditions improves the use of existing technology and helps. All things being equal, the non-adopters total output will potentially increase in the range of 40kg-53kg if they adopt the soil and water conservation methods.

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4.7.2 Sorghum production

The findings from the analysis reveals that, for the aggregate data, the mean TE scores obtained are 90%, 18%, 71% and 80% respectively for the exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions of the one-sided error. Similarly, for adopters of soil and water conservation methods, the mean TE scores for sorghum producers obtained from the analysis are 51%, 56%, 47%, and 63% respectively for the exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions of the one-sided error. The mean TE scores for non-adopters of soil and water conservation methods are 63%, 39%,42% and 63% respectively for exponential-normal, truncated-normal, half-normal and normal-gamma distributional assumptions of the one-sided error.

The general finding is that sorghum producers are technically inefficient. The suggestion is that, sorghum producing households can potentially obtain substantial gains in output and or cost reduction in the use of current technology available. This is possible for adopters and non-adopters of soil and water conservation methods in the sorghum industry. Inefficiencies in sorghum production will potentially result in the loss of an average of total output in the range of 9kg-72kg based on the distributional assumptions of the one-sided error.

In comparing the TE scores of household that adopted and those that do not adopt soil and water conservation methods, the findings reveal that adopters have higher mean TE scores compared to non-adopters. The paper found significant differences in mean technical efficiency between adopters and non-adopters of soil and water conservation methods in sorghum production. The explanation is that the adopters of soil and water conservation methods makes use of the existing technology better than the non-adopters. This is because controlling for environmental effects might aid in preventing leaching and maintaining conducive moisture levels for better utilization of other inputs. Sensitivity of the TE measures to the distributional assumptions of the one-sided error were conducted and the results revealed that TE scores were sensitive. There are statistically significant differences in the mean TE scores obtained from the various distributional assumptions.

In the second-step, a Tobit estimates of the variables influencing TE scores for sorghum indicates household size, educational level of the head of household, and soil and water conservation methods impact TE scores. The household size variable has negative and significant impact on TE scores. This indicate that, smaller households are better able to use existing technologies than larger households. Education has a negative and significant impact on TE scores for sorghum producing households. This unexpected impact means the less educated household heads are better users of the existing technology compared to their counterpart who have access to information.

The soil and water conservation variable is also found to have positive and statistically significant impact on TE scores for sorghum producing households. This suggests that sorghum producing households that adopted soil and water conservation methods exhibit higher TE scores compared to non-adopters. This results confirms the differences in mean TE scores for adopters and non-adopters of soil and water conservation methods. It also supports the idea that, controlling for environmental conditions, improves the use of existing technology. Assuming all thing being equal, non-adopters of soil and water conservation methods will potentially increase their average total output in the range of 0.5kg-8kg for adopting these technologies.

The paper identified rural households, educational level, regions except Niamey and Agadez as important variables affecting the technical efficiency scores of millet. In sorghum production, household size and educational level of the household head are the important variable affecting the technical efficiency scores. Soil and water conservation methods adoption also has a positive impact on technical efficiency scores of both millet and sorghum production. Improving TE will improve the food security situation, improve household income from both increased output and the cost savings which hitherto would have been used in the production. This will help stabilize prices of such cereals which are very volatile due to seasonality of output levels. Soil and water conservation will have a profound impact on a sustained land productivity for both millet and sorghum production and for climate variability in the area. On the distributional assumptions of the one-sided error, TE scores are sensitive to the assumption of the distributional form of the inefficiency part for household level data.

References

Abdulai, A., and W. Huffman "Structural adjustment and economic efficiency of rice farmers in northern Ghana." *Economic Development and Cultural Change* 48 (2000):503-20.

Aigner, D., C.K. Lovell, and P. Schmidt "Formulation and estimation of stochastic frontier production function models." *Journal of Econometrics* 6 (1977):21-37.

Baccouche, R., and M. Kouki "Stochastic production frontier and technical inefficiency: a sensitivity analysis." *Econometric Reviews* 22 (2003):79-91.

Battese, G.E. "Frontier production functions and technical efficiency: a survey of empirical applications in agricultural economics." *Agricultural economics* 7 (1992):185-208.

Belotti, F., S. Daidone, G. Ilardi, and V. Atella "Stochastic frontier analysis using Stata." (2012):

Binam, J.N., K. Sylla, I. Diarra, and G. Nyambi "Factors affecting technical efficiency among coffee farmers in Cote d'Ivoire: Evidence from the centre west region." *African Development Review* 15 (2003):66-76.

Binam, J.N., J. Tonye, G. Nyambi, and M. Akoa "Factors affecting the technical efficiency among smallholder farmers in the slash and burn agriculture zone of Cameroon." *Food Policy* 29 (2004):531-45.

Bravo-Ureta, B.E., and R.E. Evenson "Efficiency in agricultural production: the case of peasant farmers in eastern Paraguay." *Agricultural economics* 10 (1994):27-37.

Bravo-Ureta, B.E., and A.E. Pinheiro "Efficiency analysis of developing country agriculture: a review of the frontier function literature." *Agricultural and Resource Economics Review* 22 (1993):88-101.

Bravo-Ureta, B.E., D. Solís, V.H.M. López, J.F. Maripani, A. Thiam, and T. Rivas "Technical efficiency in farming: a meta-regression analysis." *Journal of productivity Analysis* 27 (2007):57-72.

Chavas, J., R. Petrie, and M. Roth "Farm household production efficiency: evidence from the Gambia." *American Journal of Agricultural Economics* 87 (2005):160-79.

Coelli, T.J. "Recent developments in frontier modelling and efficiency measurement." *Australian Journal of Agricultural Economics* 39 (1995):219-45.

Cullinane, K., T. Wang, D. Song, and P. Ji "The technical efficiency of container ports: comparing data envelopment analysis and stochastic frontier analysis." *Transportation Research Part A: Policy and Practice* 40 (2006):354-74.

FAO, 2015. http://www.fao.org/countryprofiles/index/en/?iso3=NER&paia=2 (accessed 4/16/2015)

FAOSTAT, 2015. http://faostat3.fao.org/download/Q/QC/E (accessed 4/16/2015)

Goodwin, B.K., and A.K. Mishra "Farming efficiency and the determinants of multiple job holding by farm operators." *American Journal of Agricultural Economics* 86 (2004):722-9.

Helfand, S.M., and E.S. Levine "Farm size and the determinants of productive efficiency in the Brazilian Center-West." *Agricultural Economics* 31 (2004):241-9.

Idiong, I. "Estimation of farm level technical efficiency in Smallscale Swamp rice production in Cross River State of Nigeria: A stochastic frontier approach." *World Journal of Agricultural Sciences* 3 (2007):653-8.

Jacobs, R. "Alternative methods to examine hospital efficiency: data envelopment analysis and stochastic frontier analysis." *Health care management science* 4 (2001):103-15.

Nkamleu, G.B. "Productivity growth, technical progress and efficiency change in African agriculture." *African Development Review* 16 (2004):203-22.

Oduol, J.B.A., J.N. Binam, L. Olarinde, A. Diagne, and A. Adekunle "Impact of adoption of soil and water conservation technologies on technical efficiency: Insight from smallholder farmers in Sub-Saharan Africa." *Journal of Development and Agricultural Economics* 3 (2011):655-69.

Sherlund, S.M., C.B. Barrett, and A.A. Adesina "Smallholder technical efficiency controlling for environmental production conditions." *Journal of Development Economics* 69 (2002):85-101.

Solís, D., B.E. Bravo-Ureta, and R.E. Quiroga "Soil conservation and technical efficiency among hillside farmers in Central America: a switching regression model*." *Australian Journal of Agricultural and Resource Economics* 51 (2007):491-510.

Speelman, S., M. D'Haese, J. Buysse, and L. D'Haese "A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation schemes in North-West Province, South Africa." *Agricultural systems* 98 (2008):31-9.

Tadesse, B., and S. Krishnamoorthy "Technical efficiency in paddy farms of Tamil Nadu: an analysis based on farm size and ecological zone." *Agricultural economics* 16 (1997):185-92.

Thiam, A., B.E. Bravo-Ureta, and T.E. Rivas "Technical efficiency in developing country agriculture: a meta-analysis." *Agricultural Economics* 25 (2001):235-43.

Wang, H. "Heteroscedasticity and non-monotonic efficiency effects of a stochastic frontier model." *Journal of Productivity Analysis* 18 (2002):241-53.

Xu, X., and S.R. Jeffrey "Efficiency and technical progress in traditional and modern agriculture: evidence from rice production in China." *Agricultural economics* 18 (1998):157-65.

Chapter 5 - Conclusions and recommendations

The impact of climate variability on tropical agriculture is estimated to negatively impact livelihoods, food security and the ecosystem services especially for smallholders. Hence adaptation strategies may require the use of sustainable agricultural intensification practices (SAIPs) to minimize the effect of climate variability on rainfed production systems (FAO, 2009). This chapter summarizes the results, conclusions and provides recommendations for policy and for future research.

The general objective of the dissertation was to evaluate the effect of training on the adoption of sustainable agricultural intensification practices (SAIPs) in Ghana. Secondly, the effect of adopting SAIPs on the technical efficiency scores of sorghum and millet production in Niger was also determined. The research questions were:

1. Is there a knowledge change on sustainable agricultural intensification practices since the 2010 baseline when measured again, two years after training?
2. Is the accumulated knowledge change due to the farmer participatory research?
3. If yes to the above, did the knowledge gain have an impact on adoption of SAIPs?
4. Are the adoption of SAIPs complementary or substitutes for each other?
5. Can SAIPs increase household sorghum and millet technical efficiency?

This chapter summarizes the results of the three papers and provides a general recommendation for policy. The chapter is organized into 4 sections. The first section (section 5.1) presents the summary results on the first essay. The second section (section 5.2) presents the summary results and conclusions on the second essay and the third section (section 5.3) presents the summary results and conclusion on the third essay. The fourth section (section 5.4) presents the overall synthesis and recommendations drawn from the three papers.

5.1 Essay 1- Perceptions and Performance of Conservation Agriculture in Northwestern Ghana

To understand the change in knowledge due to participatory training on sustainable agricultural intensification conducted since 2010, 118 households were sampled in 2012 after two farmer field schools and compared against the baseline data collected in 2010. Paired t-tests were used to evaluate the differences in knowledge between households that participated in training on SAIPs and non-participating farm households. Enterprise budgets were constructed to evaluate the economic performance of SAIPs relative to farmers' practices.

The results indicate that farm households that took part in the training accumulated more knowledge on SAIPs, when compared to non-participant households, indicating that the farmer field schools are effective in information delivery. Knowledge on zero/no-tillage also spilled over to other local farmers that did not participate in the training program. Results of the economic performance indicators show a reduction in total variable cost of production due to lower cost of tractor services as farm households switched to herbicides for weed control during land preparation.

Training and farmer-to-farmer communication are effective tools to increase knowledge on crop and resource management practices. Hence knowledge on conservation agricultural practices or SAIPs can be filled through training. Short-run net returns to conservation agricultural practices do not appear to be greater than conventional (farmer) practices. However, more data were required to establish a causal link that can attribute the adoption of specific practices to farmer participatory training in SAIPs.

5.2 Essay 2- Learning, knowledge and imitation in the adoption of Sustainable Agricultural Intensification Practices (SAIPs) in Ghana

Additional data were collected in 2014 from 168 households to evaluate the effect of farmer participatory training on conservation knowledge and to assess the effect of the knowledge change on the adoption of SAIPs. To achieve the multiple objectives set out, a three-step regression approach was adopted. The first step involved the use of a Probit model to evaluate the effect of farm, individual and household characteristics on farm household decisions to participate in training. This was done to control for the non-participating households and to control for self-selection bias. The second step estimated the factors affecting the change in the knowledge score while controlling for training using a Tobit regression. The relative effect of knowledge change on the interdependent adoption of SAIPs was evaluated using a multivariate Probit model in the third-step.

These regressions build upon the first essay by controlling for the factors that condition participation, knowledge growth and the adoption of sustainable intensification practices. The results show training had a positive and significant impact on household aggregate knowledge score change. Other covariates influencing aggregate knowledge change include the age of household head, experience in farming and whether the household head was male or not. The knowledge change is found to have a significant impact on the adoption of SAIPs. It was also shown that there is a spillover effect of the farmer participatory research (FPR) training within the community to non-participants that positively impacted knowledge and adoption of SAIPs. However, these indirect effects were smaller than the direct effects of training.

Finally, the multivariate Probit model was used to assess the factors affecting adoption and the relative interdependence of SAIP components. This model accounts for the effects of covariates on the probabilities of adopting specific components of sustainable intensification agricultural practices, and the interdependence of the components, by allowing the unobserved portions of the model to be freely correlated. The results showed accumulated knowledge of sustainable intensification to have positive and significant impact on the adoption of SAIP components. It was also found that SAIPs components are complementary to each other. Farmer participatory research can help change farmer perceptions through exposure and education. This leads to knowledge change and can increase the adoption of crop management practices that promote sustained use of natural resources.

5.3 Essay 3- The impact of soil and water conservation methods on farm household technical efficiency scores: a parametric application to sorghum and millet in Niger

This essay looks at the impact of SAIPs practices on the technical efficiency scores of millet and sorghum production in Niger. The paper also looks at the sensitivity of technical efficiency estimates to the different distributional assumptions of the one-sided error using 518 and 754 observations on millet and sorghum production data from the Living Standards Measurement Survey Integrated Surveys on Agriculture collected by the World Bank A two–step modelling approach was used. The first-step estimated the technical efficiency (TE) scores and the second step estimated the factors influencing TE estimates. The frontiers were estimated using a Cobb-Douglas stochastic frontier specification.

The results show that millet and sorghum producing households are, on average, 61% and 64% technically efficient respectively. The indication is that both millet and sorghum producers are technically inefficient in their use of current technology. Sorghum producers were relatively more efficient than millet producers. Hence, producers of both millet and sorghum can still improve their productivity with efficient use current technology. Inefficiency results in the loss of an average output in the range of about 183kg to 408kg and 9kg to 72kg respectively for millet and sorghum production. A paired t-tests was carried out to evaluate the mean difference in the TE scores for adopters and non-adopters of SAIPs. The results show that adopters of SAIPs had statistically significant higher TE scores than non-adopters for both millet and sorghum.

The paper evaluated the sensitivity of different distributional assumptions of the one-sided error term on the TE scores using the paired t-test. There were statistically significant mean differences in the TE scores obtained from four distributional assumptions (half, exponential, truncated and gamma). Spearman's correlation was used to test the dependency of the TE scores obtained from the distributional assumptions. The results indicate that the TE scores from the four distributional assumptions were consistent. The results in the second-step model show that the adoption of SAIPs has a positive and statistically significant effect on TE scores of millet and sorghum production. Non-adopters of SAIPs can increase their TE scores in the range of about 40kg to 53kg and 0.5kg to 8kg respectively for millet and sorghum.

5.4 Recommendations

Based on the results above, training and farmer to farmer communication are effective tools for raising knowledge on crop and resource management practices. Hence, knowledge on SAIPs can be filled through training of farm households and this has a positive impact on the adoption of the components. The dissertation also demonstrates the positive impact of SAIPs on the productivity of sorghum and millet production is the Sahel region. Policies on SAIPs need to be adopted as an adaptive measure to curb the effects of climate change. Specifically, training of smallholder households at the farm level is important in removing biases associated with new farming practices associated with climate change adaptation.

Governments in Ghana and in Niger can promote the training of smallholder farmers in crop and resource management practices as a measure to minimize the effect of climate variability and to improve agricultural productivity. This can be done through educational programs that include active learning such as the farmer participatory research approach. According to the research results, these training activities should directed at the smallholders who are young and belong to farmer organizations to be the most effective. Farmer organizations should be strengthened for disseminating crop and resource management practices.

Future research should focus on whether the adoption of the technologies by smallholders were in bundles or otherwise and it will be important for a full scale evaluation of the training on SAIPs in the entire of northwestern region of Ghana. Research should focus on the effects of social networks on the diffusion of the technologies in order to maximize spillover effects for technology transfer.

Appendix A - Parameter estimates

Table A.1 Maximum Likelihood estimates for millet production

Variable	Total sample (N=518)				Adopter of S &W conservation (N=102)				Non-adopters of S & W conservation (N=416)			
	E-norm[5]	H-norm[6]	T-norm[7]	G-norm[8]	E-norm	H-norm	T-norm	G-norm	E-norm	H-norm	T-norm	G-norm
	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)	Coef (S.E)
Constant	6.253***	6.479***	6.259***	6.162***	7.908***	7.623***	7.902***	7.891***	5.293***	5.368***	5.338***	5.823***
	(0.433)	(0.409)	(0.330)	(0.313)	(0.583)	(0.576)	(0.704)	(0.673)	(0.408)	(0.398)	(1.776)	(2.571)
lnmanure	-0.062	-0.073	-0.063	-0.061	0.041	-0.013	0.041	0.048	0.076	0.013	0.022	0.043
	(0.085)	(0.086)	(0.083)	(0.083)	(0.120)	(0.141)	(0.157)	(0.149)	(0.071)	(0.060)	(0.059)	(0.058)
lnfertilizer	0.088	0.096	0.088	0.088	-0.086	-0.054	-0.085	-0.088	-0.064	0.051	0.039	0.020
	(0.102)	(0.104)	(0.101)	(0.100)	(0.154)	(0.179)	(0.207)	(0.198)	(0.085)	(0.076)	(0.084)	(0.080)
lnseed	0.251***	0.251***	0.251***	0.250***	0.169***	0.221***	0.170**	0.159**	0.117***	0.104***	0.108***	0.108***
	(0.042)	(0.043)	(0.043)	(0.043)	(0.065)	(0.071)	(0.080)	(0.077)	(0.037)	(0.033)	(0.038)	(0.040)
lnlabor	0.139***	0.144***	0.139***	0.139***	0.066	0.084	0.066	0.064	0.116***	0.101***	0.107***	0.097***
	(0.041)	(0.042)	(0.403)	(0.040)	(0.069)	(0.080)	(0.116)	(0.110)	(0.034)	(0.030)	(0.030)	(0.027)
lnland	0.068	0.070	0.068	0.068	0.110	0.091	0.110	0.110	0.018	-0.022	-0.023	n0.010
	(0.048)	(0.049)	(0.049)	(0.049)	(0.083)	(0.096)	(0.121)	(0.116)	(0.041)	(0.035)	(0.037)	(0.037)
Diffa	-0.972***	-0.951***	-0.975***	-0.972***	-1.317***	-1.003***	-1.311***	-1.364***	0.092	0.290	0.276	0.154
	(0.376)	(0.356)	(0.234)	(0.232)	(0.418)	(0.385)	(0.308)	(0.295)	(0.384)	(0.378)	(1.773)	(2.561)
Dosso	-1.386***	-1.379***	-1.390***	-1.383***	-1.340***	-1.061***	-1.335***	-1.386***	0.092	0.229	0.213	0.125
	(0.362)	(0.340)	(0.213)	(0.212)	(0.426)	(0.400)	(0.353)	(0.338)	(0.375)	(0.378)	(1.770)	(2.561)
Maradi	-1.478***	-1.472***	-1.483***	-1.476***	-1.365***	-0.913*	-1.357***	-1.436***	-0.080	0.125	0.100	0.031
	(0.362)	(0.339)	(0.216)	(0.215)	(0.488)	(0.473)	(0.496)	(0.464)	(0.372)	(0.373)	(1.771)	(2.561)
Tahoua	-1.370***	-1.344***	-1.375***	-1.372***	-1.332***	-1.034***	-1.324***	-1.377***	-0.212	0.035	0.005	n0.097
	(0.369)	(0.350)	(0.217)	(0.217)	(0.419)	(0.379)	(0.295)	(0.293)	(0.381)	(0.380)	(1.771)	(2.562)
Tillaberi									0.303			

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[5] Exponential-normal distribution

[6] Half-normal distribution

[7] Truncated normal distribution

[8] Normal Gamma distribution

	*-0.843***	*-0.865***	*-0.847****	*-0.839****	*-1.244****	*-0.853***	*-1.237****	*-1.307****	*(0.379)*	*0.389*	*0.386*	*0.300*
	(0.371)	*(0.349)*	*(0.238)*	*(0.233)*	*(0.432)*	*(0.396)*	*(0.351)*	*(0.324)*		*(0.377*	*(1.771)*	*(2.562)*
Zinder	*-1.013****	*-0.989****	*-1.017****	*-1.016****	*-1.054****	*-0.666**	*-1.047****	*-1.120****	*0.067*	*0.247*	*0.236*	*0.118*
	(0.361)	*(0.338)*	*(0.204)*	*(0.204)*	*(0.405)*	*(0.359)*	*(0.240)*	*(0.234)*	*(0.372)*	*(0.371)*	*(1.770)*	*(2.561)*

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively*

Table A.2. Variance parameters after Maximum Likelihood estimates for millet

Variable	*Total sample (N=518)*				*Adopter of S &W conservation (N=102)*				*Non-adopters of S & W conservation (N=416)*			
	E-norm	*H-norm*	*T-norm*	*G-norm*	*E-norm*	*H-norm*	*T-norm*	*G-norm*	*E-norm*	*H-norm*	*T-norm*	*G-norm*
σ_u	0.512***	0.968***	10.319	0.495***	0.608***	0.979***	12.031***	0.624***	0.615***	1.181***	1.266***	0.730***
σ_v	0.680***	0.938***	0.679	0.693***	0.417***	0.441**	0.419	0.421***	0.378***	0.171***	0.196***	0.001
$\gamma = \sigma_u^2/\sigma^2$	-	0.71***	0.99	-	-	0.83***	0.99***	-	-	0.98***	0.98***	-
λ	0.753 ***	1.544***	15.193	0.711***	1.458***	2.221***	28.713	1.482***	1.627***	6.826***	6.469***	730
θ	1.954***	-	-	1.713***	1.643***	-	-	1.338***	1.626***	-	-	2.358***
P	-	-		0.719***	-	-	-	0.697*	-	-	-	2.966***
$\overline{TE_\iota}$	0.63	0.50	0.63	0.69	0.61	0.52	0.61	0.66	0.60	0.53	0.52	0.35
LL	-644.523	-650.067	-644.569	-643.519	-106.586	-110.947	-106.613	-106.15	-414.848	-414.339	-650.067	-408.785

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively.*

Table A.3. Variance parameters after Maximum Likelihood estimates for millet

Variable	*Total sample (N=754)*				*Adopter of S &W conservation (N=102)*				*Non-adopters of S & W conservation (N=652)*			
	E-norm	*H-norm*	*T-norm*	*G-norm*	*E-norm*	*H-norm*	*T-norm*	*G-norm*	*E-norm*	*H-norm*	*T-norm*	*G-norm*
σ_u	0.108*	0.442*	0.834*	0.250*	0.727**	1.156***	14.628***	0.757***	0.482***	1.219***	1.118***	0.486**
σ_v	1.124***	1.098***	0.799**	1.102***	0.506***	0.526***	0.506**	0.509***	0.866***	0.669***	0.972***	0.864***
$\gamma = \sigma_u^2/\sigma^2$	-	0.139**	0.522**	-	-	0.829***	0.998***	-	-	0.768***	0.973***	-
λ	0.096	0.402**	1.044**	0.227**	1.437***	2.198***	28.898	1.487***	0.557***	1.822***	5.971**	0.563***
θ	9.25	-	-	4.086	1.375***	-	-	1.050***	2.074***	-	-	2.080***
P	-	-	-	1.044***	-	-	-	0.632*	-	-	-	1.024***
$\overline{TE_\iota}$	0.90	0.71	0.18	0.80	0.56	0.47	0.57	0.63	0.63	0.43	0.40	0.63
LL	-1161.69	-1161.68	-1161.44	-1161.71	-125.38	-128.36	-125.40	-124.91	-915.57	-912.45	-902.43	-915.57

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively*

Table A.4. Maximum Likelihood estimates of Cobb-Douglas production function for sorghum

Variable	*Total sample (N=754)*				*Adopter of S &W conservation (N=102)*				*Non-adopters of S & W conservation (N=652)*			
	E-norm	*H-norm*	*T-norm*	*G-norm*	*E-norm*	*H-norm*	*T-norm*	*G-norm*	*E-norm*	*H-norm*	*T-norm*	*G-norm*
	Coef (S.E)	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*	*Coef (S.E)*
Constant	*3.574***	*3.818****	*5.336**	*3.719****	*6.516****	*6.610****	*6.515*	*6.426*	*3.238****	*3.560****	*4.404*	*3.247*
	(1.548)	*(0.686)*	*(3.014)*	*(0.845)*	*(0.777)*	*(0.914)*	*(140.781)*	*(6895)*	*(0.696)*	*(0.679)*	*(9.793)*	*(4.827)*
lnfertilizer	*-0.029*	*-0.029*	*-0.028*	*-0.029*	*-0.194*	*-0.141*	*-0.193*	*-0.211*	*-0.037*	*-0.018*	*-0.007*	*-0.037*
	(0.104)	*(0.104)*	*(0.109)*	*(0.107)*	*(0.248)*	*(0.286)*	*(0.413)*	*(0.387)*	*(0.096)*	*(0.093)*	*(0.075)*	*(0.085)*
lnseed	*0.638****	*0.637****	*0.636****	*0.637****	*0.173*	*0.182*	*0.173*	*0.167*	*0.438****	*0.413****	*0.478****	*0.438****
	(0.102)	*(0.102)*	*(0.109)*	*(0.110)*	*(0.122)*	*(0.138)*	*(0.163)*	*(0.150)*	*(0.113)*	*(0.111)*	*(0.108)*	*(0.129)*
lnlabor	*0.192**	*0.191**	*0.186*	*0.190*	*0.008*	*0.013*	*0.008*	*0.008*	*0.133*	*0.118*	*0.087*	*0.133*
	(0.101)	*(0.100)*	*(0.127)*	*(0.124)*	*(0.132)*	*(0.154)*	*(0.233)*	*(0.212)*	*(0.099)*	*(0.099)*	*(0.141)*	*(0.119)*
lnland	*0.137***	*0.138***	*0.137***	*0.139***	*0.043*	*0.079*	*0.043*	*0.029*	*0.111***	*0.121***	*0.125****	*0.111***
	(0.057)	*(0.057)*	*(0.055)*	*(0.054)*	*(0.103)*	*(0.111)*	*(0.104)*	*(0.095)*	*(0.056)*	*(0.053)*	*(0.047)*	*(0.053)*
Diffa	*0.075*	*0.074*	*0.058*	*0.073*	*-0.382*	*-0.327*	*-0.379*	*-0.402*	*0.672*	*0.791*	*0.670*	*0.673*
	(0.677)	*(0.677)*	*(0.676)*	*(0.673)*	*(0.741)*	*(0.887)*	*(140.776)*	*(6895)*	*(0.694)*	*0.674)*	*(9.792)*	*(4.824)*
Dosso	*-0.684*	*-0.681*	*-0.675*	*-0.678*	*-0.383*	*-0.310*	*-0.380*	*-0.408*	*-0.028*	*0.198*	*0.218*	*-0.026*
	(0.670)	*(0.669)*	*(0.662)*	*(0.659)*	*(0.754)*	*(0.903)*	*(140.779)*	*(6895)*	*(0.689)*	*(0.674)*	*(9.790)*	*(4.821)*
Maradi	*-1.378***	*-1.380*	*-1.397*	*-1.380****	*-1.461**	*-1.616*	*-1.458*	*-1.393*	*-0.499*	*-0.330*	*-0.277*	*-0.498*
	(0.662)	*(0.662)*	*(0.659)*	*(0.183)*	*(0.876)*	*(0.988)*	*(140.779)*	*(6895)*	*(0.681)*	*(0.667)*	*(9.790))*	*(4.821)*
Tahoua	*-0.171*	*-0.169*	*-0.170*	*0.132*	*-0.456*	*-0.548*	*-0.455*	*-0.444*	*0.391*	*0.567*	*0.441*	*0.393*
	(0.665)	*(0.665)*	*(0.659)*	*(0.656)*	*(0.721)*	*(0.862)*	*(140.782)*	*(6895)*	*(0.687)*	*(0.672)*	*(9.791)*	*(4.821*
Tillaberi	*-0.321*	*-0.321*	*-0.327*	*-0.320*	*-0.651*	*-0.669*	*-0.649*	*-0.647*	*0.279*	*0.450*	*0.334*	*0.281*
	(0.675)	*(0.675)*	*(0.669)*	*(0.6660*	*(0.748)*	*(0.891)*	*(140.781)*	*(6895)*	*(0.698)*	*(0.683)*	*(9.792)*	*(4.823)*
Zinder	*-0.315*	*-0.315*	*-0.328*	*-0.313*	*-0.541*	*-0.537*	*-0.538*	*-0.543*	*0.348*	*0.513*	*0.381*	*0.349*
	(0.661)	*(0.661)*	*(0.655)*	*(0.652)*	*(0.703)*	*(0.846)*	*(140.775)*	*(6895)*	*(0.683)*	*(0.668)*	*(9.790)*	*(4.821)*

*Where *, ** and *** represents significance at 10%, 5% and 1% respectively*

Appendix B - Questionnaire for Household survey 2012-2014 in Ghana

Table B.1. Household members (Demographics)

We would like to know about you and your family. Can you please tell us about all the members of your family starting with yourself?

HH member code	1. List the name of all of the farmer ***(Household head first)***	2. What is the age of this household member?	3.What is the highest grade completed by this Farmer/head household ? *If no schooling completed put zero*	4. Does this person reside in this community permanently?	5. Where does this farmer reside if not in this community? *Only for members who do not reside permanently in the house*	6. For how long has this farmer lived away from this community?	7. What is the primary occupation of the household head?	8. If primary occupation is farming, how long have you been farming?	9. what is the total household income (Ghana Cedi)?	10. what % of the income is from off-farm work?
	Name	whole years completed (e.g.14.5=14)	see code below ***(EDUCAT)***	***0. No*** ***1. Yes***	Indicate Location	List year when migrated	see codes below ***(OCCUP)***	***(EXPER) in years***	***(INCOME)***	***(%)***
1										
2										
3										
4										
12								▨	▨	▨
13								▨	▨	▨
14								▨	▨	▨

(EDUCAT)

0=None

1=Pre-school

2=Primary

3=JSS or JHS-Middle school certificate

4= SSS or SHS/Technical

5= Tertiary

6=Non-formal

7=Arabic education

(OCCUP)

1=Crop production

2=Tree crop production

3=Livestock

4=Fishing

5=Crop product marketing

6=Livestock marketing

7=Petty trading

8=Salaried worker

9=other

Table B.2. Agricultural (including livestock) and non-agricultural assets

Can you please tell us about the assets owned by the household as a whole?

TABLE 2.1: AGRICULTURAL ASSETS

agric. asset code	Agricultural asset	1. How many of these assets do you own? *If partial ownership put fraction owned*	2. What is the value of your total portion of the assets if sold today? *Consider the value if sold.*	2b. *If a value cannot be determined, ask the year when bouaght and for how much when new.*	
				Year purchased	Price when purchased
		number	total value		
1	Machete/Cutlass				
2	Sickle				
3	Hoe				
4	Spade				
5	Rake				
6	Axe				
7	Backpack sprayer				
8	Motorized backpack sprayer				
9	Tractor				
10	Plow				

TABLE 2.2 NON-AGRICULTURAL ASSETS

non-agric. asset code	Non-agricultural asset	1. How many of these assets do you own? *If partial ownership put fraction owned*	2. What is the value of your total portion of the assets if sold today? *Consider the value if sold.*	2b. *If a value cannot be determined, ask the year when bouaght and for how much when new.*	
				Year purchased	Price when purchased
		number	total value		
1	Radio				
2	TV				
3	Bicycle				
4	Sewing machine				
5	Motorcycle				
6	Car				
7	Truck				
8	Cell phone				
9					
10					

11	Cart				
12	Harrow				
13	Kraal				
14	Wellington boot				
15	(other…list)				
16					
17					
18					
19					
20					

11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

		1. How many of these livestock /animals do you own at present?	2. If sold today, what would be the value of these livestock/animals?	3. Do you confine these animals to a stable?	4. If yes to (3) for how many months were these animals confined?	5. How many animals did you sell last year?	6. Did you purchase supplemental feeds for this animal last year?	7. If yes to (6), how much did you spend?	8. How much money did you spend on veterinary treatments last year for these animals? (drugs/vet clinic fee/etc)
animal	Livestock/ animals								
code		Quantity of animals	value of each animal	0=No, 1=Yes	months/animals	Quantity of animals	0=No, 1=Yes	GHC/animal/year (or total?)	GHC/animal/year (or total?)
1	Beef cattle								
2	Calf								
3	Heifer								

4	Bull (AT)								
5	Donkey								
6	Horse								
7	Goats								
8	Sheep								
9	Chicken/Guinea Fowl								
10	Pigs								
11									

Table B.3. Land use (owned, rented to another, or rented in by farmer)

Can you tell us about the plots where you grow your crops?

1. Plot Number			2. How many acres is this plot? (Farmer estimate)	3. Who decides which crop to plant on this field?	4. Is the plot irrigated?	5. How far away is this plot from your home?	6. Current Land-use (planned for 2014)	7. Land use in 2013	8. Land use in 2012	9. Land use in 2011	10. If fallow has not occurred over the past 5 years, when did you last leave fallow?	11. How will you rate the quality of the land	12. How can u describe the steepness of the land
	Write down plots' names if farmers give any or description e.g near to home, near river etc	*OWNED=O, RENTED IN=RI, RENT OUT TO ANOTHER PERSON=RO*		(see code list of individual from Table 1)	***0=no 1=yes***	Time required to walk to plot (*alt+list distance*)	**List crop from list on the code page** Note: If intercropped list both crops. E.g. Sorghum and groundnut intercrop = 33+15. If the field is split between crops indicate 33/15.					***1. Good 2. somehow 3. Poor***	***1. Flat 2. moderate 3. steep***
plot code	DESCRIPTION	CODE	acres		code	minutes	code	code	code	code	year last fallow	code	code
1			.										
2			.										
3			.										

4			.										
5			.										
6			.										
7			.										
8			.										
9			.										
10													
							see code sheet	see code sheet	see code sheet	see code sheet			

Table B.4. Biochemical inputs used on fields during the last season (2013)

What crop inputs did you apply on this field? *Remember to focus on last year's input use (2013)!! Make sure field # is correct for 2013.*

	Field	SEED				FERTILIZER				INPUT 1 (List input from TINTR)				INPUT 2 (List input from TINTR)				INPUT 3 (List input from TINTR)			
Plot number		Source of seed	Quantity	Unit	Price /Unit	Type of Fertilizer	Quantity	Unit	Price /Unit	Type of input	Quantity	Unit	Price /Unit	Type of input	Quantity	Unit	Price /Unit	Type of input	Quantity	Unit	Price /Unit
	Crop	SOURCE	#	UNIT	C/unit	TFERT	#	UNIT	C/unit	TINTR	#	UNIT	C/unit	TINTR	#	UNIT	C/unit	TINTR	#	UNIT	C/unit
1																					
2																					

3																					
4																					
5																					
6																					

(SOURCE)
1=Retained seed
2=Bought from farmer
3=Bought from local market
4=Gift from farmer
5=NGO
6=Research organization (SARI/CSIR)
7=Extension
8=Seed dealer

(UNIT)
1= 1 KG
2=2.5 KG bowl
3=5 KG sack
4=10 KG Sack
5=25 KG sack
6=50 KG sack
7=100 KG sack
8=1 litre

(TFERT)
1=Manure
2=NPK
3=Sulphate Ammonium
4=Urea
5=Compost
6=other (specify)

(UNIT)
1= 1 KG
2=2.5 KG bowl
3=5 KG sack
4=10 KG Sack
5=25 KG sack
6=50 KG sack
7=100 KG sack
8=1 litre

(TINTR)
1=Herbicide
2=Insecticide
3=Fungicide
4=other (specify)

(UNIT)
1= 1 KG
2=2.5 KG bowl
3=5 KG sack
4=10 KG Sack
5=25 KG sack
6=50 KG sack
7=100 KG sack
8=1 litre

(TINTR)
1=Herbicide
2=Insecticide
3=Fungicide
4=other (specify)

(UNIT)
1= 1 KG
2=2.5 KG bowl
3=5 KG sack
4=10 KG Sack
5=25 KG sack
6=50 KG sack
7=100 KG sack
8=1 litre

(TINTR)
1=Herbicide
2=Insecticide
3=Fungicide
4=other (specify)

(UNIT)
1= 1 KG
2=2.5 KG bowl
3=5 KG sack
4=10 KG Sack
5=25 KG sack
6=50 KG sack
7=100 KG sack
8=1 litre

9=Hay bundle 10=other (specify)	9=Hay bundle 10=other (specify)	9=Hay bundle 10=other (specify)	9=Hay bundle 10=other (specify)	9=Hay bundle 10=other (specify)

Table B.5. Labor used on crops during 2013

LABOR USED BY PLOT 1												
Activity	EXCHANGE Group Labor			Hired Labor			Family Labor					
	# of people	Days	Total cost of food etc (GH¢)	# of people	Days	Total cost (GH¢) (incl. food)	Adult male		Adult female		Child < 15	
							#	Days	#	Days	#	Days
Land preparation												
Sowing												
Watering *												
Fertilizer application												
Other chemical input spraying												
Weeding 1st												
Weeding 2nd												
Harvesting												
LABOR USED BY PLOT 2												
Land preparation												
Sowing												
Watering *												
Fertilizer application												
Other chemical input spraying												
Weeding 1st												
Weeding 2nd												
Harvesting												
LABOR USED BY PLOT 3												

Land preparation												
Sowing												
Watering *												
Fertilizer application												
Other chemical input spraying												
Weeding 1st												
Weeding 2nd												
Harvesting												
LABOR USED BY PLOT 4												
Activity	EXCHANGE Group Labor			Hired Labor			Family Labor					
	# of people	Days	Total cost of food etc (GH¢)	# of people	Days	Total cost (GH¢) (incl. food)	Adult male		Adult female		Child < 15	
							#	Days	#	Days	#	Days
Land preparation												
Sowing												
Watering *												
Fertilizer application												
Other chemical input spraying												
Weeding 1st												
Weeding 2nd												
Harvesting												
LABOR USED BY PLOT 5												
Land preparation												
Sowing												
Watering *												
Fertilizer application												
Other chemical input spraying												
Weeding 1st												
Weeding 2nd												

Harvesting												
LABOR USED BY PLOT 6												
Land preparation												
Sowing												
Watering *												
Fertilizer application												
Other chemical input spraying												
Weeding 1st												
Weeding 2nd												
Harvesting												

Table B.6. Owned plots: product description

You just told me abut the plots and what you grow on these plots in 2013.
Can you tell me a little more about what you grow and what you with what you produce after harvest?

1. Plot Number	***1. How nuch did the field produce?***			2. Do you anticipate selling the produce from this plot?	3. If yes, what is the primary product you will sell from this plot?	4. What percentage of the primary product of this crop do you anticipate selling?	5. What is the price you expect to receive for this product?	6. If you said yes, is there a secondary product you will sell from this plot?And what is it? (e.g. stalks for	7. What percentage of this secondary product do you anticipate selling?	8. What is the price you expect to receive for this secondary product?
SAME AS PREVIOUS SHEET	quantity	unit	form	*If no, confirm product is consumed by the householdand go to next table*						

										fodder, building materials etc)			
plot code	crop code	#	UNIT code below	code below	0=no, 1=yes	code below	percentage from 1-100%	price	UNIT code below	code below	percentage from 1-100%	price	UNIT code below
1													
2													
3													
4													
5													
6													

(UNIT)
1= 1 KG

(FORM)
1=grain

0=no
1=yes

1=grain as food/feed
2=grain as seed

(UNIT)
1= 1 KG

0= no secondary product
1=grain as food/feed

(UNIT)
1= 1 KG

2=2.5 KG bowl	2=pannicle		2=2.5 KG bowl	2=grain as seed	2=2.5 KG bowl
3=5 KG sack	3=cobs	3=fodder or forage	3=5 KG sack	3=Fodder or Forage	3=5 KG sack
4=10 KG Sack	4=tubers	4=Straw for bedding or building	4=10 KG Sack	4=Straw for bedding or building	4=10 KG Sack
5=25 KG sack	5=other (specify)	5=other	5=25 KG sack	5=other	5=25 KG sack
6=50 KG sack			6=50 KG sack		6=50 KG sack
7=100 KG sack			7=100 KG sack		7=100 KG sack
8=1 litre			8=1 litre		8=1 litre
9=other (specify)			9=Hay bundle		9=Hay bundle
			10=other (specify)		10=other (specify)

Table B.7. Grain (output) transactions for target crop since last harvest in 2013

This table is designed to gather specific information about all the exchanges the household engaged in over the past year for the crop output.

Lets discuss the way that GRAIN(OUTPUT) came into or out of, your farm.

Transaction	1. Which crops did you purchase, sell, barter, exchange, give or receive this season?	2. Was this transaction an inflow or outflow? (If a barter with no net loss, list both transactions)	3. With whom did you carry out this transaction?	4. How many times have you transacted GRAIN(OUTPUT) with this person/organization in the past five years?	5. Where did this transaction take place?	6. Distance to the transaction point from farm.	7. When did this transaction take place?	8. How much of the GRAIN(OUTPUT) was transacted? (Quantity of transaction)	9. Price of transaction per unit mentioned	10. Was the price you received/paid higher than the price you expected to pay, lower to or equal to what you	11. Was the quantity you sold/purchased greater than you expected to transact, less than	12. What is the most important reason for transacting

											expected to pay?	expected to transact or the same?	with this person?
	Crop code	Code (**TRANS)**	Code (**TSOURCE)**	List number	Code (list market location if not on farm) (**TLOC**)	km distance	Month of transaction **(MONTH)**	Quantity	Unit	Price per Unit	1=higher, 2=same, 3=lower	1=higher, 2=same, 3=lower	Code below (**TREAS**)
1													
2													
3													
4													
5													
6													

TRANS	**TSOURCE**	**TLOC**	**MONTH**	**(UNIT)**	**TREAS**
1=Sale	1=Small trader	1=On own farm	1=January	1= 1 KG	1=Somebody that I know
2=Barter/exchange (out)	2=Large trader	2=On neigbor farm	2=February	2=2.5 KG bowl	2=From the same kinship group but not personally known
3=Gift (out)	3=Store merchant	3= Local/village market	3=March	3=5 KG sack	3=Person speaks my language but not personally known
4=Purchase	4=Friend/neighbor	4=Town market	4=April	4=10 KG Sack	4=No reason, just an opportunity

5=Barter/exchange (in)	5=Family/Relative	5=May	5=25 KG sack	5=Product looked good
6=Gift (in)	6=Cooperative	6=June	6=50 KG sack	6=Product guaranteed by transactor
7=Relief (in)	7=Itinerant trader	7=July	7=100 KG sack	7=Transactor provided credit
8=other	8=Research/extension	8=August	8=1 litre	8=Transactor had many products available
	9=International organization	9=September	9=Hay bundle	
	10=NGO	10=October	10=other (specify)	
	11=Government source	11=November		
		12=December		

Note: exchange=out or in could be for land rent etc.

	CAPS component	***SARI***		***Tech. acceptance***				
		1. How many years have you been colaborating with SARI?	2. What type of trials have you been involeved in since 2010? **(Tick)**	3. Have you heard of Conservation practices before (CAPS)?	4. Are the technologies effective in helping to tackle soil and water problems?	5. How is CAPS helping to improve soil productivity and water management?	6. What advantages/benefits does the CAPS provide? (Rank 2 with one being the most important)	7. What are the primary constariants in using CAPS practices in your locallity?

				See code below ***(KCAPS)***	See code below ***(EFCAPS)***	List	***(BENFTS)*** *See codes below*	***(PRIMCONS)*** *see codes below*
1	***No/zero-tillage***							
2	***Crop ratation with legume***							
3	***Tied ridging and grass strips***							
4	***Residues retention***							
5	***Fetilizer management***							

(KCAPS)	***(EFCAPS)***	***(BNFTS)***	***(CONST)***
0. No	0. No	1. Time saving	1. Lack of appropriate tool for drilling
1. Yes	1. Yes	2. Improves yield	2. Use of residue for animal feed
		3. Reduce land preparation cost by using herbicide	3. More population of weeds at time of planting
		4. Timeliness of Sowing	4. Hardening of upper soil
		5. Reduces labor use	5. Financial coonstraints
		6. Increase organic matter content	6. Burning of residue
		7. Reduces soil erosion	7. Lack of herbicides
		8. Improves water holding capacity	8. High costs of herbicide
		9. Reduces labor cost significantly	9. Yellowing of leaves
		10. Other (specify)………………	10. Stubbles on the field
			11. Other (specify)………………

	CAPS component	***Willingness to adopt CAPS***

		1. Have you started using any of the CAPs on your own plots?	2. If yes to **Qn**. **1**, on which crops?	3. What is the area under cultiavtion (in acres)	4. Would you continue using CAPs after the project is ended?	5. If you are not using CAPS right now are you considering using them on your other plots?	6. if yes to ***Qn 5***, which of the CAPS are u willing to adopt
		See code below	see code below	# of cares	see code below	See code below	See code below
1	***No/zero-tillage***						
2	***Crop ratation with legume***						
3	***Tied ridging and grass strips***						
4	***Residues retention***						
5	***Fetilizer management***						

(USECAPS)	***(TYPCRP)***	***(CNTN)***	***(WTADPT)***
0. No	1. Cowpea	0. No	0. No
1. Yes	2. Maize	1. Yes	1. Yes
	3. Groundnuts		
	4. Rice		
	5. Millet		
	6. Sorghum		
	7. Others (specify)………		

Table B.8. Incentive for participating in CAPS and climate change

Preamble: In the short term there will be yeild variation and sometimes lower yields but the there is a guaranteed sustained yield or yield increases due to productivity gain which is also due to organic matter build up in the long term and hence, reduction in greenhouse gases. I will therefore want to ask you for your specific choice of the practices you would like as presented in the table below. If there is a monetary reward for adotpion which option would choose?

CAPS COMPONENT→	***Farmers pracice***	***No/Zero -tillage***	***Fertilizer management***	***Residues management***	***Tied-ridging and grass trips***	***Crop rotation***
ATTRIBUTES↓						
time saving	***No***	***Yes***	***No***	***Yes***	***No***	***No***
improves yield in the short run (1-5yrs)	***No***	***No***	***Yes***	***No***	***Yes***	***No***
reduces land preparation cost	***No***	***Yes***	***No***	***Yes***	***Yes***	***No***
Labor cost reduction	***No***	***Yes***	***No***	***Yes***	***No***	***No***
inreases organic matter in soil	***No***	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***
reduces soil erosion	***No***	***Yes***	***No***	***Yes***	***Yes***	***Yes***
improves water holding capacity	***No***	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***
Sustainanble future yields	***No***	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***
Lack of tools for drilling	***No***	***Yes***	***No***	***Yes***	***No***	***No***
high population of weed	***No***	***Yes***	***No***	***Yes***	***No***	***No***
Financial constraints	***No***	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***
top soil hardened	***No***	***Yes***	***No***	***Yes***	***No***	***No***
high cost of inputs	***No***	***Yes***	***Yes***	***Yes***	***No***	***No***

Incentive amount ($)/acre/year (circle the response)	$0.00	$1.00	$1.00	$1.00	$1.00	$1.00
	$0.00	$1.50	$1.50	$1.50	$1.50	$1.50
	$0.00	$2.00	$2.00	$2.00	$2.00	$2.00
	$0.00	$2.50	$2.50	$2.50	$2.50	$2.50
	$0.00	$3.00	$3.00	$3.00	$3.00	$3.00

"The term, “climate change adaptation” refers to a set of actions, strategies, processes, and policies that respond to actual or ex-pected climate changes so that the consequences for individuals, communities, and economy are minimized" (IFPRI, 2012)

1. Do you believe there is climate change?	2. In a sentence what is climate change?	3. What are the effects of climate change?	Short-term adaptation startegies		
			4. Are you currently doing something to protect yourself from the effects of climate change? ***0=No 1=Yes***		
			5. Risks & uncertainties	6. Farming practices	7. Off-farm strategies
0=No					
1= Yes		List	see codes below	see codes below	see codes below

1 weather & climate information services

2. awareness & access to information

3. Particpatory planning

4. Flood control

1. drought & flood resistant variteis

2. Crop diversification

3. improved crop management practices

4. Pests & disease management

1.imporve post harvest management practices

2. empower women

3. improve access to credit

5. Moisture control and
adaptive water management
6 soil conservation and
erosion control practices

7. Fertilization
8. changing plots
9. use irrigation
10. extension & training
11. Do nothing

12 others……………………….

Table B.9. Organizational contacts and participation in clubs, groups, associations

1. Have you or some other member of your family had contact with any technical assistance,

extension service or outside organization in the last 5 years up to now?

0=no (→Next table)
1=yes (→2)

organizationcode	2. What is/was the name of the organization?	3. Who participated or is participating from your family? *If more than one family member participated use different rows per each.*	4. For how many years has this household member been active with this organization?	5. How many years ago did you quit working with this organization?	6. Have you received any information about agricultural production from this organization?	7. In general, how often do you attend meetings?	8. How do you characterize the particpation of your family member (or yourself) in this group? I prefer frequencies, by person
	name	HH member code from table 1.	Number of years	Number of years ago	0=no 1=Yes	code (**MEETFREQ**)	code **(PARTIC)**

				(0)=still active)			
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

MEETFREQ	**PARTIC**
1=weekly	1=I am an officer (president, treasurer etc)
2=every 2 weeks	2=I always attend meeting
3=monthly	3=Sometimes attend meeting
4=2x per year	4=I rarely attend meetings

Table B.10. Household food insecurity access scale (HFIAS)

Adapted from FANTA and revised by the FAO Nutrition Division,Oct 2006.

For each of the following questions, consider what has happened in the past [30 days or 4 weeks – country specific terminology]. If the answer is yes, indicate whether this happened rarely (once or twice), sometimes (3-10 times), or often (more than 10 times) in the past 30 days? [or ask how frequently it happened and code according to the given range]

Response Options

No = it did not happen in the past 30 days

Rarely = once or twice in the past 30 days

Sometimes = three to ten times in the past 30 days

Often = more than 10 times in the past 30 days

Or locally-defined explanations equivalent to these frequencies

NO.	Question	Response Options	Code
1	In the past [4 weeks], did you worry that your household would not have enough food?	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|
2	In the past [4 weeks], did it happen that you or someone in your household were not able to eat the <u>kinds of foods you would have preferred</u> to eat because of lack of resources? *(Note emphasis on KINDS of foods)*	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|
3	In the past [4 weeks], did it happen that you or any household member had to eat a <u>limited variety</u> of foods because of lack of resources?	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|
4	In the past [4 weeks] did it happen that you or someone in your household had to eat some foods that <u>you really did not want to eat</u> because of lack of resources? (*Note the emphasis is that one was forced because of no resources)*	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|
5	In the past [4 weeks] did it happen that you or any household member had to eat a <u>smaller meal</u> than you felt you needed because there was not enough food?	0 = No If yes: 1 = Rarely 2 = Sometimes	….|___|

		3 = Often	
6	In the past [4 weeks] did it happen that you or any other household member had to eat fewer meals in a day because there was not enough food?	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|
7	In the past [4 weeks] did it happen that there was no food to eat of any kind in your house, because of lack of resources to get food?	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|
	If yes, description of event *[not for data entry purposes but for verification of the answer]*:		
8	In the past [4 weeks] did it happen that you or any household member went to sleep at night hungry because there was not enough food?	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|
	If yes, description of event *[not for data entry purposes but for verification of the answer]*:		
9	"In the past [4 weeks] did it happen that you or anyone in your household went a whole day and night without eating anything at all because there was not enough food?"	0 = No If yes: 1 = Rarely 2 = Sometimes 3 = Often	….|___|

	If yes, description of event *[not for data entry purposes but for verification of the answer]*:	

Table B.11 Knowledge and perceptions on conservation practices and credit and loans

Conservation practice		***Reason for the practice***	***True(T)/False(F)***
Residue retention	9.1	Crop residues are a source of organic matter for soil.	
	9.2	Higher soil organic matter content improves water holding capacity.	
Soil fertilty mgmt	9.3	Manure is as strong of a fertilizer as purchased inorganic fertilizer.	
	9.4	Manure improves water holding capacity of the soil	
Tillage	9.5	I can plant directly into the soil without plowing.	

Now we would like to know how you percieve new farming practices. Kindly respond to the following by answering Yes or No to the statement.

Code	***Statement***	***Yes(1)/No(0)***
1	I update myself with current information on new farming practices	
2	I am cautious in trying out new farming practices	
3	I do not see why I should change my farming practices	
4	I only try out promisisng new practices	
5	I usually check out for results from my neighbors field before trying a new farming practice	
6	Taditional ways of farming are the best	

	9.6	Tillage assists in water infiltration.	
Seed bed	9.7	Increases soil water holding capacity	
	9.8	Improves aeration in the soil	
Rotation	9.9	Rotating cereals and legumes improves soil fertility	
	9.1	Prevents some plant diseases	
Cover crops	9.11	Prevents soil erosion	
	9.12	increases the microbes in the soil	

7	Less labor is used in the no-till system compared to the conventional tillage system	
8	Cost of land prepartion is less with zero/no-tillage compared to conventional tillage	
9	Yields from no-tillage plots are high or almost indifferent compared to conventional tillage	
10	Net benefit of the zero/no-tillage is higher than conventional tillage	
11	Tied ridging contibutes to water retention on the field	
12	Erosion through run-off is minized or stopped completely by tied ridging	

	1. Did anyone in the house ask for credit from any of the following sources during year 2012/2013?	2. Was the request accepted?	3. Why was your request refused?	4. What was the main use of the loan?	5.When did you get the loan?	6. What was the length of the loan in months (repayment)?	7. Was it in kind or in cash?	8. How much was the loan?		9. How much did you have to pay back (including interest)?	
	Please read each of the following sources		1=have debts	*See code sheet*	1=Jan	*Indicate length in months if there is a*	1=cash				
					2=Feb						
		1= yes→4	2=do not have guarantees		3=March		2=seed	in kind	cash	in kind	cash

							fixed date.					
	0=no →*next source un til the end of the list. If all 0 go to next table.*		**0= no→3**	3=not poor enough		....	98=end of harvest	3=fertilisers pesticides	*9999=does not know*	*9999=does not know*	*9999=does not know*	*9999=does not know*
	1=yes →2		*Go to next credit source until the end of the list*	4=other		12=Dec	99=no fixed date	4=other in kind				
Code		Code	code	*Go to table 4.2question no. 2*	loan code	month	no. of months	code	kg	currency	kg	currency
1	FORMAL BANK											
2	OTHER NGO											
3	LOCAL LENDER											
4	FAMILY/ FRIEND											
5	OTHER (SPECIFY)											
	………… …….											

1. What was the reason why you did not ask for credit last year?	2. How would you use the money if you could get the credit?	
1=Did not need it	1=seed	9=land
		10=land improvement (terraces, irrigation etc)
2=Interest rate too high	2=farm equipment	
3=No guarantees (collateral) for loan	3=animals	11=clothing

4=Too risky 5=Don't know how or where to get credit 6=I already have debts 7=Too many requirements 8=other (specifiy)		4=business 5=home imporvement 6=consumption 7=household items 8=fertilizer, pesticides other chemical inputs	12=wedding/festival 13=other
Code		Code	