Evaluating trade-offs between agricultural productivity and long-term ecosystem services provision among maize farmers practicing conventional and conservation agriculture in Kafue, Zambia

by

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DECLARATION OF ORIGINALITY

I, Namulula Mwangana, declare that the thesis/dissertation, which I hereby submit for the degree of MSc (Agric) Economics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature .... Date..

DEDICATION

I dedicate this dissertation to my husband, Lloyd Muyumbana Simambo for his sincere love and encouragement, and to my family for their inspiration and support in advancing my education.

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Degree: MSc Agric (Agricultural Economics)

Supervisor: Professor Eric Mungatana

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ABSTRACT

Maize is a staple crop and underpins food security for Zambia. Maize productivity in Zambia is almost half the potential due to low uptake of conservation agricultural practices. This study tests the hypothesis of the trade-offs between agriculture productivity and long-term ecosystem services (ES) provision among maize farmers practising conventional agriculture on the one hand, and those practising conservation agriculture on the other hand, in Kafue district, Zambia. In addition, challenges which affect conservation agriculture uptake are assessed. Besides these challenges, the study notes that adoption of a new technology is also influenced by its efficiency, and therefore technical efficiency scores were estimated using the Stochastic Frontier Approach (SFA) to compare efficiency levels of the two agricultural systems. Kafue was purposefully selected as it is among the first districts where conservation agriculture was introduced. Through purposive and random sampling, the households surveyed were split into two distinct groups namely conservation agriculture (CA) farmers (treatment group) and conventional agriculture (CV) farmers (control group).

The analysis significantly shows that farmers practicing CA have more knowledge than CV farmers about the capacity of conservation agriculture to reduce soil erosion, increase soil

fertility, retain nutrients, mitigate pests and weeds and increase crop yield. However, both farming groups knew that CA helps conserve soils and that soil maintenance is important for food production. On the other hand, significantly, CV farmers knew more than CA farmers that CV reduces crop yield and increases soil erosion. On the other hand, CV farmers expressed a higher level of willingness to adopt CA practices than CA farmers who are unwilling to expand their area under CA. The study further shows that at least 55% of farmers practicing CA find inadequate labour to be the main challenge faced in CA. It appears that a policy that improves the farmers' knowledge on CA would help improve the uptake of CA.

CA farmers were significantly more knowledgeable than CV farmers about the detrimental effects of CV, such as increasing air and water pollution, thus raising the need for training among CV farmers with emphasis on the effects of their farming system on the environment which affect the supply of ecosystem services.

Efficiency is also a means of improving productivity hence the Stochastic Frontier Analysis (SFA) was employed to estimate technical efficiency levels in maize production. Using SFA, the study found that the technical efficiency of maize among CV farmers is 71.3% on average while that of CA farmers is 57.9% on average. Moreover, the study found that there was a significant difference (t=3.9854, P=0.0002) in the technical efficiency scores of the both CV and CA farmers. Nevertheless, the study also found that 77% of output variation among CA farmers can be explained by variation in technical efficiency. However, 33.4 % of total maize output can be explained by variation in technical efficiency among CV farmers. This means that CA farmers have a higher potential to increase their current output than CV farmers.

Finally there was no significant difference in fertiliser usage between CA and CV farmers (t=1.3825, P=0.1700). Further, from SFA fertiliser responsiveness to maize output showed that a 1% increase in the use of synthetic fertiliser leads to 0.678% and 0% increase in maize output per hectare for CA and CV respectively at both 1% and 10% level of significance at the expense of water and air quality. Therefore, it can be concluded that there is a higher trade-off between maize production and water and air quality under conventional than under conservation agriculture.

Key words: ecosystem services, productivity, trade-offs, farmer knowledge, conservation agriculture, conventional agriculture, maize production, technical efficiency.

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LIST OF ABBREVIATIONS

CFU	Conservation agriculture Unit
ES	Ecosystem Services
FAO	Food Agriculture Organisation
FISP	Fertiliser Input Support Program
GART	Golden Valley Agriculture Research Trust
HA	Hectare
KG	Kilograms
MAL	(Zambian) Ministry of Agriculture and Livestock
ML	Maximum Likelihood
RTS	Return to Scale
SSA	Sub-Saharan Africa
TE	Technical Efficiency
UNDP	United Nations Development Programme
WB	World Bank
WFP	World Food Programme
ZMW	Zambian Kwacha

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

Agriculture is important for the growth of Sub-Saharan Africa (SSA). Agriculture accounts for 65% of Africa's labour force and 32 percent of SSA Gross Domestic Product (GDP) (World Bank, 2013). The per capita growth of the SSA agriculture sector lags behind other regions (Todaro and Smith, 2009) and the world's highest prevalence of hunger is found in SSA where 25 percent of the population is undernourished (FAO, 2015). The World Bank (2013) has singled out agriculture as the key sector in reducing poverty, hunger and degradation of the natural environment. The hunger situation in SSA is predicted to worsen in future due to predicted climate change. The most vulnerable households to hunger are disproportionately affected by climate shocks (WFP, 2016). Increasing agricultural production and productivity to reduce hunger and poverty remain a challenge in SSA. The most prevalent farming systems in SSA accelerate land degradation and soil fertility loss.

Therefore, given the abovementioned challenges, the promotion of sustainable agricultural practices is a vital policy intervention to ending the vicious poverty cycle in SSA. Agricultural land is important for the production of fibre, fuel and food. Contemporary agriculture has recorded notable successes in increasing food, fibre and fuel production. Besides the positive result of increased food, fibre and fuel production in striving to meet the growing world demand due to population increase and changes in preferences and tastes, agriculture has led to negative impacts also. For instance, some farming systems have resulted in soil degradation, reduction in soil fertility and water pollution which result in costs that will one day need to be taken care of by others (Pretty et al. 2001). The decline in soil fertility leads to a decline in crop productivity, consequently leading to increased rural poverty and food insecurity (Andersson and D'Souza, 2014). Sometimes the negative impacts resulting from such practices may not be felt in the short run. However, in the long run such impacts tend to be massive on both agricultural production and the environment.

Besides food production, agricultural land also provides other ecosystem services (ES). ES refer to the gains people get from the natural environment (Kragt and Robertson, 2012). These services include biodiversity, control of pests, diseases, and weeds, pollination, soil quality, carbon sequestration, nutrient management, resistance and resilience to climate change, water-holding capacity and crop productivity (Kremen and Miles, 2012). The ES are classified into four groups (The Millennium Ecosystem Assessment (MEA), 2005):

- Supporting services: This refers to services which are important for the production of other ecosystem services, for example, oxygen production.
- Provisioning services: This refers to products which are obtained from the ecosystem. These products include fuel, water and food.
- Regulating services: This refers to the gains obtained from the ecosystem processes regulation such as water purification and climate regulation.
- Cultural services: These refer to the immaterial gains obtained from the ecosystems such as, recreation and aesthetic experiences.

Agricultural production systems affect the delivery of the aforementioned ES. Some agricultural systems can enhance or maintain the supply of ES while others tend to degrade the ES bringing about a trade-off between agriculture production and the supply of ES (Palm, Blanco-Canqui, DeClerck, Gatere and Graced, 2014). For example, Pacini, Wossink, Giesen, Vazzana and Huirne (2003) reported that intensive agriculture production systems such as conventional agriculture (CV) may offer an increased yield but degrades the supply of ES. In conventional agriculture, crop productivity is maintained by heavy reliance on chemical fertilisers. Furthermore, CV is characterised by mono-cropping, burning of crop residues and complete tillage (Baudron, Mwanza, Triomphe and Bwalya, 2007). A trade-off of ES for increased agriculture production poses a challenge to environmental and agriculture sustainability including crop production, thereby increasing food insecurity and poverty. CV also has environmental consequences, such as soil degradation, that consequently reduce crop productivity. CV further contributes to climate change and loss of biodiversity (Conservation agriculture Unit, 2012). CV tends to concentrate on immediate productivity at the expense of long-term costs such a degradation of ES.

On the other hand, conservation agriculture (CA) is among the methods that strike a balance between increasing agriculture production and the supply of ES. CA originated in North America in the 1930s. It was aimed at reducing soil erosion and thus conserving the soils. CA is based on three principle practices, which include continuous minimal mechanical soil disturbance, permanent soil cover and crop rotation (FAO, 2011). A combination of these practices results in synergies in agriculture. For example, cover crops can increase soil organic matter, which increases water storage and reduces soil erosion. Also, incorporation of legumes in crop rotation can maintain soil fertility by reducing nutrient losses. Retaining crop residues can reduce soil erosion and increase soil carbon sequestration which assists in climate change mitigation. Furthermore, CA enhances the provision of ES thus addressing problems of declining crop productivity and soil organic matter and soil erosion caused by intensive agriculture production systems (Haggblade and Tembo 2003; Dale and Polasky, 2007; Thierfelder and Wall 2012; Kragt and Robertson, 2012). In this regard, CA is seen as an alternative farming system that offers minimal trade-offs between increased agriculture production and ecosystem services.

Knowledge of trade-offs, synergies and the environmental impacts of agricultural production systems facilitates a shift from one system to the other. The Doré et al. (2011) study found that farmers use knowledge, based on their own experiences and on exchanges with other farmers and advisers, thus building their own knowledge. Farmers' choice of inputs and farming systems results in trade-offs between agricultural production and ecosystem services such as biodiversity, water and soil quality (Jolejole, Swinton, Robertson, and Syswerda, 2009). Therefore, given the trade-offs and synergies of agriculture production systems, technology selection and policy intervention are important to minimise environmental consequences of agriculture technology, and increase productivity. This would consequently improve farm incomes and economic welfare of the smallholder farmers.

1.2 BACKGROUND

In Zambia, smallholder agriculture is the major contributor to food and nutrition security and is also the main source of income for the rural population. The smallholder farmers cultivate land below 20 hectares (Saasa, Chiwele, Mwape and Keyser, 1999). About 70% of Zambia's population rely on agriculture for their livelihood (Sitko et al. 2011). Just as in other SSA countries, agriculture in Zambia is dominated by two production systems, namely CV and CA. CV has been in existence since independence, dating back to 1964, while conservation agriculture was introduced in the early 1990s (Baudron et al., 2007). CA was introduced in Zambia to help reverse the declining productivity and improve food security (Andersson and D'Souza, 2014). It was promoted by the Conservation agriculture Unit (CFU) and Golden Agriculture Research Trust (GART). CFU is a unit that was established by the Zambia National

Farmers Union (ZNFU) and it has taken a central role in CA promotion and smallholder farmer training in the country. The other organisation that has promoted conservation agriculture is the Food and Agricultural Organisation of the United Nations (FAO) (FAO, 2011). This study comes at a time when climate change threatens to exacerbate the food insecurity situation in SSA and when governments and development organisations are looking at CA as the viable and sustainable choice for smallholder farmers to minimise the impact of climate change on agriculture.

1.3 PROBLEM STATEMENT

The global population is estimated to increase by at least 1 billion from 2015 to 2030, reaching 8.5 billion in 2030, and to reach 9.7 billion by 2050. Africa has the fastest growing population among the major continents (United Nations, 2015). The projected increase in world population is making exceptional demands for food and natural resources. To produce food which satisfies the growing demand, it will require increased agricultural production through agricultural intensification (Foley et al., 2011) and sustainable use of the natural environment. Cultivation methods that lead to reduced soil productivity would make meeting world demand for food in the long run problematic. Agricultural practices that degrade the environment include monoculture production, high dependence on pesticides and herbicides, burning of crop residues and intensive tillage. Zambia has not been left out in the pressures of a rapid population on the food system (Sitko et al., 2011).

CA is seen as the solution to production challenges confronting the smallholder farming community in SSA (Shaxon, 2006). However, little is known about the smallholder farmers' knowledge of CA. Moreover, smallholder farmers' perceptions need to be regularly established since they change. Knowing the farmers perceptions and knowledge of CA would help to know how best to increase CA adoption rates.

In Zambia maize is the main staple crop and it dominates smallholder cropping patterns. It is grown in all the districts, including Kafue district (Arslan, McCarthy, Lipper, Asfaw, and Cattaneo, 2013). More than 80 percent of rural smallholder farmers grow maize as their main crop. Therefore, maize is the major crop that underpins food security. Thus, increasing maize productivity is critical for the country. Maize has received massive support through the Farmer Input Support Programme (FISP) and has a well-established market through the Food Reserve Agency (FRA). FISP is a Zambian agricultural programme that provides subsidised inputs to smallholder farmers without which crop rotation might not have been encouraged (Umar, Aune, Johnsen, and Lungu, 2011).

Despite the aforementioned importance of maize to Zambia's economy, the average productivity of maize from smallholder farmers is below the average global yield. Several factors are responsible for this low productivity, but land degradation and loss of soil fertility due to intensive use of CV are seen as the prominent causes of low productivity (Chapoto, 2010). Being resource constrained may lead the smallholder farmers to opt for low input unsustainable farming systems such as CV (Todaro and Smith, 2009).

The negative trade-offs in CV have resulted in a decline in rural human welfare. This has necessitated the promotion of adoption of CA. Empirical evidence has shown the attractive benefits of CA. For instance, studies on CA basins in both Zambia and Zimbabwe have revealed significant increases in maize yields in comparison with conventional agriculture tillage methods. The increase in maize yields in CA basins were observed because of early sowing , water harvesting potential, improved infiltration of water in the basins, and more utilisation of nutrients as the nutrients are closest to the plants (Umar et al., 2011). Yet other studies have claimed that the benefits are season specific. Chikowo (2011) and Rusinamhodzi et al. (2011) found that CA based on crop rotation, soil cover and high input use increased maize yields over time in low rainfall areas.

Andersson and D'Souza (2014) argue that farmers do not achieve the expected benefits due to partial implementation of CA principles on which its benefits rests. CA principles are not always fully implemented by smallholder farmers due to various constraints. The constraints frequently observed in the literature include limited availability of crop residues and competing uses for crop residues, weed pressure (Umar et al., 2012; Marongwe et al., 2011), capital requirements for accompanying fertilisers, herbicides, implements (hoes, rippers, sprayers) and labour demand for weeding for those without herbicides (Baudron et al., 2012; Mazvimavi, Ndlovu, Henry and Murendo, 2012). A shift of the labour burden to women is also observed as a concern. Thus the suitability of CA for smallholder farmers in Africa has been questioned considering the economic and social conditions.

Furthermore, CA is associated with higher input use than conventional agriculture. The higher input use translates into higher input costs (Gowing and Palmer, 2008; Giller, Witter, Corbeels and Tittonell, 2009). Moreover, according to Mazvimavi et al. (2012) the technical efficiencies of the two technologies were observed to be the same at about 68% among the smallholder maize farmers in Zimbabwe. These scores can be used as a guide to establish the continued practice of CV by smallholder farmers amidst its trade-offs. Scientists have been cautioned against promoting CA as a universal remedy to reduced agricultural productivity and land degradation (Giller et al., 2009). Despite these controversies surrounding CA, its promotion among smallholder farmers is growing because of its role in increasing crop productivity and protecting the environment. However, CA's adoption among smallholder farmers has been low (Environmental Conservation Association of Zambia (ECAZ), 1999; Chiputwa, Langyintuo and Wall, 2011; Erenstein, Sayre, Wall, Hellin and Dixon, 2012) despite having higher returns than CV (FAO, 2011). There is need to establish smallholder farmers' perceptions and knowledge of CA in order to understand the prevailing low adoption rates.

1.4 RESEARCH OBJECTIVES

(i) To determine farmers' factual knowledge of the relative capacities of conventional and conservation agriculture to supply ecosystem services.

(ii) To estimate levels of technical efficiency across the two farming systems.

(iii) To identify factors that explain variations in technical efficiency levels of farmers across the two farming systems.

(iv) To assess farmers' willingness to adopt conservation agriculture in the interest of enhanced production of ecosystem services.

(v) To assess constraints farmers face in adopting conservation agriculture in the interest of enhanced production of ecosystem services.

1.5 STUDY HYPOTHESES

Understanding the trade-offs and synergies produced in conventional agriculture and conservation agriculture respectively is important in sustainably increasing agricultural productivity and enhancing the supply of ecosystem services (Kassam and Friedrich 2011; Kragt and Robertson, 2012; Kremen and Miles, 2012). On the other hand, conventional agriculture increases crop production at the expense of ecosystem service delivery. However, the two farming systems have the same production efficiencies. In the study by Mazvimavi et al., (2012), the results revealed that maize production technical efficiency levels for conventional and conservation farmers were the same with an average of 68 percent across the two farming technologies in Zimbabwe. Consequently, the following hypotheses were proposed:

Hypothesis 1:

H_0: farmers who practice conservation agriculture are equally likely to know about its capacity for delivering ecosystem services as farmers who practice conventional agriculture.

H_1: farmers who practice conservation agriculture are more likely to know about its capacity for delivering ecosystem services than farmers who practice conventional agriculture.

Hypothesis 2:

H_0: farmers who practice conventional agriculture are equally likely to know about its capacity for delivering ecosystem services as farmers who practice conservation agriculture.

H_1: farmers who practice conventional agriculture are more likely to know about its capacity for delivering ecosystem services compared to farmers who practice conservation agriculture.

Hypothesis 3: The technical efficiency of conventional agriculture and conservation agriculture is the same.

Hypothesis 4: Conservation farmers are more likely to expand the area under conservation agriculture than conventional farmers are to adopt conservation agriculture practices.

1.6 SIGNIFICANCE OF STUDY

Agriculture is the backbone for the rural population in developing countries who continuously mine nutrients from agricultural lands without replenishing them. This is done in order to sustain their livelihoods, but at the expense of the supply of ecosystem services that support agricultural production. However, conventional agriculture in the long term would reduce the capacity of land to produce adequate food quantities thus justifying the promotion of conservation agriculture as one of the methods to increase productivity with available resources thus improving smallholder household food security (Marongwe et al., 2011).

Different studies in Zambia have been on issues related to conservation agriculture. Studies have been done to assess the determinants of adoption of conservation agriculture (Ng'ombe, Kalinda, Tembo and Kuntashula, 2014; Arslan et al., 2013) such as drought mitigation (Mhambi-Musimwa, 2009), mitigating the effects of climate change (Nyanga et al., 2011), and yield gains (Haggblade and Tembo, 2003). Therefore this study establishes the farmer's knowledge of the trade-offs and synergies of conventional and conservation agriculture on crop productivity and ecosystem services delivery and extends to the willingness of farmers to adopt conservation agriculture which is still unclear in Zambia. The findings of this study would help the Ministry of Agriculture and other stakeholders in the promotion of environmentally friendly agricultural practices to redress imbalances between food production and ecosystem service provision. In addition, the study findings would help farmers become more efficient as the efficiency scores will reveal the potential for productivity improvement by improving technical efficiency.

It is also important that farmers, as land managers, understand that there are agricultural practices that can protect their environment. This study will allow smallholder farmers to become aware of environmentally sound agricultural practices that also enhance ecosystem service provisioning. In this way, the smallholder farmers will be able to sustain their livelihoods and at the same time preserve the land for future generations. This study will also provide insight into what farmers know about the agricultural practices in relation to the environment and ecosystem services, which will allow policy makers to develop appropriate technologies amidst the challenges they face. Consequently, this will alleviate poverty levels among the rural population.

In conclusion, well-managed agricultural lands through conservation agriculture will strike a balance between increased agriculture yields and enhanced or maintained supply of ecosystem services and consequently reduce negative environmental effects. Hence, this justifies the need for this study.

1.7 ORGANISATION OF STUDY

This dissertation is divided into five chapters. The first chapter gives an introduction to the study. In this chapter, the background and problem statement, research objectives, and the justification of the study are given. The second chapter highlights the review of literature on farming systems trade-offs and synergies with regard to ecosystem services and the environment. It further looks at technical efficiency studies. This is followed by the third chapter that looks at the research methods and procedures. It includes method of data collection, characteristics of the study area, and the sampling method used. It continues to look at the theoretical and empirical methods used in the data analysis. The fourth chapter provides the results and discussion of the study. Finally, the fifth chapter provides a conclusion and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews literature on ecosystem services associated with conservation and conventional agriculture. It discusses the trade-offs that occur in conventional agriculture. It also reviews studies on production efficiency. The chapter further highlights the methods of analysis commonly used in thne study of ecosystem services in agriculture.

There are a number of studies that have been done on conservation agriculture which include adoption studies, efficiency studies and returns to conservation agriculture in comparison to conventional agriculture. Furthermore, some studies have been done to determine socio-economic factors that have an influence on decisions on whether to adopt a given technology.

Independent studies have also been done on farmers' perceptions and knowledge of ecosystem services and farming systems. For instance, comparisons have been made between two different farming technologies, such as organic farming and diversified farming versus conventional agriculture.

2.2 CONSERVATION AGRICULTURE AND ECOSYSTEM SERVICE DELIVERY

Conservation agriculture is a holistic farming system in promoting sustainable agricultural development. According to Erenstein et al. (2008) conservation agriculture is being promoted generally in many areas of Sub-Saharan Africa and elsewhere in the tropics to restore degraded soils. However, conservation agriculture in Africa, Sub-Saharan Africa inclusive, is limited among other reasons by the amount of residues produced due to low productivity, and other uses of residue (Giller et al., 2009; Palm et al., 2014). In Zambia conservation agriculture was promoted as a strategy to improve soil productivity. According to The Conservation Farming Unit (CFU) (CFU, 2006) farmers were engaged in inefficient, exploitative and environmentally destructive agricultural practices such as monocropping for a long time. The study also reported the heavy application of mineral fertilizers as one of the reasons for land degradation. Another study by Haggblade and Tembo (2003) reported that excessive use of subsidized mineral fertilizers from the early 1970's until 1991, coupled with low levels of organic material led to serious land degradation characterized by erosion, acidification, reduction in Soil Organic Matter (SOM) and a buildup of plough pans across much of the southern part of the country.

Conservation agriculture has economic, agronomic, environmental and social benefits. Environmental benefits refer to benefits that support ecosystem services, protect the soil and make agriculture more sustainable. These benefits include reduction in soil erosion, efficient nutrient cycling, improvement of air and water quality, biodiversity increase and carbon sequestration. Economic benefits refer to benefits that improve production efficiency by reducing production costs whereas the agronomic benefits refer to benefits that improve soil productivity; the. To achieve these benefits conservation agriculture depends on three principles that enhance ecosystem service delivery namely minimum mechanical soil disturbance, crop rotation and permanent soil cover (FAO, 2011). A number of studies have been conducted to investigate how conservation agriculture benefits the environment and enhances ecosystem service provision (Erenstein, Sayre, Wall, Dixon and Hellin, 2008; Giller et al., 2009; Palm et al., 2014; Kassam and Friedrich, 2011; Sanderson et al., 2013).

According to Holland (2004), the principle of minimum soil disturbance and use of cover crops reduces nutrient and soil runoff and pollution as well as mitigate climate change. Further, Kassam and Friedrich (2011) revealed that legumes in conservation agriculture rotations result in reduction of applied quantities of nitrogenous fertilizers due to increased nitrogen availability. Appropriate sequences in crop rotation will also enhance biodiversity as each crop will draw a different spectrum of microorganisms. Rotation of crops adds fertility to the soil, reduces the build-up of weeds, insect pests and pathogens by disrupting their life cycles, making them more susceptible to natural predator species.

Conservation agriculture has resulted in trade-offs between agricultural productivity and ecosystem service provision. There are positive trade-offs in conservation agriculture. Citing examples, Kragt and Robertson (2012) state that the use of minimum tillage and cover crops increases the soil organic matter which helps in water storage and reduces soil erosion; legumes maintain soil fertility by reducing nutrient losses; and retaining crop residues can reduce soil erosion and increase soil carbon sequestration, which assists in mitigating climate change . These trades-offs result in improved agricultural productivity and enhancement of other ecosystem services and farmers practicing conservation agriculture are able to meet their food needs from smaller pieces of land.

2.3 CONVENTIONAL AGRICULTURE AND ECOSYSTEM SERVICE DELIVERY

Conventional agriculture affects the delivery of ecosystem services and the environment, as well as human health (Foley et al., 2005; Tegtmeier and Duffy, 2004). Conventional agriculture involves practices such as burning of crop residues, mono-cropping and complete tillage (Baudron et al., 2007). These agricultural practices reduce ecosystem services such as soil fertility, organic matter and water-holding capacity and consequently reduce agricultural productivity. Comparison studies with respect to ecosystem service delivery of conventional agriculture and other farming systems have been done. Kremen and Miles (2012) suggest that in comparison with conventional agriculture, diversified farming exhibits greater biodiversity, soil quality, carbon sequestration, and water-holding capacity in surface soils, energy-use efficiency, and resistance and resilience to the impact of climate change.

In another study, Sandhu, Wratten and Cullen, (2010) compared conventional agriculture to organic farming based on three ecosystem services, namely biological pest control, soil formation and plant nutrient mineralisation. This study showed that biological pest control in conventional agriculture was rigorously and significantly reduced compared with fields under organic farming. Although the ecosystem services associated with soil formation and plant nutrient mineralisation did not differ significantly between organic and conventional agriculture, and yields obtained in organic farming were similar to those in conventional ones.

The comparative studies conducted by Palm et al., 2014 among others, concluded that conservation agriculture compared to conventional agriculture practices produces the soil conditions that result in reduced erosion and runoff and improved water quality. Similarly, water-holding capacity and storage are enhanced with conservation agriculture providing some buffer to crop production during drought conditions. Soil organic matter is nearly consistently higher in the surface soil with conservation agriculture practices compared to conventional practices and influences many other soil properties and processes involved in the delivery of ecosystem services. The deliveries of most other ecosystem services, including soil carbon sequestration, emission of greenhouse gases, and pest control, are not so clear cut.

Tegtmeier and Duffy (2004) reported on the human health and environmental concern of agricultural practices associated with conventional agriculture. The environmental problems include biodiversity loss, climate change, pollution and declining soil quality. Mono-cropping leads to biodiversity loss, and complete tillage and lack of soil cover results in soil erosion. In addition, conventional agriculture leads to heavy reliance on chemical fertilisers to maintain crop productivity. Smallholder farmers in Zambia perceive conventional agriculture to have economic benefits such as reduced labour input, easiness with managing of weed pressure, destroying pests and soil fertility enhancement (Baudron et al., 2007). Indeed, a study by Kanmegne (2004) highlighted that burning of fields reduces the weed seed-bank, cleans the field and improves short-term soil fertility. But these benefits are a trade-off against other ecosystem services in the long term.

Similarly, conventional agriculture practices affect human health through air and water pollution For instance, runoff from lands under agriculture in the form of soil erosion, pesticides, and other agricultural and animal wastes, pollute the water bodies such as rivers and streams and soil particles released by soil erosion and smoke from burning of fields pollute the air (Pimentel, Hepperly, Hanson, Douds and Seidel, 2005).

2.4 TRADE-OFFS OF FERTILISER USAGE IN CONVENTIONAL AGRICULTURE

Foley et al. (2005) and Sandhu et al. (2010) observed that increases in food production trades off the supply of long-term ecosystem services. Modern agriculture focuses on the use of mineral fertiliser, water and pesticides to increase food production and productivity at the expense of ecosystem services provision and the environment (Tilman, Cassman, Matson, Naylor and Polasky, 2002). Mineral fertilisers contain nitrogen and phosphorous and are a source of agricultural nitrogen. Among other sources are animal waste and nitrogen fixing plants. The majority of the crops only take up 30 to 50% of nitrogen applied and the other 50% is lost to the environment. The nitrogen lost to the environment results in negative consequences which include soil degradation, green gas emissions, eutrophication of surface and ground water that leads to the death of fish and other wildlife. Additionally, the nitrogen lost to the environment negatively affects human health when consumed.

Umar et al., (2010) compared conservation and conventional agriculture, according to inorganic fertiliser usage. The study showed that more fertiliser was used on the conventional agricultural plots. Furthermore, Baudron et al. (2007) reveal that conventional agriculture and excessive use of inorganic fertilisers resulted in land degradation in Zambia. Therefore, increasing crop production by excessive use of fertiliser in the long term counteracts the ability of lands under agriculture to produce large amounts of food and fibre. However, in the long term, conservation agriculture maintains yields more effectively than conventional agriculture.

2.5 CHALLENGES ASSOCIATED WITH CONSERVATION AGRICULTURE

Conservation agriculture has its challenges, which includes the competing uses of crop residues (livestock grazes on the crop residue), high labour demand and high input use. The inputs in this case, include hybrid maize seed, manure, lime and synthetic fertilisers (urea and D compound). The high labour demand (weeding and land preparation) and high input use under conservation agriculture are some of the challenges that farmers face in adopting the technology (Baudron et al., 2007; Mazvimavi et al., 2012). The figure below shows the constraints related to conservation agriculture practices.

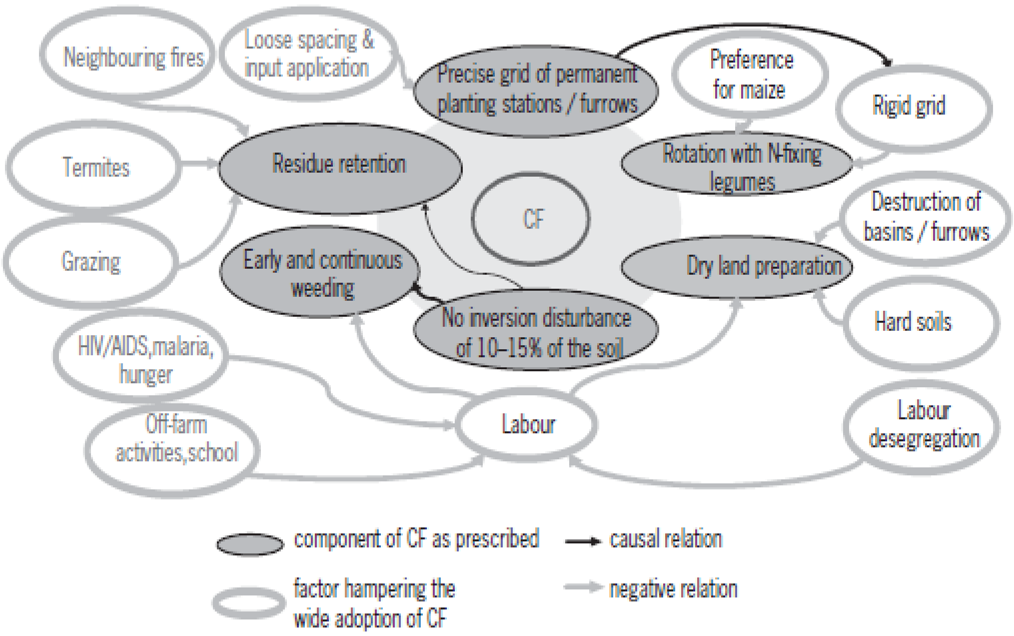

Figure 2. 1: Constraints associated with conservation agriculture
Source: Baudron et al., 2007

However, the promoters of conservation agriculture have argued that the need for synthetic fertilisers in conservation agriculture in the long term, compared to conventional agriculture, is reduced due to legumes incorporated in the rotation, lower nutrient losses through erosion and leaching and higher availability of soil nutrients to the crop. They have further argued that the demand for labour decreases progressively yearly as farmers gain more experience and do it correctly. The labour demand is halved after six years (Giller et al., 2009). In addition, the use of herbicides has been recommended to counter the high labour demand for weeding, but these result in additional costs. The use of herbicides in conservation agriculture is higher than in conventional agriculture due to the increased weed pressure under conservation agriculture. However, according to Baudron et al. (2007) conservation agriculture using basins almost doubles weeding effort compared with the conventional ploughing system. Similarly, it increases labour requirements for preparing land in the first year. For land preparation, the promoters have argued that since it is done in the dry season (off-farming season) the labour supply is adequate since there are only a few income-generating activities that farmers are engaged in during the off-farming season.

2.6 MAIZE PRODUCTIVITY

The production of food, fibre, fodder and other consumable goods and services is the main purpose of agriculture. In southern Africa, cereals and grains are the most important crops. The cereals and grains produced include maize, sorghum, millet, wheat and rice. Among them, maize is the main staple for consumption, provides fodder for livestock and for other countries it is exported (Khumalo, Chirwa, Moyo and Syampungani, 2012). In this regard, Chapoto (2010) says that about 80 percent of Zambian smallholder farmers grow maize though it is still coupled with low agricultural productivity. In addition, 59 percent of the area cultivated is allocated to maize leaving 41 percent for other crops (Burke, Hachaabwa, Banda and Jayne, 2011). The low agricultural productivity is attributed to unsustainable farming practices such as conventional agriculture practices. Conventional agriculture is associated with complete disturbance of the soil and a heavy reliance on inorganic fertilisers to maintain crop productivity.

Maize is a staple crop in Zambia. The graph below shows the data on Zambia's maize production and yield per hectare in tonnes. The yield is a measure of productivity (that is, expected output over a given cultivated area). From the graph, production and yield levels have fluctuated over the years. However, there is a similarity in the shape of the curves for both production and yield. In 1992, there was a sharp decline followed by an increase in 1993 and 1996 in both production and yield tonnage.

Sitko et al. (2011) attributed the increase in crop productivity from 2006 upwards to favourable weather conditions. An increase is also observed from 2009 to 2011 for both production and yield, with 2011 recording the highest yield of 2.7 tonnes/ hectare. Yet the yields are still below the global average (4 tonnes/ hectare). The increase in tonnage could be attributed to the good rains throughout the country recorded between 2010 and 2012. The years of similar behaviour show a relationship between production and yield. It shows a positive relationship implying that as production increases, the yield also increases and vice versa.

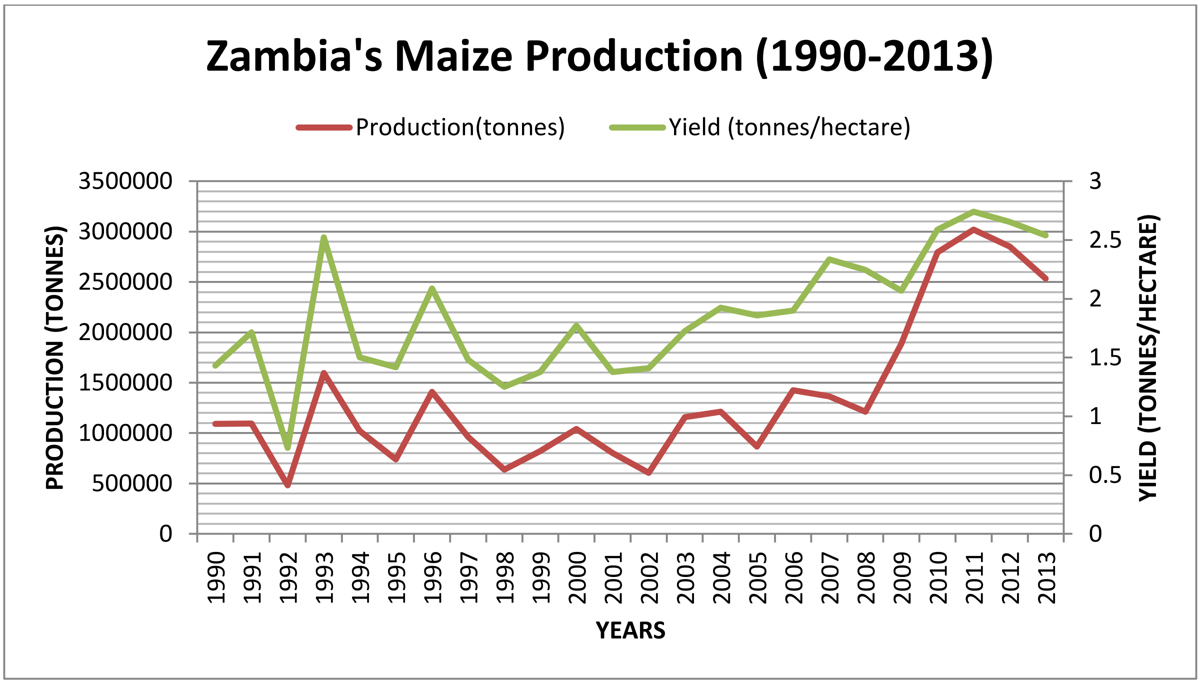

Figure 2.2 Zambia's maize production (1990-2013)
Source: Authors construct from FAOstat

Another reason for increases in productivity is the use of fertilisers. According to the United Nations Development Programme (UNDP) (2010), agricultural productivity increases are heavily dependent on fertiliser and liming in Zambia. This is supported by the introduction of maize subsidies to smallholder farmers by the Zambian government through the Farmer Input Support Programme (FISP). This has to some extent increased the smallholder farmers’ access to fertilisers and certified seed. The farmers access maize seed and fertiliser (top and basal dressing) at a subsidised price. The promotion of conservation agriculture practices is also one of the reasons attributed to increased yield. It is in this regard, that to address low agricultural productivity levels there is need to promote sustainable agriculture. Sustainable crop production intensification requires concurrent achievement of increased agricultural productivity and enhancement of natural capital and ecosystem services, efficient use of important inputs such as water, nutrients, pesticides, energy, land and labour, use of managed and natural biodiversity to build system resilience to biotic and economic stresses. Conservation agriculture meets these requirements. It is aimed at improving yields in the long term in a viable and sustainable manner, though there are trade-offs in the initial years in the form of extra costs for herbicides and machinery. Improved crop yields will help farmers meet their food requirements from smaller pieces of land. Consequently, conservation agriculture contributes to an improved stability of food supplies (Kassam and Friedrich, 2011).

2.7 EFFICIENCY STUDIES

Agricultural efficiency studies have been done in developing countries on different crops and the agriculture sector. For instance a study in Ghana revealed that the agricultural sector was 18 percent technically inefficient and concluded that there was a negative relationship between land and agricultural output (Djokoto, 2012). The analysis was done using the Time Series Stochastic Frontier Estimation approach. Another study done in Eastern Ethiopia on vegetable production using the Data Envelopment Analysis approach, found the mean technical, allocative and economic efficiencies to be 91%, 60% and 56%, respectively (Haji, 2006). In Nigeria a study to evaluate the productivity and technical efficiency among beneficiary farmers of the Second National Fadama project in Kaduna State, using the stochastic frontier production function revealed that the mean technical efficiency of the project beneficiaries was higher (92%) than the mean technical efficiency (48%) of the non-beneficiaries (Simonyan, Olukosi, Omolehin and Atala, 2012.). Furthermore, a similar study was also done on Cassava, and the author concluded that cassava farms in the study area exhibit decreasing positive return-to-scale and the poor smallholder farmers were efficient in allocating resources (Ogundari and Ojo, 2006).

Efficiency studies have also been done to compare crops grown under different technologies using different functions. In Northern Ghana a study was done to estimate technical efficiency across different rice farming systems that are irrigators and non-irrigators. The findings are that rice farmers, both irrigators and non-irrigators, are technically inefficient. The average technical efficiencies for irrigators and non-irrigators were 51% and 53%, respectively (Al-Hassan, 2008). Another study on productivity and efficiency of maize producers revealed that the technical efficiency of maize grown under conservation and conventional agriculture were the same (Mazvimavi, 2012). According to Kibaara (2005) the mean technical efficiencies generated from the different functions namely Translog, Cobb-Douglas, quadratic and transcendental production functions were almost identical. The author also concluded that the use of purchased hybrid seed, use of tractors for land preparation, level of education, in interaction of off-farm income and education, purchase of hybrid seed on credit, younger age of the household heads and households in the high potential areas are associated with a higher technical efficiency. The technically inefficient producers make the lowest annual income that translates to less than one US dollar a day.

In Zambia, recent efficiency studies have been done on maize and sorghum. Kabwe (2012) and Chiona (2011) carried out an assessment of technical, allocative and economic efficiency of smallholder maize producers using the Stochastic Frontier Approach and the Data Envelopment Analysis. The studies showed technical, allocative and economic inefficiencies among smallholder maize producers.

Some researchers have also shown evidence of conservation agriculture yielding higher yields and profits than conventional agriculture in Africa (Haggblade and Tembo 2003; Nolin and von Essen 2005; Kabamba and Muimba-Kankolongo 2009; Ngwira et al., 2012). Nolin and von Essen (2005) attributed the improved yields under conservation agriculture to a combination of early planting, rainwater harvesting and better infiltration rates, and increased precision in applying inputs.

2.8 FARMERS' KNOWLEDGE REGARDING ECOSYSTEM SERVICES

A number of studies have been done to capture the perceptions and knowledge of farmers of ecosystem services on farmlands. Munyuli (2011) looks at the farmers' knowledge and perceptions of the importance of ecosystem services delivered in farmlands and of pollinators for coffee-yield increase and stability. Pollination is one of the ecosystem services delivered on agricultural land. This study was done in Uganda and it reveals that coffee farmers are not aware of the role of bees in the production of the crop. Bees provide an ecosystem service, specifically, a pollination service. The study also shows that the majority of the farmers feel and agree that some ecosystem services and functions are important in their crop production improvement, for instance restoration of soil fertility. However, about 70% of the male farmers believe that micro-organisms have no influence on soil fertility replenishment.

Sandhu et al. (2010) looked at perceptions of farmers of ecosystem services on arable farmland, bearing in mind that farmers are producers and beneficiaries of ecosystem services. A comparison is made on perceptions of farmers practicing conventional agriculture and organic farming and the study was done in Canterbury in New Zealand. This study showed that both organic and conventional farmers rank pollination and soil fertility as the most important ecosystem services. The top five important ecosystem services ranked by conventional farmers are food production, pollination, hydraulic flow, soil fertility and soil erosion control. Farmers practicing organic farming ranked pollination and soil fertility as the most important ecosystem services. This does not come as a surprise as their farming technology is more dependent on nature's services to support production of food and fibre. However, organic and conventional farmers did not differ significantly on their perceptions of ecosystem services except for biological control. For making comparisons of perceptions of individuals' ecosystem services by conventional and organic farmers the Fisher's exact test is used.

A study conducted in Namibia, South Africa, Botswana, Zimbabwe and Mozambique revealed that across all countries provisioning services such as fuel wood, grazing land, wild fruits and vegetables, construction materials and water supply are the common ecosystem services received. Services such as water regulation and flood control were the next most frequently mentioned while, in terms of supporting service, soil fertility is more often mentioned than biodiversity. Cultural services are almost never mentioned (Shackleton et al., 2008).

2.9 CONCLUSION

From the different studies highlighted above it be may concluded that conservation agriculture results in increased yields which translate into increased returns and high profitability. Despite the high profitability, there is a high input use. There is also evidence from the study done in Zimbabwe that the two farming systems have the same technical efficiency. Based on the high profitability farmers are more likely to choose conservation agriculture over conventional agriculture as supported by the "Theory of the Firm" which states that farmer (firm) has an objective to maximise profits. From the above studies, conservation agriculture also has attributes that enhance the provision of ecosystem services, thus the need to find out if farmers are aware of these benefits. There is also a need to carry out an efficiency analysis due to the high production costs under conservation agriculture and the continued practice of conventional agriculture.

The studies reviewed in this chapter used different approaches for analysis. The two methods of efficiency analysis used in the different studies are Data Envelopment Analysis and Stochastic Frontier Analysis. In this study the stochastic production frontier analysis was used.

CHAPTER THREE: RESEARCH METHODS AND PROCEDURES

3.1 INTRODUCTION

The overall purpose of the study was to compare conventional and conservation agriculture in terms of their production efficiency levels and potential for supplying ecosystem services among smallholder farmers. This included investigating the farmers knowledge of the trade-offs between increasing agricultural productivity and ecosystem services provisioning in conservation agriculture. On the other hand, it involved comparing production efficiencies, specifically technical efficiency scores across the two agriculture systems. Socio-demographic factors affecting the efficiency levels were investigated.

This chapter presents the research design, data collection, data analysis procedures and theory basis that were used to address the objectives of the study.

3.2 STUDY AREA

Zambia has three agro-ecological zones (Zone I, Zone II and Zone III) that are classified based on the amount of rainfall received. Agro-ecological zone I is characterised by low rainfall of less than 800 mm annually. It includes the southern portion of the Southern and Western Provinces. This zone is also associated with a short growing season, high temperatures through the growing season, and a high drought possibility. Zone III is characterised by high rainfall of more than 1000 mm annually. It also has a long growing season, low drought possibility, and cooler temperatures through the growing season. It includes areas in the north of the country in the Copperbelt, Luapula, Northern and North Western Provinces.

Agro-ecological zone II receives medium rainfall ranging from 800-1000 mm annually and falls in between Zone I and III for most climatic characteristics. It runs east-west through the centre of the country on the plateau of Central, Lusaka, Southern and Eastern Provinces. Agro ecological Zone II is further subdivided into, two namely IIa and IIb. Agro-ecological zone IIa comprises the degraded plateau of Central, Southern, Lusaka and Eastern provinces while Zone IIb is characterised by lower rainfall and sandy soils and passes through the Western Province (the semi-arid plains). Due to the climatic characteristic such as vulnerability to drought, adoption of conservation agriculture has been strongest in agro-ecological regions I and II (Haggblade and Tembo, 2003; Siegel, 2008; Baudron et al., 2007).

The research was conducted in Kafue district of Lusaka province in Zambia. Kafue lies in two agro-ecological zones, I and IIa, and conservation agriculture has been promoted in the district by the Conservation agriculture Unit (CFU), making the district suitable for this study. In addition, Haggblade and Tembo (2003) reported that particularly agro-ecological zones I and II soils became acidic thereby reducing land quality and productivity. Kafue district was purposely selected as it is one of the districts affected by low productivity and is among the first districts where conservation agriculture was introduced. It has three agricultural blocks which are further subdivided into 12 agricultural camps. Conservation agriculture is being promoted in eight agricultural camps but in this study four were randomly selected. These are namely Chikupi, Lukolongo, Kabweza and Mungu agricultural camps.

Based on the 2010 national population census data, Kafue district has an estimated population of 242 754 people of whom 69 percent live in rural areas with agriculture production being the main economic activity (CSO, 2011). It has five major land-based ecosystem services which include forestry, agriculture production, fresh water use, wetlands, and hydro-power generation which contribute to the livelihood of both the local and outside communities in the district. Furthermore, agriculture, livestock rearing, general trading are the main economic activities. Major crops grown in the district include maize, sugarcane, sunflower, groundnuts, cotton and beans. The map (Figure 3.1) below shows the location of Kafue district.

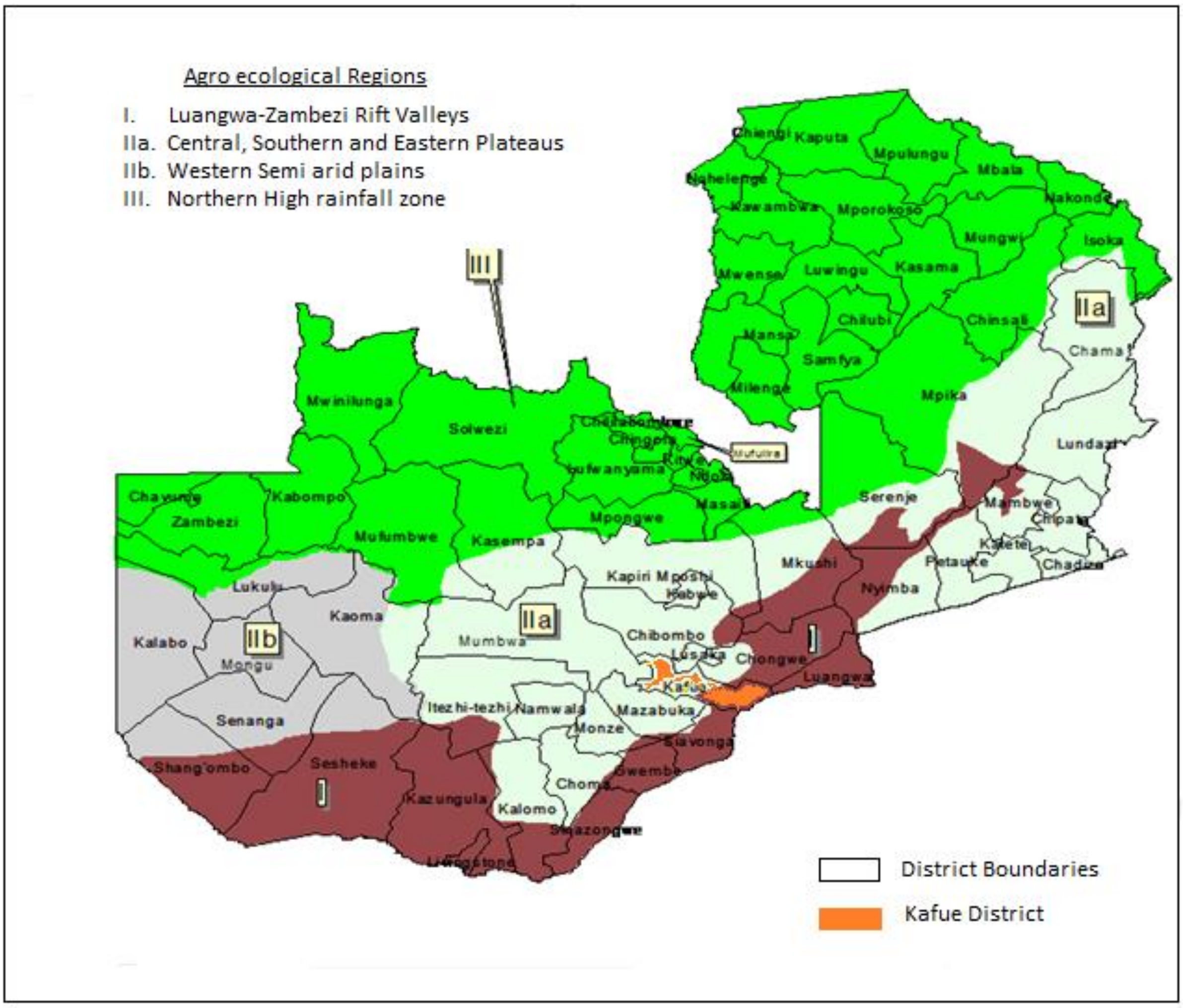

Figure 3.1: Agro ecological zones in Zambia
Source: Sitko et al. 2011

3.3 DATA COLLECTION METHODS

For purposes of this study, both secondary and primary data are used. Primary data were obtained based on the 2012/2013 farming season by administering a one on one questionnaire to the household heads. The household heads were interviewed using the pre-tested structured questionnaire. There were predetermined statements with regards to ecosystem services and environmental outcomes of agriculture systems. The statements were compiled from existing literature. To supplement the primary data, secondary data were sourced from the Ministry of Agriculture and livestock (MAL) and Conservation agriculture Unit who work closely with the farmers.

The enumerators made appointments with the lead farmers of conservation farmers in the areas under study. The purpose of the research study was explained to the farmers before administering the questionnaires.

3.4 SAMPLING

In this study the sample population was the smallholder maize farmers in Kafue district and the target for the questionnaire was the farming household .A basic rule in sampling is: The larger the sample, the more reliable the results (Leedy and Ormrod, 2013). However, such a generalised rule is not helpful to a researcher who has financial limitations. In this regard, it is important to note that the size of an adequate sample depends on how homogeneous or heterogeneous the population is with respect to the characteristics of research interest. According to Leedy and Ormrod (2013) if the population is heterogeneous, a larger sample would be necessary than if the population is fairly homogeneous. The smallholder maize farmers are fairly homogenous in Zambia (Saasa, 2003).

This study was based on purposive sampling. Purposive sampling was used because the main goal was to focus on particular characteristics of a population of interest in Kafue, which helped answer the research questions. The sampling was done in four stages. The researchers could not find a sampling frame for the farmers in Kafue district which segregates farmers practicing conventional agriculture and conservation agriculture respectively. In the absence of the sampling frame, based on a priori information, eight agricultural camps were purposefully selected from which four were randomly selected. In these eight camps CFU have their presence.

There were two sources of farmer lists used in the study. The first source was from the farmer facilitators under CFU. The famer facilitators are based in each camp and each has a list of conservation farmers from which conservation agriculture respondents were randomly selected. The farmer facilitators helped in the physical location of the respondents. The second source was from extension officers under the Ministry of Agriculture. The extension officers have a list of all the farmers in the camp, both conventional and conservation farmers. In this study the conventional farmers were identified with the help of the extension officer as the list was not segregated according to farming system. Building on the studies in (Dahlberg and Burlando, 2009; Grossman, 2015; McCann, 1997), 48 conservation famers and 50 conventional farmers, were sampled resulting in a total sample size of 98. Table 3.1 below provides the sampled respondents from the four villages.

Table 3.1: Sampled farming households

	Sampled Households		
Agricultural Camp	**Conventional farmers**	**Conservation farmers**	**Total**
Chikupi	16	7	23
Kabweza	12	13	25
Mungu	12	13	25
Shimabala	10	15	25
Total	**50**	**48**	**98**

3.5 THEORETICAL FRAMEWORK AND EMPIRICAL MODEL SPECIFICATION

In this study both parametric and non-parametric statistical methods were used. The parametric method used is the t- test .The T-test was used to test if there were any differences in the socioeconomic characteristics of conservation and conventional farmers. The non-parametric method used is the Chi-square test. The Chi-square test was used to test for differences in responses of the conservation and conventional farmers in the agreement of statements of ecosystem services provided by the respective farming systems.

3.5.1 Chi square test

The Chi-square test is used to compare proportions between two or more independent groups. Chi-square can also be used to investigate whether there is any association between two nominal variables. The assumptions underlying the use of a Chi-square test are that the sample must be randomly selected from the population and that the sample size, n, must be large enough so that the expected count in each cell is greater than or equal to 5.

The Chi-square test gives the probability that the data could occur by chance. The Chi-square test compares the observed value in the table with expected values if the two distributions are completely independent. The Chi-square test uses categories which are mutually exclusive (each observation falls in one category or class interval) and not more than 25% of the cells in the table should have expected values of less than 5. The null hypothesis for the Chi-square test is that the two binary variables are unrelated; that there is no difference in the rates of "yes" between the two groups in the population (Saunders, Lewis and Thornhill, 2009).

The following is the formula for calculating the Chi-square statistic (Stigler, 2008):

$$(x)^2 = \sum \frac{(0 - e)^2}{e} \qquad (1)$$

Where,

x^2 = Chi-squared.

$\sum$ = summation.

0 = observed values.

e = expected values.

The Chi-square test was used in this study to test for each statement provided of the farmer's knowledge of ecosystem services. A comparison of proportions in each farming system that chose each response was made. The two groups in this case were farmers who practiced conservation agriculture and conventional agriculture. The independent variable in this test was farming system, which is a categorical variable. It is either you are practicing conservation agriculture or conventional agriculture. The dependent variable(s) is each statement provided on ecosystem services and farming systems. Likewise, a Chi-square test was used to compare the farmer's awareness of the positive trade-offs associated with conservation agriculture and their intention to use practices that lead to these trade-offs.

3.5.2 The T-test

According to Gujarati and Porter (2009), the t-test is an alternative but complementary approach to the confidence-interval method of testing statistical hypotheses. This test statistic is parametric and follows the t distribution. This analysis is appropriate when comparing means of two groups, to determine whether two means are statistically significant. It uses continuous and ordinal scale variables. The assumptions underlying the t-test are that:

- The sample is randomly selected from the population
- The sample size is adequate
- The data when plotted results in a normal distribution
- There exists equal variance in standard deviation.

The t-test statistic is calculated as follows:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{{S_1}^2}{N_1} + \frac{{S_2}^2}{N_2}}} \qquad (2)$$

Where:

$\overline{x_1}$ = mean sample 1

$\overline{x_2}$ = mean sample 2

N_1 = number of observations in sample 1

N_2 = number of observations in sample 2

$S_1{}^2$ = variance of sample 1= $\frac{\sum(x_1-\overline{x_1})^2}{N_1}$

$S_2{}^2$ = variance of sample 2 = $\frac{\sum(x_2-\overline{x_2})^2}{N_2}$

The null hypothesis is that no relationship exists between the two different measured variables. The decision to accept or reject the null hypothesis is based on the calculated t-test statistic from the data. When the calculated t-test statistic is less than the t-table value (obtained from statistical tables at appropriate significance level and degrees of freedom), you fail to reject the null hypothesis.

In this study, the T-test was used to find out whether there are differences in fertiliser usage and technical efficiency scores in maize production between farmers who practice conservation agriculture and farmers who practice conventional agriculture. The test was also used to establish any differences in socioeconomic factors between the two farming groups considering that conservation and conventional farmers were independent groups and were randomly selected from Kafue district.

3.5.3 Microeconomic theory

The theoretical framework is based on producer behaviour and thus grounded on the "Theory of the Firm". This theory is a microeconomic concept founded in neoclassical economics and specifies that the farmer, who is the producer, has an objective to maximise profits, but is faced by a cost challenge. This microeconomic theory assumes that firms within the framework of free-market rules should allocate input and output efficiently with the aim of obtaining maximum profit and/or minimum cost (Erkoc, 2012). Up to now, the productive efficiency of a firm has been calculated by means of measuring the distance to a particular frontier, such as the revenue frontier, cost frontier or production frontier.

However, from a theoretical point of view, producers do not always optimise their production functions. A production function is a model that shows the relationship between a set of inputs and the production of goods. The production frontier characterises the minimum number of necessary combinations of inputs for the production of diverse products, or the maximum output with various input combinations and a given technology. Producers operating above the production frontier are considered technically efficient, while those who operate under the production frontier are denoted technically inefficient (Constantin, Martin and Rivera, 2009).

3.5.4 Efficiency measurement approaches

Efficiency measurements originate from the works of Farrell, 1957, who defines a simple measure of firm efficiency that could account for multiple inputs and multiple outputs. He proposed that the efficiency of a firm consists of two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. The product of the two measures is economic efficiency, which could be defined as the ability of the firm to produce a well-specified output at minimum cost (Farrell, 1957). However, over time the efficiency measurement approaches have been extended from Farrell's work and have been categorised into two major approaches, namely parametric and non-parametric approaches. The parametric and non-parametric approaches are the Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) respectively. A non-parametric approach, the DEA, was developed by Charnes, Cooper and Rhodes (1978) and the parametric approach, the SFA was developed by Aigner, Lovell and Schmidt (1977) and Meeusen and Broeck (1977). Both approaches are used in empirical work.

The DEA and SFA approach each has weaknesses and strengths. The strengths associated with the DEA approach include no specification requirement of the functional form for the underlying technology, it can handle multiple outputs and inputs, no judgment as to the relative importance of inputs and outputs is required, and it yields meaningful targets for improvement amongst inefficient Decision Making Units (DMUs). It solves a separate linear programme for each DMU (for example farm) searching for the linear combination of other DMUs that produce most outputs given the same or fewer inputs. However, its weakness is that all deviations from the frontier are associated with inefficiency. In agriculture this assumption is restrictive considering that production is variable due to factors such as weather, pests and diseases. On the other hand, the stochastic production frontier allows for error in measurement, deals with the stochastic noise and permits statistical tests of hypotheses pertaining to the structure and the degree of inefficiency, though its main weakness is the assumption of an explicit functional form for the technology and frequently for the distribution of the inefficiency terms. In addition, technical inefficiency may be correlated with the inputs causing inconsistent parameter estimates and inefficiency. To address this problem, this study used the single step approach where the exogenous factors affecting technical inefficiency are included directly in the production function as expressed in equation (3).

3.5.5 Stochastic Frontier Analysis using the Cobb-Douglas Function

The Stochastic Frontier Analysis (SFA) was first developed by Aigner et al. (1977) and Meeusen and Broeck (1977). Stochastic production frontier provides the technical efficiency estimates and recognises that they are factors beyond the control of farmers that affect their production. Therefore, in these models, the impact of random shocks (such as labour or capital performance) on the product can be separated from the impact of technical efficiency variation.

There are a number of different functional forms used in the literature to model production functions, which include the Cobb-Douglas and Translog function. The Cobb-Douglas is an exact specification and the translog is a flexible form. Both functional forms have been used in empirical work (Haji and Andersson, 2006; Kirimi and Swinton, 2004). However, a weakness associated with the Cobb- Douglas function is that it imposes specific structures on the production function which then distort efficiency measures. On the other hand the translog function, which is a flexible functional form, imposes no a priori restriction on the elasticity of substitution and allows economies of scale to vary with output level. However, despite the limitations of the Cobb- Douglas functional form, it is self-dual thus allowing an examination of economic efficiency. For this study, the Cobb–Douglas functional form is used to represent the maize production function.

The stochastic frontier production function model for estimating farm level technical efficiency is specified as:

$$Y_i = f(X_i; \beta) + \varepsilon_i \quad i = 1, 2, \ldots n \tag{3}$$

Where Y_i is output, X_i is denotes the actual input vector, β is vector of production function and ε is the error term that is composed of two elements. That is:

$$\varepsilon = V_i - U_i \tag{4}$$

V_I and U_I constitute the error term and are assumed to be independently distributed. v_i is the random error or variations in output that are assumed to be independent and identically distributed as N (0, σ_v^2) due to factors outside the control of farmers (for example weather and natural disasters) and $u_i$is a non-negative truncated half normal, associated with technical inefficiencies of production which are assumed to be independently distributed and normally distributed as N (0, σ_u^2), allowing actual production to fall below the frontier but without attributing all short-fall in output from the frontier as inefficiency. The non-negativity property of the u_i term ($u_i \geq 0$), ensures all the observed outputs should lie below or on the stochastic frontier. According to Aigner et al., 1977, any deviation from the abovementioned frontier will be treated as the result of factors controlled by the firm that are named as technical and economic inefficiency. The distributional assumptions are vital to the estimation of the parameters.

Following Jondrow, Lovell, Materov and Schmidt (1982), the technical inefficiency estimation is given by the mean of the conditional distribution of inefficiency term u_i given ε; and thus defined by:

$$\mathrm{E}(\mathrm{U_i}|\varepsilon_\mathrm{i}) = \frac{\sigma_u . \sigma_v}{\sigma} . [\frac{f(\varepsilon_j \lambda|\sigma)}{1 - F(\varepsilon_i \lambda|\sigma)} - \frac{\varepsilon_i \lambda}{\sigma}] \qquad (5)$$

Where $\lambda = \sigma_u/\sigma_v$, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ while f and F represents the standard normal density and cumulative distribution function respectively evaluated at $\varepsilon_j \lambda / \sigma$

The farm -specific technical efficiency is defined in terms of observed output (Yi) to the corresponding frontier output (Yi*) using the available technology derived from the result of the equation (5):

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{E(Y_i|u_i X_i)}{E(Y_i|u_i = 0, X_i)} = E[\exp(-u_i)/\varepsilon_i \tag{6}$$

TE takes its value on the interval (0, 1), where 1 indicates a fully efficient farm.

3.5.6 Model specification

The Maximum Likelihood (ML) estimate procedure was used in estimating and determining the factors that influence technical efficiency (Battese and Coelli, 1983). Two separate models were estimated for conservation and conventional agriculture respectively. The Cobb-Douglas functional form was selected to model maize production technology and was specified as:

$$Y_i = \beta_0 {X_{1i}}^{\beta_1} {X_{2i}}^{\beta_2} {X_{3i}}^{\beta_3} {X_{4i}}^{\beta_4} {X_{5i}}^{\beta_5} {X_{6i}}^{\beta_6} \varepsilon^{v_i - u_i} \tag{7}$$

Which, when linearised, becomes:

$$In\, Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + V_i - U_i \tag{8}$$

Where,

Subscript i = 1, 2... N denotes number of households in the data set

Y = Maize output produced (Kg)

X_1 = Seed (Kg)

X_2 = Land (Ha)

X_4 = Labour (Man days)

X_5 = Fertiliser (Kg)

X_6 = Capital (ZMK)

β = Vector of unknown parameters to be estimated

V = Farm specific character related to efficiency

U = Statistical disturbance term

The inefficiency effects model included in equation (8) provides the socio-economic factors that provide explanations for variations in technical efficiency levels among farmers and is stated as follows:

$$u_i = \delta_0 + \delta_1 Z_{1i} + \delta_2 Z_{2i} + \delta_3 Z_{3i} + \delta_4 Z_{4i} + \delta_5 Z_{5i} + \delta_6 Z_6 + \delta_7 Z_{7i} + \delta_8 Z_{8i} + \delta_9 Z_{9i} + \delta_{10} Z_{10i} \quad (9)$$

Equation (9) depicts the inefficiency model where:

Z_1 = Household size (number)

Z_2 = Level of education (years)

Z_3 = Age of head of household (years)

Z_4 = Gender of household head (=1 if male)

Z_5 = Off-farm income (ZMW)

Z_6 = Extension service (=1 if received)

Z_7 = Farming experience (years)

Z_8 = Belongs to farmer group (=1 if yes)

Z_9 = Owns a ripper (=1 if yes)

Z_{10}= Access to credit (= 1 if yes)

δ = Vector of unknown parameters to be estimated

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter evaluates and discusses the results of this study. The T-test and Chi-square test was used for analysis and the results are presented as descriptive statistics on tables. Results on the comparison of farmer knowledge of the contribution of conservation agriculture to the environment and awareness of trade-offs in conservation agriculture are presented The focus was on smallholder maize farming households and the Stochastic Frontier Analysis was also used to compare technical efficiency between conservation agriculture and conventional agriculture. The socio-economic factors that influence the efficiencies of the two farming systems were also identified. The results on challenges of conservation agriculture are also discussed.

4.2 SOCIO-ECONOMIC CHARACTERISTICS OF FARMERS

In this section, the T-test was used to determine any differences in the means of the demographic characteristics of conservation and conventional farmers. The analysis was based on the following null hypothesis (H_0):

H_0: Conservation and conventional farmers have the same socio-economic characteristics

H_A: Conservation and conventional farmers differ in their socio-economic characteristics

Maize is a major crop produced by smallholder farmers and all the respondents in this study. The results in table 4.1 show that there were no significant differences in maize output by both conservation and conventional farmers. The results also showed similarities in terms of land owned, age, education, crop diversity and household size. It is expected that conservation farmers will have crop diversity as it is supported by conservation agriculture based on the principle of crop rotation (Kassam and Friedrich, 2011). However, the results show that the two farming groups had grown at least three crops. This may be so, as most of the farming households grow at least maize and some other crops to be food secure (Siegel, 2008) In this study both conservation and conventional farmers had received primary education and on average had the same household size.

Table 4.1: Farmers' socioeconomic characteristics

Characteristic	Conventional farmers Mean	Conservation farmers Mean	T test statistic(P)
Years of farming	19.94	6.73	6.73***(0.000)
Land owned (hectares)	5.53	8.14	1.15(0.2519)
Age of household head (years)	50.28	53.42	1.01(0.3154)
Education	1.8	1.65	0.83(0.4082)
Crop diversity (number)	3.2	3.4	0.45(0.6567)
Household size	8	8	0.03(0.9726)
Source of household income	1.3	1.2	1.28** (0.0233)
Maize yield (kilograms)	5216.4	5019.792	0.1308 (0.8963)

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level.
Source: Authors Survey Data 2014

The findings show that farming is the major source of household income for farmers practicing conservation agriculture and farmers practicing conventional agriculture. However, there was a significant difference between conservation and conventional farmers with regards to their source of income (t =1.28, P = 0.0233). jThere was also a significant difference in the years of farming (t = 6.73, P = 0.000). The mean years of farming was 20 and 6 years for conventional and conservation agriculture, respectively. This is because conventional agriculture has been practiced longer than conservation agriculture (Baudron et al., 2007). All the farmers practicing conservation agriculture are coming from conventional agriculture background.

4.3 FARMERS' KNOWLEDGE OF TRADE-OFFS DELIVERED IN CONVENTIONAL AGRICULTURE

Different statements relating ecosystem services to agricultural practices were read and explained to farmers. The conventional agricultural practices include burning of crop residues, monocropping and complete turning of the soil. The ecosystem services of focus where soil fertility, water holding capacity, nutrient retention, soil quality, disease mitigation and crop yield. The purpose was to identify if farmers who practice conservation and conventional farmers knew that increases in yield under conventional agriculture trades off long-term ecosystem services. Therefore, this section was based on the following hypothesis:

H_0 : Conservation farmers are equally likely to know about the trade-offs in conventional agriculture as conventional farmers

H_A : Conventional farmers are more likely to know about the trade-offs in conventional agriculture than conservation farmers

From Table 4.2 conventional farmers knew more than conservation farmers that complete turning of the soil increases soil erosion. However, both farming groups equally knew that monocropping increases crop disease and reduces crop diversity. They equally knew that conventional agriculture reduces crop yield. When asked on the ability of conventional agriculture to reduce water loss from the soil, 58% of conservation farmers and 60% of conventional farmers disagreed with the statement. This indicates that they equally knew that conventional farming does not reduce water loss from the soil.

However, there was an exception on the farmers' knowledge levels of the ability of burning crop residues to temporally increase soil fertility where both farming groups expressed low levels of agreement with the statement. The respondents were asked on the ability of burning crop residues to increase soil fertility temporally and 88% of the conventional farmers and 91.67% of conservation farmers disagreed with the statement. Therefore, there is need for training on the trade-offs between increasing soil fertility and long-term provisioning of ecosystem services.

Table 4.2: Comparison of conventional and conservation farmers' knowledge on the trade-offs delivered by conventional agriculture

Statements on trade-offs in conventional agriculture systems	%Agree		$x^2(P)$	%Disagree		$x^2(P)$	%Don't Know		$x^2(P)$
	CV farmers	CA farmers		CV farmers	CA farmers		CV farmers	CA farmers	
Burning of crop residues temporally increases soil fertility	12	8.33	0.3593 (0.549)	88	91.67	0.3593 (0.549)	0	0	NA
Conventional agriculture reduces water loss from the soil	30	29.79	0.0282 (0.867)	60	58.33	0.0082 (0.928)	10	10.42	0.0046 (0.946)
Monocropping reduces crop diversity	76	83.33	0.8108 (0.368)	2	10.42	3.0184* (0.082)	22	6.25	4.9612** (0.026)
Monocropping increases crop diseases	90	89.58	0.0046 (0.946)	0	4.17	2.1267 (0.145)	10	6.25	0.4594 (0.498)
Complete turning of the soil increases soil erosion	84.00	95.83	3.7426** (0.053)	4	0	1.9600 (0.162)	12	4.17	2.0045 (0.157)
Conventional agriculture reduces soil fertility	88.00	95.83	2.0045 (0.157)	2	2.08	0.0009 (0.977)	10	2.08	2.6704 (0.102)
Conventional agriculture reduces crop yield	82.00	97.92	6.7711* (0.009)	8	0	4.0034** (0.045)	10	2.08	2.6704 (0.102)

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level. Note: NA means no test was applicable.
Source: Authors Data Survey, 2014

Conventional agriculture reduces crop yield, and 97.92% of conservation farmers and 82% of conventional farmers knew about this reduction. Both conservation farmers (95.83%) and conventional farmers (84%) knew that complete turning of the soil increases soil erosion. However, conventional farmers significantly knew more than conservation farmers that conventional agriculture reduces crop yield (χ^2 =6.7711, p = 0.009) and that, specifically, complete turning of the soil increases soil erosion (χ^2 =3.7426, p = 0.053). These results show that there is need to strengthen training on long-term benefits of adopting recommended sustainable farming practices such as those associated with conservation agriculture, providing an understanding that food production trades off other ecosystem services (for example degrading soil quality).

4.3.1 Farmers' knowledge on conventional agriculture on-farm environmental impacts

Conventional agricultural practices namely burning of crop residues, complete turning of the soil and monocropping affect the supply of the ecosystem services such as nutrient retention which later affect agricultural productivity. This section sought to determine if farmers also knew that conventional agriculture affects the environment by asking respondents about the environmental consequences they knew.

Table 4.3 Comparison of farmer knowledge on conventional on-farm environmental outcomes

Environmental outcomes of conventional agriculture	% Conventional farmers	% Conservation farmers	$\chi^2 (P)$
Increases air pollution	46	66.67	4.2476** (0.039)
Increases water pollution	18	45.83	8.7727** (0.003)
Increases soil erosion	48	60.42	1.5204 (0.218)
Increases global warming	8	10.42	0.1715 (0.679)
Reduces biodiversity	38	43.75	0.3352 (0.563)

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level.

Source: Authors Data Survey, 2014.

The results in table 4.3 show that conservation farmers were more knowledgeable on the environmental consequences of conventional agriculture. However, both groups generally exhibited low levels of knowledge. There were significant differences in knowledge levels with regards to air pollution and water pollution. In this case, conventional farmers had more knowledge on the potential of conventional agriculture to increase air pollution and increase water pollution.

The other environmental consequences of conventional agriculture are reduced biodiversity, increased soil erosion and increased global warming. Results (table 4.3) show 48%, 8%, and 38% of conventional farmers knew that conventional agriculture increases soil erosion, increases global warming and reduces biodiversity respectively. For conservation farmers 60.42%, 10.42% and 43.75% knew that conventional agriculture increases soil erosion, increases global warming and reduced biodiversity respectively. There were no significant differences in their knowledge levels, implying that both farming groups equally knew that conventional agriculture reduces biodiversity and increases both soil erosion and global warming.

4.4 FARMERS' KNOWLEDGE ON ECOSYSTEM SERVICE SUPPLY IN CONSERVATION AGRICULTURE

Relative to conventional agriculture, conservation agriculture enhances the supply of ecosystem services. In this section the ecosystem services that were captured include nutrient retention, soil fertility, soil conservation, disease and pest mitigation and crop yield. The purpose was to determine whether farmers know about the potential of conservation agriculture practices to supply these ecosystem services and simultaneously increase crop yield. Conservation agriculture practices include minimum tillage, crop rotation and crop residue retention. This section was based on the following hypothesis:

H_0 : Conventional farmers are equally likely to know about the trade-offs in conventional agriculture as conventional farmers

H_A : Conservation farmers are more likely to know about the trade-offs in conventional agriculture than conservation farmers

It was expected that conservation farmers would have more knowledge of the ecosystem services delivered from conservation agriculture. From the findings (table 4.4) of the study, 85.42% and 78% of conservation and conventional farmers respectively knew about the potential of conservation agriculture to conserve soil. And conservation (93.74%) and conventional farmers (84%) knew about the importance of soil maintenance in food production. However, there was no significant difference in the level of knowledge with regard to these ecosystem services. These results suggest that the two farming groups know the importance of conserving and maintain soils for food production; this may be due to the strong ties that farming households have to the land (McCann, 1997). Therefore, in order to promote a shift from conventional agriculture to conservation agriculture, policy makers should put emphasis on the importance of conserving soils to meet current and future food demands.

Table 4.4: Comparison of conventional and conservation farmers' knowledge of the ability of conservation agriculture to supply ecosystem services

Statements on ecosystem services delivered in conservation agriculture systems	**% Agree**		$x^2(P)$	**% Disagree**		$x^2(P)$	% Don't Know		$x^2(P)$
	CV farmers	CA farmers		CV farmers	CA farmers		CV farmers	CA farmers	
Conservation agriculture has a high capacity for soil conservation	78	85.42	0.8984 (0.343)	14	14.58	0.0068 (0.934)	8	0	4.0034** (0.045)
Soil fertility is important to be maintained to increase crop yields	88	100	6.1357** (0.013)	0	0	NA	12	0	6.1357** (0.013)
Minimum tillage will help reduce soil nutrient runoff	86	100	7.2369** (0.007)	2	0	0.9699 (0.325)	10	0	5.0581** (0.025)
Crop residue retention can help to top up nutrients to agricultural land and thereby increase soil fertility	90	100	5.058** (0.025)	4	0	1.9600 (0.162)	6	0	2.9709* (0.085)
Crop residue retention decreases soil erosion	84	97.92	5.6869** (0.017)	2	0	0.9699 (0.325)	14	2.08	4.6389** (0.031)
Crop rotation reduces crop pests, thereby contributing to better yield of your crops	88	100	6.1357** (0.013)	2	0	0.9699 (0.325)	10	0	5.0581** (0.025)
Legumes in crop rotations reduces the use of inorganic fertilisers	84	100	8.3627** (0.004)	4	0	1.9600 (0.162)	12	0	6.1357** (0.013)
Crop residue retention reduces the amount of weeds	82	93.75	3.1465* (0.076)	4	4.17	0.0017 (0.967)	14	2.08	4.6389** (0.031)
Increased crop production and food we eat cannot be obtained without soil maintenance	84	93.74	2.3363 (0.126)	4	0	1.9600 (0.162)	12	6.25	0.9708 (0.324)
Conservation agriculture can increase soil fertility	82	100	9.5137**(0.002)	4	0	1.9600 (0.162)	14	0	7.2369** (0.007)
Conservation agriculture can increase crop yield	82	100	9.5137** (0.002)	8	0	4.0034** (0.045)	10	0	5.0581** (0.025)

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level. Note: NA means no test was applicable.

Source: Authors Data Survey, 2014

On the other hand, many significant results were observed between the knowledge levels of conservation and conventional farmers. It is expected that farmers that practice conservation agriculture would be more knowledgeable on its ability to deliver ecosystem services and increase crop yields based on its principles (Sanderson et al., 2013: Kassam and Friedrich, 2011). The majority of the conservation farmers (above 90%) knew more than convention farmers (above 80%) about the ecosystem services delivered from conservation agriculture. Farmers who practice conservation agriculture had more knowledge than farmers who practice conventional agriculture of the potential of conservation agriculture to increase crop yield, improve soil fertility, retain nutrients, reduce soil erosion, and mitigate pests and weeds.

Conservation farmers agreed more with the statements on these ecosystem services delivered to lands under conservation agriculture. All conservation farmers agreed that conservation agriculture (χ^2=9.5137, P = 0.002) and soil fertility maintenance (χ^2=6.1357, P = 0.013) increase crop yield. Every farmer practicing conservation agriculture knew that both minimum tillage (χ^2=7.2369, P = 0.007) and crop residue retention (χ^2=5.058, P = 0.025) help retain nutrients. Each farmer practicing conservation agriculture also agreed with the statement on the ability of crop rotation to mitigate pests (χ^2=6.1357, P = 0.013). These results may be due to the training support on ecosystem services for conservation agriculture than farmers who practice conservation agriculture receive, which makes the former more knowledgeable than their counterparts. This also shows that conservation farmers are well equipped with information with regards to these ecosystem services and hence may help policy makers as a means of transmitting information to farmers practicing conventional agriculture, that is, through farmer to farmer training (Haggblade and Tembo, 2003.

4.4.1 Farmers' knowledge of conservation agriculture on-farm environmental benefits

This section discuses farmer knowledge with regards to the on-farm benefits that conservation agriculture practices provide to the environment based on its principles. The principles are, namely, minimum tillage, crop rotation and retention of crop residues. The results in table 4.5 indicate that conservation farmers where significantly more knowledgeable on the potential of conservation agriculture to reduce water pollution and soil erosion.

Table 4.5: Comparison of farmer knowledge on conservation agriculture on-farm environmental benefits

Environmental benefits of conservation agriculture	% Conventional farmers	% Conservation farmers	$\chi^2 (P)$
Reduces air pollution	56	64.58	0.7531 (0.386)
Reduces water pollution	22	41.67	4.3799** (0.036)
Reduces soil erosion	60	81.25	5.3077** (0.021)
Increases biodiversity	36	41.67	0.3313 (0.565)

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level.
Source: Authors Data Survey, 2014

The other environmental benefits of conservation agriculture are improved biodiversity and reduced soil erosion. In the case of conservation farmers, 81.25% and 41.67% knew that conservation agriculture reduces soil erosion and improves biodiversity respectively. There were no significant differences in the knowledge levels of both farming groups, implying that both farming groups equally knew that conservation agriculture reduces soil erosion and increases biodiversity.

4.5 TECHNICAL EFFICIENCY ANALYSIS

The maximum likelihood (ML) estimates of the parameters of the stochastic frontier production function and the inefficiency model were simultaneously obtained in STATA for both conventional and conservation agriculture. In this study the efficiency measurement was based on several inputs and one output, maize produced. The two farming systems showed that technical inefficiencies existed. In addition the input elasticities with respect to maize produced were estimated separately.

4.5.1 Maximum likelihood estimates for conventional agriculture

Table 4.6 presents the result of the estimated Cobb-Douglas function and technical efficiencies of the stochastic production function model. The table presents the variables of the production and technical inefficiency functions. The results are based on the assumption that the inefficiency term was half normally distributed. Many alternative distributions are proposed in literature, but the half normal distribution was assumed as it is usually the standard distribution for efficiency measurements.

Table 4.6: ML estimates of Cobb-Douglas function for conventional farmers

Variable name	Coefficient	Standard error
Production function		
Dep. variable: Log (maize output/ha)		
Constant	5.305**	2.101
Log (seed)	-0.204	0.296
Log (land)	0.701**	0.304
Log (labour)	-0.566*	0.298
Log (fertiliser)	0.256	0.449
Log (capital)	0.384	0.239
Technical inefficiency function		
Constant	-1.505	3.061
Age of household head	0.0180	0.014
Marital status	0.470	0.372
Gender	-0.484*	0.268
Off-farm income (ZMW)	-0.0717	0.093
Access to credit	0.0817	0.293
Level of education (years)	0.417	0.536
Farming experience (years)	-0.0574***	0.018
Belong to farmer group	0.900	0.555
Household size	0.106*	0.059
Variance parameters		
Lambda (λ)	*0.707****	0.268
Sigma square (σ^2)	0.665	0.457
Sigma_u (σ_u)	0.471	0.721

Sigma_v (σ_v)	0.666***	0.193
Gamma (γ)	0.334	
Log likelihood	-54.779	
Mean technical efficiency	0.713	
Sample size		50

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level.
Source: Authors Data Survey, 2014

The estimated value of gamma (γ) was 0.334. Gamma (γ) ratio indicates the variation in total maize output that is explained by the variation in technical inefficiencies of the sample. In this study, the result means that the 33.4 percent of the variation of maize output by smallholder farmers that practiced conventional agriculture was due to the variation in their technical inefficiencies. Put differently, the variation in their total maize output was not merely due to random errors but rather due to their technical efficiencies. The results show that smallholder farmers that practiced conventional agriculture had an average score of 71.3 percent of their technical efficiency. Stated differently, conventional agriculture farmers were 71.3 technically efficient. This means that they could still increase their technical efficiency levels by about 28.7 percent. The presence of technical inefficiencies is confirmed by rejection of the null hypothesis that inefficiencies were absent at 1 percent since the log likelihood test was 5.04 and statistically significant.

The higher technical efficiency for farmers practicing conventional agriculture with some achieving maximum efficiency (100%), may be as a result of the number of years of experience (table 4.1). There is a tendency to specialise when an activity is done over a longer period of time.

4.5.2 Maximum likelihood estimates for conservation agriculture

Table 4.7 presents the result of the estimated Cobb-Douglas function and technical efficiencies of the stochastic production function model.

Table 4.7: ML estimates of Cobb-Douglas function for conservation farmers

Variable name	Coefficient	Standard error
Production function		
Dep. Variable: Ln(maize output/ha)		
Constant	4.945***	1.829
Log (seed)	-0.196	0.163
Log (land)	0.509***	0.169
Log (labour)	-0.072	0.249
Log (fertiliser)	0.678***	0.205
Technical inefficiency function		
Constant	-0.399	1.033
Household size	-0.256	0.429
Level of education (years)	0.092*	0.050
Age of household head (years)	0.008	0.010
Gender of household head (=1 if male)	0.207	0.260
Off-farm income (ZMW)	0.240*	0.145
Extension service (=1 if received)	0.060	0.080
Farming experience (years)	-0.023	0.053
Belong to farmer group (=1 if yes)	-0.197	0.335
Own a ripper (=1 if yes)	0.009***	0.003
Access to credit (=1 if yes)	0.154	0.231

Variance parameters		
Lambda (λ)	1.836***	0.646
Sigma square (σ^2)	0.870*	0.506
Sigma_u (σ_u)	0.819*	0.422
Sigma_v (σ_v)	0.446*	0.236
Gamma (γ)	0.771	
Log likelihood	311	
Mean technical efficiency	0.579	
Sample size	48	

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level.

Source: Authors Data Survey, 2014

The estimated value of lambda (λ) is higher than the one estimated under conventional agriculture and statistically significant at 1 percent. The higher value of λ (1.836) implies that the model under conservation agriculture was of a better goodness of fit and its statistical significance implies that the chosen model distribution of the inefficiency term was also correctly specified as in the first case.

The estimated value of gamma (γ) as shown in Table 4.7 was 0.771. Hence 0.771 implies that about 77 percent variation in total maize output per hectare that was explained by the variation in technical efficiency of the conservation farmers sampled. In comparison to the smallholder conventional farmers, more of the variation in the total farm output by smallholder conservation farmers was explained by the variation in their technical efficiencies (77.1 percent compared to 33.4 percent). The average technical efficiency of the smallholder conservation farmers was 57.9 percent. Compared to conventional farmers, conservation farmers were less technically efficient (57.9<71.3percent). This means that farmers who practice conservation agriculture could still increase their technical efficiency levels by about 42.1 percent to reach their frontier. The lower technical efficiency for farmers practicing conservation agriculture compared to conventional farmers, might be that conservation agriculture is knowledge intensive.

4.5.3 Comparison of conventional and conservation farmers' technical efficiency level distributions

The technical efficiency analysis to compare the technical efficiency levels of smallholder maize farmers that practice conservation and conventional agriculture was done. The results showing a comparison of the technical efficiency distribution are summarised in Table 4.8.

Table 4.8: Distribution of specific smallholder farmers' technical efficiencies

Conservation farmers				**Conventional farmers**		
Technical efficiency	**Number of household s**	**Percent**	**Cumulative percent**	**Number of households**	**Percent**	**Cumulative percent**
< 20%	1	2.08	2.08	0	0	0
20.01- 30%	4	8.33	10.42	0	0	0
30.01- 40%	1	2.08	12.5	0	0	0
40.01- 50%	8	16.67	29.17	1	2	2
50.01- 60%	9	18.75	47.92	1	2	4
60.01- 70%	12	25	72.92	17	34	38
70.01 - 80%	9	18.75	91.75	28	56	94
80.01 - 90%	4	8.33	100	3	6	100
90 -100%	0	0		0	0	
Total	**48**	**100**		**50**	**100**	
Mean	**0.579**			**0.713**		
Standard deviation	0.168			0.070		
Minimum	0.146			0.434		
Maximum	0.837			0.853		

Comparing the technical efficiency levels of both farming systems, conventional agriculture (71.3 percent) is more efficient than conservation agriculture (57.9 percent). These findings are not consistent with Mazvimavi et al., (2012) who reported that the level of technical efficiency for both farming systems was the same in Zimbabwe.

Similarly, the results for conservation farmers showed great variation of technical efficiencies ranging from as low as 14.6 percent to 83.7 percent. In contrast, conventional farmers had technical efficiency levels ranging between 43.4 percent and 85.3 percent with mean technical efficiency of 71.3 percent. In addition, 62 percent of conventional farmers compared to only 27.08 percent of conservation farmers, had technical efficiency of 70 percent and above, as presented in table 4.5. This means that if the average farmer in the sample was to achieve technical efficiency level of its more efficient counterpart then the average farmer could realise a 16.41 percent cost saving [1-(71.3/85.3)x100]. A similar percent calculation of the most technically efficient conservation farmer reveals a cost saving of 30.82 percent [1-(57.9/83.7) x100). Therefore improving the technical efficiency among conservation farmers can result in greater cost savings. Equally there could more cost saving by conservation farmers of 82.56 percent [1-(14.6/83.7)x100] compared to 49.12 percent [1-(43.4/85.3)x100] for conventional farmers, that is, for the most technically inefficient farmer to be like the most efficient farmer. It is worthwhile for farmers to adopt conservation agriculture.

4.5.4 Equality of technical efficiency scores for conservation and conventional Farmers

It was expected that the technical efficiency scores for maize between conservation and conventional farmers would be the same. Table 4.9 shows the findings of the study in comparing the mean technical efficiency scores for the two farming groups. The average technical efficiency for farmers who practice conventional agriculture is 71.3% and the farmers who practice conservation agriculture have a technical efficiency score of 57.9%. However, the results show that there was a significant difference in technical efficiency scores between farmers who practice conservation and farmers who practice conventional agriculture at 5% level of significance.

Table 4.9: Equality of TE scores for conservation and conventional farmers

Farming type	Sample size(n)	Mean efficiency	Standard Deviation	T-test statistic (P)
Conventional farmers	50	0.713	0.11	3.9854 (0.0002)
Conservation	48	0.579	0.21	

The policy implication is that Zambia has an opportunity to improve the productivity levels of maize by not only introducing new technologies but also improving technical efficiency. Possible options include transforming farmers from conventional agriculture to conservation agriculture through farmer trainings and strengthening of extension service delivery.

4.5.5 Socio-economic factors affecting technical efficiency of conventional agriculture

This section determines the factors that influence the technical efficiency of conventional smallholder farmers. The technical inefficiency function in table 4.6 above, shows the factors that affect the technical efficiency of farmers who practice conventional agriculture. From the results obtained, gender of the household head, farming experience and household size were statistically significant, thus they are important determinants of technical efficiency for conventional farmers.

The gender variable coefficient showed a negative relationship with the predicted inefficiencies and was statistically significant at 10%. This means that households that are headed by males would be more technically efficient than the households headed by females, holding other factors constant. This maybe because males are considered to be stronger than females and farming is a traditional labour intensive activity. This means that presence of a male head of the household would significantly contribute to increased technical efficiency of that household in farming unlike when the head is female. Females are usually involved in house activities such as cooking, ensuring hygiene of the house, while males are traditionally responsible for farming, herding cattle and other labour demanding activities. Thus they are taken to be suit well to agricultural activities.

From the results, the farming experience showed a negative relationship with the predicted technical inefficiencies and statistically significant at 1%. A negative coefficient for the farming experience variable means that an increase in the years of farming experience by the household head would result in an increase in technical efficiency by the farmer, when other factors are held constant. This is in agreement with a prior knowledge as it is expected that long years of experience would positively enhance one's ability to apply a technology over some time. A less experienced farmer would rather do the opposite. This could be supported by the fact that conventional agriculture has been in existence longer, since Zambia's independence (Baudron et al., 2007).

That the positive coefficient on the household size was statistically significant at 10% implies that holding other factors constant, an increase in household size would increase technical inefficiency of that farm household. Although the coefficient shows a positive relationship, smallholder farming households rely on family labour as the main source of labour and it is expected that a bigger household size would reduce technical inefficiencies. The study findings perhaps suggest that the positive relationship is usually true in the short run period of production.

4.5.6 Socio-economic factors affecting technical efficiency of conservation agriculture

This section addresses one of the objectives of the study which was to determine the factors that influence the technical efficiency of conservation smallholder farmers. Results from the technical inefficiency function (Table 4.7) shows that coefficients of the household size, farming experience and belonging to a farmer group showed a negative relationship with the predicted inefficiency. But since these factors were statistically insignificant, they are not important factors in this case. The other factors exhibited a positive relationship – these include years of education, age of household, gender, off-farm income, access to credit and ownership of a ripper. However, among these factors only three variables were statistically significant in affecting smallholder farmers' technical efficiency. These include level of education of household head, off-farm income and ownership a ripper by the household.

The coefficient of the level of education showed a positive relationship and was statistically significant at 5%. This implies that technical inefficiency tends to increase as the years of education increases. Although the sign on the coefficient is positive, it is expected that as one's years of education increase, technical inefficiency must decrease. Education enhances the ability of farmers to make good use of information about production inputs, thus improving the efficient use of inputs, yet this is not the case among conservation farmers. This may be because educated persons would concentrate on off-farm income generating activities such as consultancy work, employment and become less dedicated to farm work. This is in agreement with the results for off-farm income. Off-farm income also showed a positive relationship and was statistically significant at 5%. This means that as off-farm income levels increase, technical inefficiency increases. The findings suggest that the farmer will spend less time at their farms doing farm work. The coefficient on the ripper ownership showed a negative relationship with the predicted inefficiency and was significant at 1%. The negative coefficient for ownership of a ripper means that smallholder farmers that practice conservation agriculture and owned a ripper as farming equipment would be more technically efficient than their counterparts who did not own it.

4.5.7 Input elasticity for conventional agriculture

Determination of elasticities is necessary for the estimation of responsiveness of yield to inputs. The results from the stochastic frontier production function in table 4.6 shows that only land and labour were statistically significant resources used. Land was statistically significant at 5 percent while labour was statistically significant at 10 percent. The resources; seed, fertiliser and capital, were not statistically significant. These coefficients for the stochastic frontier production function represent output elasticity values. The positive coefficient for land means that a 10 percent increase in land amount allocated for the production of maize by conventional farmers would be associated with about 7.01 percent increase in the total maize output holding other factors constant.

For labour, the results indicate that when other factors are held constant, an increase in labour by one percent would be associated with a decrease in total maize output by about 5.66 percent. Though statistically insignificant, the positive coefficient of fertiliser means that an increase in fertiliser allocation by smallholder farmers by 1 percent would be associated with about 2.56 percent increase in total maize output holding other factors constant. Furthermore, the positive result on capital means that an increase in allocation to maize farming by 1 percent by smallholder farmers was associated with about 3.84 percent rise in total maize output, holding other factors fixed, however, this result is statistically insignificant. For seeds, the negative coefficient for seeds means that a 1 percent increase in seeds allocated to farming by smallholder farmers would result in about 2.04 percent fall in total maize output.

Table 4.10: Elasticity and Return to Scale of the parameters of SFP function for conventional farmers

Variables	Elasticities
Seed	-0.204
Land	0.701
Labour	-0.566
Fertiliser	0.256
Capital	0.384
RTS	**0.571**

However, from table 4.10, the returns to scale (RTS) from the results in the production function is 0.571. The RTS parameter serves as a measure of total resource productivity and is obtained from the summation of the coefficients of the estimated inputs. This means that smallholder farmers that practiced conventional agriculture faced decreasing positive returns to scale and were hence operating in stage II of their production functions. This implies that resources allocation and production were efficient. In this regard, the results show that yield is highly responsive to land, then followed by capital, fertiliser, seed and labour. Similarly, the log likelihood ratio test of existence of inefficiencies (LR=-54.779) for the model, given the null hypothesis of technical inefficiencies was not rejected at 5 percent. This conforms to the presence of technical inefficiency (28.7 percent) of conventional agriculture.

4.5.8 Input elasticity for conservation agriculture

Estimated results (table 4.7) showed positive coefficients of land and fertiliser implying that as each of these variables is increased, maize output increases. The production function of smallholder conservation farmers indicated that both land and fertiliser inputs were statistically significant at 1 percent and they both had expected signs. Therefore, the positive coefficient for land means that holding other factors constant, increasing land by 1 percent would result in about 5.09 percent increase in the total amount of maize produced per hectare by the smallholder farmers who adopted conservation agriculture. Besides, when other factors are held constant, a 1 percent rise in amount of fertiliser used by the smallholder farmers that adopted conservation agriculture would result in about 6.78 percent rise in total maize output. Notice that fertiliser input is statistically significant for conservation agriculture unlike for conventional agriculture, perhaps because conservation agriculture usually involves fertiliser application in basins.

However, labour was not statistically significant in this case, a result that is surprising as most literature indicates that labour is a significant input for conservation agriculture for it is labour intensive (Haggblade and Tembo, 2003; Nyanga et al., 2011; Ng'ombe et al., 2014). While seed and labour showed negative coefficients which implies that as each of these variables is increased, maize output decreased, these variables were not statistically significant.

Table 4.11: Elasticity and return to scale of parameters of SFP function for conservation farmers

Variables	**Elasticities**
Seed	-0.196
Land	0.509
Labour	-0.072
Fertiliser	0.678
RTS	**0.919**

The return to scale (RTS) was 0.919 (table 4.11) which indicates that the maize production in the study area was in stage II production. The production functions exhibited decreasing returns to scale where resource allocation and production are efficient. With conservation agriculture, yield is highly responsive to fertiliser, followed by land, labour and seed. Likewise the existence of technical inefficiencies was confirmed using the log likelihood ratio (LR) test. The log likelihood ratio (LR=311) for the model, given the null hypothesis of no inefficiency was not rejected at 5 percent. This is true as the conservation agriculture had experienced technical inefficiencies (42.1 percent).

The returns to scale for both farming systems is less than one indicating that they both have potential to increase productivity. Similarly both farming systems have positive significant elasticities with regards to land which is expected as it is a key factor in production. However conservation agriculture showed a positive elasticity relationship to fertilizer while conventional agriculture showed a negative relationship to labour. These findings imply that output under conventional farming may be increased with less labour. Therefore in order enhance farmer adoption of conservation agriculture, policy makers should consider promotion labour saving equipment such as rippers.

4.6 TRADE-OFFS BETWEEN INCREASED SYNTHETIC FERTILISER USE AND THE ENVIRONMENT

In this section, the purpose was to determine agricultural inputs that have an influence on the environment. The results in table 4.12 show that similar amounts of fertiliser were used by farmers practicing conservation and conventional agriculture in maize production (t=1.3825, p=0.1700). More fertiliser was applied by conventional farmers (mean=634.4kg) than conservation farmers (mean=522.92kg).

Table 4.12: Equality of fertiliser use by conservation and conventional farmers

Farming type	Sample size(n)	Mean	Standard Deviation	T-test statistic (P)
Conventional farmers	50	634.40	404.04	1.3825 (0.1700)
Conservation farmers	48	522.92	394.23	

However, a comparison was made between conventional agriculture production function regressions (Table 4.6) and conservation agriculture production function (Table 4.7). The result shows that a 1% increase in the use of synthetic fertiliser leads to 0.678% and 0% increase in maize output per hectare for conservation agriculture and conventional agriculture respectively, at both 1% and 10% levels of significance. This shows that to increase maize yield by the same amount using fertiliser, maintaining the level of other inputs constant, conventional agriculture requires a higher amount of fertiliser than conservation agriculture. Yet, according to Tilman et al. (2002) the use of more fertiliser increases yield at the expense of water and air quality as the fertiliser required to produce a given yield per hectare is higher under conventional agriculture than conservation agriculture. In addition, Kassam and Friedrich (2011) also found that under conservation agriculture, because of the principle of crop rotation, there is a reduced fertiliser usage. Therefore it can be concluded that there is a greater trade-off between increasing agriculture production and water and air quality under conventional agriculture than under conservation agriculture.

4.7 COMPARISON OF FARMERS' AWARENESS AND WILLINGNESS TO ADOPT CONSERVATION AGRICULTURE

Different statements (table 4.13) explaining the trade-offs in conservation agriculture were read and explained to farmers. The purpose was to identify if farmers were aware of the ecosystem services delivered from agricultural lands under conservation agriculture and if they could adopt these practices or expand the area under conservation agriculture for the practicing farmers. The awareness of the ecosystem services delivered in conservation agriculture may affect the decisions to adopt conservation agriculture practices. This section is based on the following hypothesis:

H_0: conventional farmers are equally likely to be aware of the ecosystem services delivered in conservation agriculture as conventional farmers

H_A: conservation farmers are more aware of the ecosystem services delivered in conservation agriculture than conventional farmers

There were significant results on farmer awareness and willingness to adopt and expand existing lands under conservation agriculture. The results in table 4.13 show generally high levels of awareness (86-100%) among the farmers, irrespective of farming system the farmer was engaged in. Farmers were familiar with the benefits of minimum tillage, retention of residues and crop rotation. The findings indicate that farmers practicing conservation agriculture were more aware than conservation farmers of its ability to deliver ecosystem services but not all of the conservation farmers were aware of the benefits of conservation agriculture. Pretty (2008) and the Food Agriculture Organisation (FAO) (2011), show that conservation agriculture is promoted based on minimum tillage, residue retention and crop rotation. In addition, Haggblade and Tembo (2003) shows that these practices are the major ingredients of conservation agriculture in Zambia. Therefore, the higher awareness result among the conservation farmers is expected

Despite the high level of awareness among farmers who practice conservation (greater than 95%), not all of them were willing to expand the land under conservation agriculture. Further, all the farmers practicing conservation agriculture were aware that crop rotation helps improve soil fertility and mitigate weeds, pests and diseases, yet not all of them were willing to expand the land under conservation agriculture. This suggests that awareness does not necessarily mean you would expand areas under conservation. This observation shows that the promotion and expansion of conservation agriculture by policy makers should be aimed at raising its use by farmers.

Table 4.13: Farmers' awareness and willingness to adopt and expand area under conservation agriculture

Statements on conservation agriculture practices ability to enhance ecosystem services. Are you aware that …………	Conventional farmers			Conservation farmers			χ^2 (P)
	% Not aware	% Aware and willing to adopt CF	% Aware but not willing to adopt CF	% Not aware	% Aware and willing to expand area under CF	% Aware but not willing to expand area under CF	
Minimal turning of the soil as practiced in conservation agriculture reduces soil erosion?	14	95.35	4.65	2.08	70.21	29.79	82.9861*** (0.000)
Permanent planting station as practiced in conservation agriculture reduces nutrient loss?	14	95.35	4.65	4.17	67.39	32.61	81.9331 *** (0.000)
Crop rotation as practiced in conservation agriculture improves soil fertility?	12	95.45	4.55	0	68.75	31.25	84.9278*** (0.000)
Crop rotation as practiced in conservation agriculture reduces the build-up of weeds, pests and disease?	10	93.33	6.67	0	70.83	29.17	83.1074*** (0.000)
Retention of crop residues as practiced in conservation agriculture reduces water loss?	12	95.45	4.55	2.08	72.92	27.08	85.0535*** (0.000)
Conservation agriculture helps the land to be more productive for much longer periods of time	12	95.45	4.55	2.08	68.75	31.25	84.9278*** (0.000)

***Significant at 1 percent; **Significant at the 5 percent level *Significant at the 10 percent level.

Source: Authors Data Survey, 2014

In contrast to conservation farmers, conventional farmers expressed a higher (greater than 93%) willingness to adopt practices associated with conservation agriculture. These results suggest that the initiators of conservation agriculture should upscale their training on conservation agriculture with emphasis on the benefits that conservation agriculture provides by striking a balance between crop productivity and long-term ecosystem services.

4.8 CONSTRAINTS FARMERS FACE IN ADOPTING CONSERVATION AGRICULTURE

Another objective this study sought to accomplish was to find out the challenges smallholder farmers face in putting into use the environmentally sound agronomic practices associated with conservation agriculture – which includes minimum soil disturbance, crop residue retention and crop rotation. The challenges captured in the study were established from existing literature (Umar et al., 2011; Baudron et al., 2007; Kassam and Friedrich, 2011). These challenges include competing uses of crop residue, weed pressure, lack of labour, lack of implements and lack of access to oxen and inputs such as herbicides.

Table 4.14: Conservation agriculture challenges

Challenges	**Frequency**	
	% Yes	% NO
Lack of inputs such as seeds and herbicides	27.08	72.92
Lack of labour	54.17	45.83
Increased weed pressure	16.67	83.33
Lack of implements such as rippers	75	25

Source: Authors Data Survey, 2014

The results (Table 4.14) show that conservation farmers lack inputs, labour, implements and experience increased weed pressure. This is consistent with literature that conservation agriculture practices are labour intensive (Haggblade and Tembo, 2003; Nyanga et al., 2011; Ngombe et al., 2014). These findings are also consistent with Baudron et al., (2007) and Kassam and Friedrich (2009) who reported that weed pressure in the initial years increases the labour requirements. Despite the highlighted challenges, none of the farmers practicing conservation agriculture had a challenge of inadequate land, competing uses of crop residue or damage of crops by livestock.

Table 4.15: Responsible person for overcoming the challenges of conservation agriculture

	Frequency		
	% Farmer	% Government	% Non-Governmental Organisation
Who has the main responsibility of overcoming the challenges of conservation agriculture	58.33	35.42	6.25

When the farmers were asked "Who has the main responsibility of overcoming the challenges of conservation agriculture", about 58.33% (table 4.15) of the respondents responded that these challenges can be overcome by themselves through use of herbicides, hiring of labour and engaging in other income generating activities to supplement their agricultural activities as shown in table 4.16. Hired labour shows the lowest percentage (6.25) perhaps because smallholder farming households rely on labour from family members.

Table 4.16: Possible actions to be taken to overcome conservation agriculture challenges

	Frequency				
	% Government loans	% Use of herbicides	% Engaging in income generating activities	%Use of rippers	%Hire labour
What action do you think can be taken?	23.68	44.74	10.53	14.8	6.25

Umar et al. (2011) found effective use of herbicides saves on labour requirements for weeding. Therefore policy makers should intensify training on herbicide use in order to raise the adoption levels of conservation agriculture.

CHAPTER FIVE: CONCLUSIONS, RECOMMENDATIONS AND LIMITATIONS

5.1 CONCLUSIONS

Understanding farmer knowledge on ecosystem services and productivity with regards to conservation agriculture and conventional agriculture is important, as they affect the wellbeing of smallholder farmers. In this study, a Chi-square test was used to establish any relationship between the farming system that the farmers are engaged in and their level of knowledge. The long-term ecosystem services captured in this study include control of pests, diseases, and weeds, soil fertility, nutrient retention, soil conservation and crop yield. Conservation agriculture practices enhance ecosystem services and increase productivity while conventional agriculture trades off immediate increases in productivity for long-term ecosystem services. Generally conservation farmers expressed a higher level (>76 %) of knowledge of trade-offs in conventional agriculture compared to conventional farmers as shown by their agreement to statements in the Appendix. With an exception on the ability of burning crop residues to temporally increase soil fertility, where both farming groups showed low levels of knowledge. The results showed significant similarities in farmer knowledge of the potential of conventional agriculture and increases in soil erosion and reduce yield. Moreover, conventional farmers were more knowledgeable on the potential of conventional agriculture to pollute both air and water.

On the other hand, they were significant differences in farmer knowledge of the potential of conservation agriculture to supply long-term ecosystem services. Conservation farmers were more knowledgeable than conventional farmers on the ability of conservation agriculture practices to retain nutrients, improve soil fertility, reduce soil erosion, reduce pests and weeds and increase crop yield. However, the two farming groups where equally knowledgeable on the ability of conservation agriculture to conserve soil. And both farming groups knew that soil maintenance is important for food production. Moreover, conservation farmers were more knowledgeable on the potential of conservation agriculture to reduce both water pollution and soil erosion.

Conservation farmers were more aware of the environmental benefits and ecosystem services delivered from lands under conservation agriculture, but expressed lower willingness to expand areas under conservation agriculture. This shows that awareness does not translate directly into utilisation of expansion of technology. For conventional farmers, both awareness and willingness to adopt conservation agriculture practices were high. The study also indicated the challenges experienced by conservation farmers, including lack of access to inputs such as seed, labour and implements such as rippers.

This study notes that efficiency is also a means of improving productivity and therefore the Stochastic Frontier Analysis (SFA) was employed to estimate technical efficiency levels in maize production. Using SFA, the study found that the technical efficiency of maize among conventional farmers is 71.3% on average, while the technical efficiency of conservation agriculture farmers is 57.9% on average. The t-test revealed that there were no significant differences in the technical efficiency scores. This indicates that there is room for improvements in the efficiency levels in the production of the crop, and that more has to be done to raise conservation agriculture efficiency to make it attractive among the smallholder farmers.

The study further revealed that conventional and conservation farmers' technical efficiency is affected by different socio-economic factors. The results showed that the level of education of the household head, off-farm income and ownership of a ripper by the household were statistically significant in explaining the inefficiency levels for conservation farmers and these factors reduce efficiency. On the other hand for conventional farmers, the technical efficiency is significantly affected by gender of the household head, farming experience and household size. Among these factors, gender and farming experience increase efficiency, while the household size reduces efficiency.

It is worth noting that the years of experience contribute to an increase in technical efficiency among conventional farmers, while level of education plays a role in increasing technical efficiency among conservation agriculture. Thus, farmers practicing conventional agriculture seem to be managing their efficiency yet, trading off the environmental benefits. Conservation agriculture is knowledge intensive but there are environmental pay-offs in its efficiency improvements. These findings would help policy makers to consider factors that have a potential to improve farmers' level of technical efficiency.

This study also presented results from a t-test on inorganic fertiliser usage by convention and conservation agriculture. Farmers who practice conventional agriculture used more synthetic fertiliser in maize production than conservation farmers. However, they there is no statistical difference in fertiliser usage. The study further compared the conservation and conventional agriculture production function and the result showed that a 1% increase in the use of synthetic fertiliser leads to 0.678% and 0% increase in maize output per hectare for CA and CV respectively at both 1% and 10% level of significance. This shows that to increase maize yield by the same amount using fertiliser, while maintaining the level of other inputs constant, conventional agriculture requires a higher amount of fertiliser than conservation agriculture. The use of fertiliser increases yield at the expense of water and air quality. Since the fertiliser required to produce a given yield per hectare is higher under conventional agriculture than conservation agriculture. Therefore, it can conclude that there is a higher trade-off between agriculture production and water and air quality under conventional than under conservation agriculture.

5.2 RECOMMENDATIONS

Considering that conservation agriculture benefits are not enjoyed by farmers immediately, there is need for training amongst the smallholder farmers with emphasis that they are investing and preserving their environment to meet the current and future generations' food demand. The findings suggest that farmers' awareness levels are high, hence in order to make a shift from conventional agriculture to conservation agriculture, policy makers should introduce programs that provide incentives to farmers who practice conservation agriculture. There is need to strengthen extension service providers in order to disseminate information to farmers on conservation agricultural practices for increased productivity.

Following the findings of the research, besides promoting conservation agriculture among the smallholder farmers, there is need for subsidised implements such as rippers that would help increase the adoption of the farming system. For example, putting up infrastructure that will stock rippers placed within the farmers' proximity. The farming households can come to an agreement that the smallholder farmers pay for such implements in the form of maize.

Alternatively, the government can include the subsidised implements for conservation agriculture, such as rippers, in the agricultural programs such as in the Fertiliser Input Support Programme (FISP) that is currently running in Zambia. This is in order to reduce the challenges associated with access to implements. In the same vein, herbicides can be included in the package to reduce labour costs. The enforcement may be done by the extension officers who would make sure that the beneficiaries are only people that practice conservation agriculture.

5.3 LIMITATIONS OF STUDY

The study sample involved only smallholder farmers who practiced either conventional agriculture or conservation agriculture. This brings about a challenge on the study, as the results of this study cannot be generalised to farmers not using conventional and/or conservation agriculture. Another challenge on the data set was that the farmers practicing conservation agriculture were involved in conventional agriculture prior to the introduction of conservation agriculture. Therefore, the results of this study can be generalised to farmers and places with similar characteristics.

The research can be extended to all farmer categories and farming systems further estimating the allocative and economic efficiency to help policy makers in the promotion of environmentally friendly agricultural practices.

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APPENDIX A: QUESTIONNAIRE

Evaluating trade-offs between agricultural productivity and long-term ecosystem services provision among maize farmers practicing conventional and conservation agriculture in Kafue, Zambia

Questions are based on 2012/2013 farming season

A) General Information

1) Household identification number……………………….
2) District.. 4) Village.....................................
3) Name of interviewer.. 5) Date of interview......................

B) Socio-economic and demographic data

The purpose of this section is to understand the farmer characteristics that influence farmer decisions. (***Enumerator: tick the appropriate response***)

I will start my learning by knowing something about you as a farmer. (Enumerator: fill in the table below)

Age of household head at last birthday	Gender	Marital status	Education level	Major source of income
Q6	**Q7**	**Q8**	**Q9**	**Q10**

Q7
1=Male
2=Female

Q8
1=Single
2=Married
3=Divorced or Separated
4=Widowed
5=Others Specify............

Q9
1 =Primary Education
2=Secondary Education
3=University
4= No Education

Q10
1= Farming
2= Trading
3= Formal employment
4=Casual work

11) What is your household size including yourself? Please specify below

Household Member	Number
Adults aged 65 and above	
Adults aged between 16 and 64 years of age	
Children below 16 years	

"Household member" defined as someone who stays there for at least 3 months in a year

12) Are you a member of a farmer group? (a) Yes ☐ (b) No ☐

C) Farming systems and farm resources

The purpose of this section is to get information on your farm resources and the type of farming systems practiced on the farm and the related challenges and what can be done to overcome them.

13) Does your household own any of the following assets? (**tick all that apply)**

Asset	Number of assets owned	Assets	Number of assets owned
☐ Traditional hoe		☐ Chaka hoe	
☐ Axe		☐ Pigs	
☐ Tractor		☐ Chickens	
☐ Ripper		☐ Cattle	
☐ Ridging plough		☐ Goats	
☐ Slasher		☐ Pigeons	
☐ Oxen		☐ Sheep	
☐ Ox cart		☐ Donkeys	
☐ Ox drawn harrows		☐ Guinea Fowl	
☐ Ox drawn plough		☐ Bicycle	
☐ Cultivators		☐ Radio	
☐ Knapsack sprayers		☐ TV set	
☐ Well		☐ Vehicle	

14) Did you get any credit to finance your production in the 2012/2013 farming season?

(a) Yes ☐ (b) No ☐

15) If yes, please mention the source(s) of credit

....

....

16) Fill in the table below

How much land do you own (ha)	Land not owned but farmed by you (ha)	Land owned by you but rented out (ha)	Land owned but left fallow (ha)

17) Do you practice conservation agriculture? By conservation agriculture I mean things like turning of the soil only where you will plant your crop, leaving crop residues in the field and crop rotation. (a) Y ☐ (b) ☐

18) If yes, is the whole farm under conservation agriculture? (a) Y ☐ (b) No ☐

19) If your answer to the above question was No, could you indicate the reasons why you have not expanded conservation agriculture to other areas of your land?

....

....

....

....

20) Do you practice conventional agriculture? By conventional agriculture, I mean things like complete turning of the soil, removal of crop residues and monocropping.

(a) Yes ☐ (b) No ☐

21) If yes, what are the advantages of practicing conventional agriculture over conservation agriculture?

....

....

....

....

22) How long have you practiced

(a) Conservation agriculture?..years

(b) Conventional agriculture?..years

23) Mention **five** major crops you have grown in the last five years

....

....

....

24) How much land did you allocate to maize in the 2012/2013 production season?

Area of land under conservation agriculture (ha)	Area of land under conventional agriculture (ha)

25) If there are differences in area allocation for maize, why is the area under conservation/ conventional agriculture smaller than the other?

....
....
....
....

26) What are the major challenges you face when practicing conservation agriculture? **(Do not read out the list. Tick all that apply).**

☐ Lack of funds to purchase inputs (seed, fertilisers, chemicals)

☐ Labour constraint

☐ Inadequate land

☐ Competing uses of crop residue for animal feed and soil cover

☐ Crop damage by livestock

☐ Other (specify): ....

27) Of the challenges you have mentioned, what action do you think can be taken to overcome them?

....

....

....

....

28) Have you taken any of the mentioned actions to overcome the challenges of conservation agriculture?

(a) Yes ☐ (b) No ☐

29) If yes, what action have you taken?

....

....

30) Who do you think has the **main** responsibility for overcoming the challenges of conservation agriculture?

(a) Farmer ☐

(b) Government ☐

(c) Non-Governmental Organisation ☐

(d) Others (specify): ....

D) Production Information on Maize Input Utilisation (2012/2013 Farming Season)

The purpose of this section is to get information on the quantities of inputs involved in the production of maize based on the 2012/2013 farming season.

31) I am going to ask you about the inputs you used in maize production for the 2012/2013 farming season. (Enumerator: fill in the table below)

	CONVENTIONAL AGRICULTURE		**CONSERVATION AGRICULTURE**	
Input type	**Quantity used (kg/ha)**	**Cost of input (ZMK/Kg)**	**Quantity used (kg/ha)**	**Cost of input (ZMK/Kg)**
Seed				
Urea				
D compound				
Herbicides				
Lime				
Manure				
Others (specify)........				

32) Have you ever received any form of training on input use in maize production?

(a) Yes ☐ (b) No ☐

33) If yes, who provided the training?

(a) Extension agent (Government) ☐ (b) NGO ☐ (c) Farmer ☐

(d) Others (specify)………

34) For the above service provider, fill in the table below on the number of times they rendered service for that farming season

Service provider	Extension agent	NGO	Farmer	Others specify
Number of times visited				

E) Labour Inputs in maize production

The purpose of this section is to get information on labour requirements for maize production under two different farming systems.

35) I am going to read out a list of activities involved in maize production. As I read out the activities, please indicate the number of days you spent doing these activities in the last farming season (2012/2013). (Enumerator: fill in the following table)

	CONVENTIONAL AGRICULTURE		CONSERVATION AGRICULTURE	
Activity	**Number of times activity was done**	**Days**	**Number of times activity was done**	**Days**
Land tillage (overturning/digging/ ripping)				
Planting				
Fertiliser application				
Weeding				

Spraying				
Harvesting				
Threshing (drying, packaging and storage)				
Transport to market				

E) Crop Output

36) How much maize was harvested in the 2012/13 farming season? (Enumerator: fill in the table below)

	Quantity harvested (50 Kg bag)
Conventional agriculture	
Conservation agriculture	

F) Ecosystem services and Conventional agriculture

The purpose of this section is to establish the knowledge of farmers regarding the environmental costs of conventional agriculture.

Enumerator: Conventional agriculture involves the complete turning of the soil. It is also characterised by removal of crop residues before land preparation and monocropping. Monocropping means that you continuously grow the same crop on the same piece of land (for example continuously growing maize on the same piece of land). Removal of crop residues refers to the after-harvest removal of plant residues for animal feed and burning. The complete turning of the soil and removal of residues leaves the soils unprotected thus making the soils prone to both wind and water erosion. The burning of crop residues releases smoke causing human health problems (for example coughing).

I am now going to ask you about how conventional agriculture affects the environment of your farm and that of others situated away from your farm.

37) How does conventional agriculture affect the environment on your farm? The environment includes things like soil, water and air. (**Do not read out the list. Tick all that apply)**

- ☐ Air pollution
- ☐ Pollution of rivers
- ☐ Increased soil erosion
- ☐ Global warming
- ☐ Reduced biodiversity (biodiversity is the variety and variability of plants, animals and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries)
- ☐ Other (specify): ....
- ☐ Don't know
- ☐ None

38) How does conventional agriculture affect the environment of other people situated away from the farm? The environment includes things like soil, water and air**. (Do not read out the list. Tick all that apply)**

- ☐ Air pollution
- ☐ Pollution of rivers
- ☐ Increased soil erosion
- ☐ Global warming
- ☐ Reduced biodiversity
- ☐ Others (specify): ....
- ☐ Don't know
- ☐ None

39) I am now going to read statements about the practice of conventional agriculture and you are going to tell me the extent to which you agree or disagree. (Enumerator: tick in appropriate box)

STATEMENTS	**Agree**	**Don't know**	**Disagree**
1. Burning of crop residues temporally increases soil fertility			
2. Conventional agriculture reduces water loss from the soil			
3. Monocropping reduces crop diversity			
4. Monocropping increases crop diseases			
5. Complete turning of the soil increases soil erosion			
6. Conventional agriculture reduces the soil fertility			
7. Conventional agriculture reduces crop yield			

G) Ecosystem services and conservation agriculture

The purpose of this section is to establish the knowledge of farmers regarding the environmental benefits of conservation agriculture.

Enumerator: Conservation agriculture is based on three principles, namely minimum soil disturbance, crop rotation and crop residue retention. Minimum tillage means that you only disturb the soil where you are going to plant your crop in order to reduce soil, water and nutrient loss. Crop rotation means rotating crops that use nutrients differently (for example, maize and beans) or are prone to attacks by different pest in order to reduce pest build up. Retention of crop residues means that after harvesting of your crop, you leave enough residues (for example maize stalks) to cover the soil in order to improve the soil fertility.

I am now going to ask you about how conservation agriculture benefits the environment of your farm and that of others situated away from your farm.

40) How does conservation agriculture benefit your environment on your farm? The environment includes the soil, air and water. **(Do not read out the list. Tick all that apply)**

- ☐ Reduced soil erosion
- ☐ Reduced air pollution
- ☐ Reduced water pollution
- ☐ Increased biodiversity
- ☐ Other (specify): ....
- ☐ Don’t know
- ☐ None

41) How does conservation agriculture benefit the environment of other people situated away from the farm? The environment includes the soil, air and water. **Do not read the list. Tick all that apply**

- ☐ Reduced soil erosion
- ☐ Reduced air pollution
- ☐ Reduced water pollution
- ☐ Increased biodiversity

☐ Other (specify): ....

☐ Don't know

☐ None

42) I am now going to read statements about the practice of conservation agriculture and you are going to tell me the extent to which you agree or disagree. (Enumerator: tick in appropriate box)

STATEMENTS	Agree	Don't know	Disagree
1. Conservation agriculture has a high capacity for soil conservation			
2. Soil fertility is important to be maintained to increase crop yields			
3. Minimum tillage will help reduce soil nutrient run-off			
4. Crop residue retention can help to top up nutrients to agricultural land and thereby increase soil fertility			
5. Crop residue retention decreases soil erosion			
6. Crop rotation reduces crop pests, thereby contributing to better yield of your crops			
7. Legumes in crop rotations reduces the use of inorganic fertilisers			
8. Crop residue retention reduces amount of weeds			
9. Increased crop production and food we eat cannot be obtained without soil maintenance			
10. Conservation agriculture can increase soil fertility			
11. Conservation agriculture can increase crop yield			

For **questions 43-48** the purpose is to find out if the farmer were to know that adoption of certain agricultural practices that increase/decrease ecosystem services reduces/increases crop productivity, would be willing to do so with this knowledge. (***Note: conservation agriculture denoted as CF)***

43) Enumerator: By disturbing the entire soil you make it vulnerable to soil erosion. For example, soil erosion on your farm will increase which means that when it is windy the air that we breathe will have increased levels of dust and when it rains the water in the rivers will have increased levels of mud.

i) Are you aware that minimal turning of the soil as practiced in conservation agriculture reduces soil erosion?

(a) Yes ☐ (b) No ☐

ii) If yes, would you

(a) Adopt CF (for non- adopters) ☐

(b) Expand area under CF (for CF-practicing farmers) ☐

(c) Leave things the same ☐

44) Enumerator: With permanent planting stations the nutrients will accumulate in the planting basin which means that the crop will be able to make efficient use of them.

i) Are you aware that permanent planting stations as practiced in conservation agriculture reduce nutrient loss?

(a) Yes ☐ (b) No ☐

ii) If yes, would you

(a) Adopt CF (for non- adopters) (a) Yes ☐ (b) No ☐

(b) Expand area under CF (for CF practicing farmers) ☐

(c) Leave things the same ☐

45) Enumerator: Crop rotation will help in replacing nutrients in the soil thus diminishing the need for nitrogenous fertilisers.

i) Are you aware that crop rotation as practiced in conservation agriculture improves soil fertility?

(a) Yes (b) ☐ No (b) ☐

ii) If yes, would you

(a) Adopt CF (for non- adopters) ☐

(b) Expand area under CF (for CF-practicing farmers) ☐

(c) Leave things the same ☐

46) Enumerator: Crop rotation interrupts the life cycle of weeds, pests and diseases thus increases productivity. However, in the first years of conservation agriculture, weeding is laborious and costly with a greater requirement for herbicides, but the weed pressure is reduced with time and residues can help suppress weed growth.

i) Are you aware that crop rotation as practiced in conservation agriculture reduces the build-up of weeds, pests and disease?

(a) Yes ☐ (b) No ☐

ii) If yes, would you

(a) Adopt CF (for non- adopters) ☐

(b) Expand area under CF (for CF-practicing farmers) ☐

(c) Leave things the same ☐

47) Enumerator: Crop residues will protect the soil and conserve water and nutrients. For example, in the times of seasonal dry spells, crops will show greater resilience, which results in increased stability of food supplies.

i) Are you aware that retention of crop residues as practiced in conservation agriculture reduces water loss?

(a) Yes (b) ☐ No (b) ☐

ii) If yes, would you

(a) Adopt CF (for non- adopters) ☐

(b) Expand area under CF (for CF practicing farmers) ☐

(c) Leave things the same ☐

48) Enumerator: Conservation agriculture helps the land to be more productive for much longer periods of time

i) Do you agree with this statement? (a) Yes ☐ (b) No ☐

ii) If yes, would you

(a) Adopt CF (for non- adopters) ☐

(b) Expand area under CF (for CF-practicing farmers) ☐

(c) Leave things the same ☐

THANK YOU FOR YOUR PARTICPATION