Impact evaluation of conservation agriculture on smallholder farmers' livelihood in Zambia and Tanzania

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Declaration

I, Linda Atupele Sankhulani declare that this thesis, which I hereby submit for the degree MSc in Agricultural Economics at University of Pretoria, is my own work and has not previously been submitted at this or any tertiary university.

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Impact evaluation of conservation agriculture on smallholder farmers' livelihood outcomes in Zambia and Tanzania

By

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ABSTRACT

Based on cross-sectional data drawn from 135 treated and 68 control farmers in Tanzania, and 133 treated and 71 control farmers in Zambia, this study uses propensity score matching to test whether conservation agriculture (CA) improves smallholder farmers' welfare, in response to the policy objective of enhancing their resilience in the face of climate change. Farmers in Tanzania assess CA as having statistically significant impacts on increasing total agricultural yield, adaptation to climate change impacts, resilience to droughts, increasing maize production, enhancing household food security, increasing number of meals per day, increasing household income, accumulation of productive assets , addressing gender disparity and social cohesion, and improving soil health . However, CA had no impact on reducing the forest area cleared per year and total agricultural costs. Farmers in Zambia assess CA as having statistically significant impacts on increasing total agricultural yield , adaptation to climate change impacts, resilience to droughts, increasing maize production, enhancing household food security, increasing number of meals per day, decreasing number of food insecure months, increasing household income, accumulation of productive assets, addressing agricultural calendar bottlenecks, increasing total agricultural costs, addressing gender disparity and social cohesion, and decreasing soil health. However, CA had no impact on reducing forest area cleared per year. Policy could use such evidence to leverage CA adoption in support of the sustainable development goals (SDGs) and Africa Agenda 2063, although its potential to sequester carbon and provide ecosystem services comes into question.

<u>Key words</u>: Propensity score matching; impact; conservation agriculture; Tanzania; Zambia

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List of Acronyms

ACT	African Conservation Tillage Network
CA	Conservation agriculture
CAADP	Comprehensive Africa Agriculture Development Plan
CSA	Climate Smart Agriculture
EAC	East African Countries
FAO	Food and Agriculture Organization of the United Nations.
PSM	Propensity Score Matching
SADC	Southern Africa Development Community
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
TLU	Tropical Livestock Unit

Chapter 1: Introduction

This research assesses the impact of adopting conservation agriculture (CA) practices by smallholder farmers in Tanzania and Zambia on pre-determined outcome variables (specifically: agronomic outcomes, food security and nutritional outcomes, economic outcomes, gender and social outcomes, and environmental outcomes). The agronomic outcomes assessed were the total agricultural yield, the farmer's ability to adapt to the impact of climate change, the farmer's resilience in the face of drought, and the total maize production. The food security and nutritional outcomes assessed were the number of food-insecure months per year, and the number of meals per day. The economic outcomes assessed were household income, accumulation of productive assets, the household's ability to address agricultural calendar bottlenecks, and the total agricultural production costs. The gender and social outcomes assessed were gender disparities and social cohesion. Finally, the environmental outcomes assessed were the impact of CA on soil health, and the forest area cleared per year.

Conservation agriculture practices are strategies that enhance productivity and adaptive capacity to climate change impact (CCAFS, 2014). CA has been used as a tool to achieve food security and build the resilience of farmers in the face of climate shocks. CA has been widely promoted, and has gained popularity as a transforming technology, particularly among smallholder farmers. CA involves a suite of elements: minimum soil disturbance, crop rotation, and continuous soil cover (FAO, 2019).

CA impact assessment measures the effectiveness of uptake and provides a benchmark for promoting the technology. Understanding the effectiveness of CA defines the significance and relevance of CA practices and provides a benchmark for upscaling the technology. In simple terms, impact assessment provides a connection between evidence and decision-making. CA impact assessment using farm-level data provides an evidence-based understanding of the measurable and robust benefits of adopting CA. CA impact assessment is a critical tool for informing policy-makers on the effectiveness of the technology for decision-making. For instance, CA has been incorporated into African agricultural policy programmes, such as the Comprehensive Africa Agriculture Development Plan, the Malabo Declaration, and 2063 African Agenda. The Malabo Declaration is specifically committed to building resilient livelihoods and food systems by promoting CA (Commission, 2014). Consistently, international organisations have supported African countries in upscaling CA adoption among smallholder farmers. The support includes investment in CA implements, agricultural extension staff, and farmers' trainings and policy formulation. In this regard, CA impact assessment in Tanzania and Zambia will provide a benchmark for decision-making in CA policy agenda.

At the global level, CA's impacts differ according to agro-ecological zones and policy environment. CA has been shown to have positive and significant impacts in highly mechanised regions, compared with production that is operated manually (Jaleta et al., 2014). Globally, CA has been shown to reduce agricultural production costs and increase agricultural productivity (Halbrendt et al., 2014). In contrast, CA's impact in Africa has shown inconsistent results due to different policy frameworks and technical capacity (Nkala et al., 2011a). It is therefore difficult to draw conclusions about CA impact on smallholder farmers in Africa. Despite the known impacts of CA on crop production, CA adoption rates remain very low in sub-Saharan Africa (SSA). The inconsistency of CA's impact and adoption rates raises the question: does CA have a positive livelihood impact on smallholder farmers so that they can achieve high adoption rates? CA's impact on smallholder farmers' livelihood outcomes is inconclusive (Nkala et al., 2011b). CA's impact on livelihood outcomes varies, depending on location and prevailing economic conditions, among other factors. Worse still, there are conflicting results of CA's impact on specific livelihood outcomes in Africa in similar locations (Abdulai and Huffman, 2014, Edralin et al., 2017, Friedrich and Kienzle, 2007, Jumbe and Nyambose, 2016, Khonje et al., 2018, Mango et al., 2017, Ng'ombe et al., 2017, Ngwira et al., 2012). This indicates that a gap exists in understanding CA's impact on livelihood outcomes in Africa. This points to the need continuously to understand empirically tested CA's impact on livelihood outcomes and how this defines CA adoption rates in sub-Saharan Africa. The combination nexus of these dynamics will inform CA promoters on the potential and context of CA investments to result in a shift in CA adoption rates.

CA has not been as widely practised in Tanzania as it has in Zambia (Hodson, 2016). There is limited literature on CA's impact on smallholder farmers' livelihood outcomes in Tanzania. The available literature focuses on adoption potential and not on livelihood outcomes (Kimaro et al., 2016, Nyasimi et al., 2017, Tumbo et al., 2019) . This indicates that a knowledge gap exists in understanding CA's impact on livelihood outcomes in Tanzania. This implies that CA policymakers have limited literature as a benchmark for upscaling the technology in Tanzania. On the other hand, Zambia has widely implemented CA in sub-Saharan Africa, and has relatively more literature on CA's impact relative to Tanzania. However, there is limited literature that tests CA's impact concurrently on multiple livelihood outcomes such as agronomic outcomes, food security and nutrition, household economic outcomes, social and gender outcomes, and environmental outcomes. The available literature is conflicting, inconsistent, and inconclusive (Abdulai and Huffman, 2014, Edralin et al., 2017, Friedrich and Kienzle, 2007, Jumbe and Nyambose, 2016, Khonje et al., 2018, Mango et al., 2017, Ng'ombe et al., 2017, Ngwira et al., 2012)

This study seeks to understand the impact of CA adoption on the livelihoods of smallholder farmers in Tanzania and Zambia. The study hypothesises that a clear understanding of CA's impact will provide evidence for CA policy-makers in the CA policy agenda, and smallholder farmers will have the evidence for decision-making about CA adoption. Considering the potential for clear and conclusive results on CA adoption, the research compared CA adopters and non-adopters on the specific livelihood outcomes to draw conclusions. The study objectively measured and quantified the difference in livelihood outcomes for CA adopters and non-adopters as evidence for CA decision-making.

1.1 Background information to the study

The low CA adoption rates in Africa have been a worrying concern to governments and climate change experts. This is against a background of huge financial investments to encourage CA adoption among smallholder farmers. Significantly, numerous international organisations have implemented CA projects to upscale adoption rates. Among the notable CA-promoting organisations, African Conservation Tillage (ACT) has spearheaded CA implementation and research to increase CA adoption in Africa. Within a range of CA projects implemented by ACT, the tripartite programme on Climate Change Adaptation and Mitigation in Africa was flagged as a huge investment. The project was a partnership with the Common Market for Eastern and Southern Africa (COMESA), and was implemented from 2010 to 2016 (COMESA, 2011). In the programme, ACT was responsible for the capacity development of partners and for knowledge and information management in CA. As part of its mandate, ACT promoted the adoption and practice of CA across different agro-ecological zones in Tanzania, Zambia, Zimbabwe, and Kenya. The project hypothesised that CA has multiple effects on the adopter's livelihood outcomes, and therefore that it was necessary to invest in increasing CA adoption among farmers. However, there have been conflicting results on the impact of CA on livelihood outcomes such as crop yields, food security, household income, labour and agricultural workload, and gender disparity (Abdulai and Huffman, 2014, Edralin et al., 2017, Friedrich and Kienzle, 2007, Jumbe and Nyambose, 2016, Ngwira et al., 2012).Thus the impact of the CA project on livelihood outcomes is not clear.

This study seeks to understand the impact of CA adoption on the livelihoods of farmers in Tanzania and Zambia. The study used data from the ACT-COMESA end-of-project evaluation collected between June 2016 and August 2016. Data was collected using a three-stage purposive and random sampling for CA hotspots in each country. Respondents included CA adopters and non-CA adopters. This research focused specifically on comparing CA adopters and non-adopters on livelihood outcomes such as agronomic outcomes, food security and nutrition, household economic outcomes, social and gender outcomes, and environmental outcomes. The study focused on understanding and quantifying the difference in livelihood outcomes for CA adopters and non-adopters, and how these impacts cut across gender outcomes. Initially, the study analysed CA technology adoption by country and challenges to CA adoption. Importantly, the study had a special focus on drawing causality between CA adoption and livelihood outcomes. The study used propensity score matching to ascertain the impact of CA on livelihood outcomes. Propensity score matching was used to deal with self-selection bias, considering that CA adoption and the choice of targeted implementation spots was not random.

1.2 Statement of the problem

Smallholder farmers have been motivated to adopt CA to improve land productivity, food security, and other livelihood outcomes (Corbeels et al., 2015).However, despite all the documented benefits of CA, their adoption rates remain low in SSA. The low CA adoption rate necessitates an investigation of the drivers of CA adoption among farmers. Within a range of drivers of CA adoption, CA's impact on livelihood outcomes tops the list of drivers to CA adoption among smallholder farmers. However, there are conflicting results on the impact of CA on smallholder farmers' livelihood outcomes (Abdulai and Huffman, 2014, Edralin et al., 2017, Friedrich and Kienzle, 2007, Jumbe and Nyambose, 2016, Khonje et al., 2018, Mango et al., 2017, Ng'ombe et al., 2017, Ngwira et al., 2012). There are also limited studies on CA's impact on different livelihood outcomes such as household food security, household income, and social and gender outcomes, making a clear conclusion difficult to reach. Furthermore, there are limited studies that concurrently evaluate all the key livelihood outcomes such as household food security and nutrition, household income, and social cohesion, and how these outcomes define CA adoption rates in sub-Saharan Africa.

It is against this background that the study evaluated the CA impact on farmers' livelihood outcomes in Tanzania and Zambia to contextualise and provide background to CA adoption rates in sub-Saharan Africa. Significantly, the study drew on the relationship between CA technology adoption and the empirically tested impact of CA. The study endeavoured to make a valuable addition to the CA literature by providing the background to the CA technologies preferred by smallholder farmers, and a robust impact assessment.

1.3 Research questions

Using 2015/2016 cross-sectional data from CA adopters and non-adopters in Tanzania and Zambia, the study seeks to respond to the overall objective: Is conservation agriculture providing tangible positive impacts on livelihood outcomes for CA adopters in Tanzania and Zambia? To achieve this objective, the study uses propensity score matching to check whether there is any statistically significant difference between CA adopters and non-adopters on livelihood outcomes. To answer the overall objective effectively, the following specific questions will be addressed.

1.3.1 Do agronomic outcomes for CA adopters significantly different from those of non-adopters?

1.3.2 Do food security and nutrition outcomes for CA adopters significantly different from those of non-adopters?

1.3.3 Do household economic outcomes for CA adopters significantly different from those of non-adopters?

1.3.4 Do social and gender outcomes for CA adopters significantly different from those of non-adopters?

1.3.5 Do environmental and natural resources benefits for CA adopters significantly different from those of non-adopters?

These research questions are interlinked to understand better the impact of CA on key livelihood outcomes. These questions are important in providing concrete answers to the debate on CA and livelihood outcomes for smallholder farmers in the two targeted countries. The study's answers to these questions will close the knowledge gap that exists in the CA spectrum.

1.4 Objectives of the study

The main objective of this study is to test whether CA results in tangible positive livelihood outcomes for smallholder farmers in Zambia and Tanzania. The research thus intends to assess and evaluate the impact of CA adoption on livelihood outcomes in Zambia and Tanzania. The research will be guided by five specific objectives:

I. To establish the differences in agronomic benefits between CA adopters and non-adopters.

II. To establish the differences in household food security and nutrition between CA adopters and non-adopters.

III. To establish the differences in household economic benefits between CA adopters and non-adopters.

IV. To establish the differences in social and gender outcomes between CA adopters and non-adopters.

V. To establish the differences in environmental and natural resources benefits between CA adopters and non-adopters.

1.5 Statement of study hypotheses

Agronomic theory portrays CA as a climate adaptation measure as well as an enhancement to agricultural productivity. Crop production is a source of livelihood for most smallholder farmers in African countries, and therefore needs climate-smart technologies. On the other hand, smallholder farmers are rational beings who are interested in adopting technologies that enhance livelihood outcomes such as food security, household incomes, and a reduced agricultural workload. However, the impact assessment of CA adoption on livelihood outcomes such as crop yields, food security, and household income has been inconsistent (Corbeels et al., 2015, Edralin et al., 2017, Mango et al., 2017, Nkala et al., 2011b).These observations inform the hypotheses motivated below.

Hypothesis 1: There are no significant differences in agronomic outcomes between CA adopters and non-adopters.

CA promoters argue that CA has a positive impact on agronomic outcomes such as soil fertility, adaptation to climate change, resilience in the face of drought, and agricultural yield. CA has been reported to enhance soil fertility and soil aeration (Edralin et al., 2017, Hodson, 2016) to have drought-resilient properties, and to perform better in dry areas (Mafongoya et al., 2016).

However, Nkala et al. (2011a) report different CA impacts in different locations and agro-ecological zones. Their study hypothesised that there are no statistically significant differences in agronomic outcomes between CA adopters and non-adopters.

Hypothesis 2: There are no significant differences in food security and nutrition between adopters and non-adopters.

Smallholder farmers are highly dependent on their own crop production for their household food needs. It is assumed and hypothesised that crop production translates into improved food security and nutrition outcomes at the household level. However, Mango et al. (2017), Ruel et al. (2019), and Tsegaye et al. (2017) found different results for the impact of CA adoption on household food security and nutrition. This can be supported by the reality that crops are also a source of income for all household needs, and therefore increased yields do not imply improved food security. Furthermore, food availability at the household level does not directly translate into improved household food security and nutrition (Conceição et al., 2016) This study hypothesised that food security and nutrition for CA adopters is not statistically significantly different from that for non-CA adopters.

Hypothesis 3: There are no significant differences in household economic outcomes between CA adopters and non-adopters

Smallholder farmers in Tanzania and Zambia are extremely dependent on on-farm incomes, with their off-farm incomes being linked to seasonal agricultural trends. Theoretically, increasing crop productivity is supposed to increase household incomes, but this has been found to be inconsistent with research results. Nkala et al. (2011) found a positive CA impact on crop yields, but not on household incomes. This may be explained by the fact that crop yields are used for different cultural functions, which may not have monetary value. On the other hand, household incomes are a combination of different factors beyond crop yields. Edralin et al. (2017) report that CA increases household incomes through reduced agricultural production costs. However, Nyanga et al. (2012) have shown that manual CA increases labour costs for weeding compared with those for conventional farming. It is from such assertions that this study hypothesised that household economic benefits for CA adopters and non-CA adopters are not statistically significantly different.

Hypothesis 4: There are no significant differences in CA social and gender impacts between CA adopters and non-adopters.

Numerous examples of research on CA's impact have been silent on its impact on livelihood outcomes across gender (Abdulai, 2016, Friedrich and Kienzle, 2007). These studies generalise that men and women are impacted equally by CA adoption. However, Nyanga et al. (2012), Parks et al. (2015), and Wekesah et al. (2019) report different CA impacts on men and women. Parks et al. (2015) found negative CA impacts on female-headed households, yet Siziba et al. (2019) reported positive CA impacts on female-headed households. These studies confirmed the inconsistent results of CA's impact on gender outcomes. This study hypothesises that CA's impact on community social cohesion and gender disparity are not significantly different between CA adopters and non-adopters.

Hypothesis 5: There are no significant differences in environmental and natural resources between CA adopters and non-adopters

CA's impact on environmental and natural resources has focused on soil health, forest area cleared for cultivation and other domestic purposes, and soil erosion. CA has been documented to have carbon sequestration benefits (Kimaro et al., 2016), and equally CA has been documented to have no carbon sequestration benefits (Palm et al., 2014). However, there is still debate on the potential of CA to sequester carbon and curb greenhouse gases (Cheesman et al., 2016, Kimaro et al., 2016, Powlson et al., 2016, Simone et al., 2017). Esser (2017) found negative CA impacts on soil water infiltration, retention, and soil health. On the other hand, Kimaro et al. (2016) found CA to be climate-smart and to improve soil health. These results suggest inconsistent and inconclusive CA impacts on soil health and environmental quality. The study hypothesises that CA's impact on environmental and natural resources is not statistically significantly different between CA adopters and non-adopters.

1.6 Limitations of the study

The study's results were limited by the quality of the available data. For instance, the study had data from two CA hotspots from each country. The study recommends a comprehensive study with a greater and more representative sample for better results. In addition, the study's econometric analysis was limited by the quality of the available data.

The questionnaire was designed to collect generalised data from CA hotspots, so it lacked a country-specific context. This was very noticeable, for instance, in analysing the constraints on CA adoption, in which the farmers did not specify all the available options as constraints on CA adoption. This therefore left a gap in understanding the challenges that are pertinent to the two countries. It is important that future studies be contextualised to country-specific implementation and be tailored to understand the contextual issues.

1.7 Organisation of the study

The study is organised into five chapters: introduction, literature review, methods and procedures, results and discussions, and conclusions and recommendations. The first chapter introduces the thesis and the problem statement and outlines the objectives and study hypotheses. The second chapter reviews the CA literature and the relevant discussions and results of the study; it reviews similar study methods and procedures; and it provides insights into the hypotheses outlined in Chapter 1. Chapter 3 presents the methods of the study, the econometric approach, and a description of the study areas. This is followed in Chapter 4 by the presentation of the results and discussions, and how the results relate to the literature in Chapter 2. Finally, Chapter 5 concludes the study and provides relevant policy recommendations to inform future programmes.

Chapter 2: Literature review

The purpose of this chapter is to review and examine the theoretical and empirical literature on CA adoption and on CA's impact on agronomic outcomes, food security and nutrition, household economic outcomes, gender and social cohesion, and the environment. The first section provides background on the CA technologies practised in Africa, CA adoption rates, and documented adoption challenges. This is followed by sections on the theoretical and documented CA impacts on agronomic outcomes, food security and nutrition, household economic outcomes, gender and social cohesion, and environmental outcomes. The chapter then reviews empirical studies that implemented the impact assessment, the method used for the impact assessment, and how the method informs the research processes used in the study.

2.1 Introduction

CA combines three principles: minimum tillage, soil cover, and crop rotation. Each of these CA technologies has its own benefits. For example, minimum tillage stabilises soil structure, which improves microbial activities and improves crop productivity (Edralin et al., 2017). Crop rotation breaks the cycle of pests and diseases and improves soil fertility through nitrogen-fixing legumes. And a permanent soil cover shields the soil from the sun, rain splashes, and wind, and forms a stable and conducive environment for plant growth (Mal et al., 2015). Soil cover is either a growing crop or dead mulch. Fundamentally, crop residue mulching has proved to decrease weed growth and reduce the demand for labour in the initial planting season (Harman Parks et al., 2015).

'Conservation agriculture' has been used interchangeably with 'conservation tillage', but these terms refer to different practices. Conservation tillage includes a wider set of agricultural practices that leave crop residues in crop fields to counter soil erosion and improve water infiltration (Reicosky, 2015). Conservation tillage practices, such as zero tillage practices, are steps to CA, but they are not necessarily CA. 'Conservation agriculture' has also been used interchangeably with 'conservation farming'; the latter term in fact means the same as 'conservation agriculture', and is used widely in Zambia (Hodson, 2016).

2.1.1 CA's adoption rates in sub-Saharan Africa

CA in SSA has been promoted for over two decades; however, adoption rates remain low. CA accentuates the need to adopt all three principles of no-till, continuous soil cover, and crop rotation for efficiency (FAO, 2019). Farmers have been inconsistent in their adoption of the full CA package; smallholder farmers judiciously adopt CA technologies that suit them (Arslan et al., 2016). It is documented that 0.3% of CA farmers comply with the Food and Agriculture Organization (FAO)'s definition of CA (Brown et al., 2018).There have been several documented challenges to full adoption of CA technologies among SSA farmers.

CA has been reported to be time- and labour-intensive; for instance, farmers have cited the labour intensity of planting basins (Mudamburi et al., 2018).CA adoption rates have been reported to be the highest in highly mechanised countries such as South Africa; nonetheless, the available data suggests a significant adoption of manual CA in low rainfall areas (Mazvimavi, 2016). Labour intensity also alters households' labour availability, and female-headed households are particularly burdened (Doss, 2001). Some studies have shown differences in the adoption of manual and minimum tillage between male and female farmers (Ndiritu et al., 2014). In manual CA, no-till has been documented to increase the labour needed for weeding, and inadequate labour to suppress weed growth constrains CA adoption (Lee and Thierfelder, 2017). Although inconsistent with climate-smart principles, CA farmers are forced to use herbicides for weed control (Kimaro et al., 2016). The use of herbicides is an extra cost to farmers, and both access and technical management have proved to be a challenge to smallholder farmers in sub-Saharan Africa (Nyanga et al., 2012).

Equally, competition between livestock feed and crop residue mulching has been recorded as a constraint to CA adoption. CA adopters have been challenged to devise the best strategy to protect crop residues from livestock. In some instances, CA farmers have opted to erect a fence around the field, which is not feasible (Whitfield et al., 2015). Crop residue mulching has been effective in areas where there are high numbers of CA adopters to institute by-laws on livestock management (Ndah et al., 2015). In other cases, CA farmers have opted for stall feeding, which increases both the labour costs and the burden on female farmers. Farmers have also decried the burden of transporting crop residue from other fields when the crop residue from within the field is not enough. Mulching has been claimed to increase and harbour crop pests and diseases from the previous season (Bhadu et al., 2018). Crop residue mulching has also been documented to reduce household income in areas where crop residue is traded for livestock feed and cooking purposes (Valbuena et al., 2012).

There is also a low adoption of crop rotation among farmers For example, a study on CA adoption in Ethiopia showed that crop rotation does not appeal to smallholder farmers, who are only interested in maize production (Tessema et al., 2016). Food security in most SSA countries is defined as household maize availability; and thus, farmers prioritise maize over other crops. The lack of reliable profitable markets for legumes, and limited access to certified legume seeds, are constraints on crop rotation adoption. Thierfelder et al. (2013) found that maize had the highest gross margin relative to other crops grown under CA, which motivates farmers to prioritise maize over other crops.

Furthermore, CA adoption has been hampered by gendered impacts. Farnworth and Colverson (2015) showed that male and female farmers differed in their access to extension and advisory services. Similarly, Ng'ombe et al. (2017) indicated that male farmers had higher chances of being supported by CA extension service providers than female farmers in Zambia and Zimbabwe. Yet female farmers have a high potential of adopting CSA technologies if such technologies meet their gender needs (Murage et al., 2015). This therefore means that deliberate gender-responsive efforts are necessary to increase extension services to female farmers and to increase CA adoption.

Importantly, agricultural policies require a strong and effective policy framework to steer support for CA adoption. Research has found weak institutional and policy frameworks on CA, and that CA policy has been hampered by policies on farm input subsidies (Dougill et al., 2017). Similarly, poor economic and infrastructural policies, such as markets and roads, are constraints on CA adoption. This confirms that CA adoption constraints vary based on prevailing policies and location. There is therefore a need for more effort and research in order to understand the policy dimensions of CA and the underlying benefits of CA.

2.1.2 CA practices in sub-Saharan Africa

Primarily, CA is practised as either manual or mechanised CA. The two systems differ in the initial stages of land preparation, seeding, weeding practices, and farming implements. Manual CA uses basin planting, and the specifications for the basins differ among countries and regions. The planting basins are used for planting and fertiliser application and decrease the chances of crop failure by enhancing the concentration of water and soil fertility. This has been shown to be particularly valuable in drought conditions (Thornton et al., 2017). These basins are created during the winter season, spreading labour during the off-season, and providing time for off-farm activities. Other farmers use rip-line seeding; these rip lines are created either after harvesting or at the onset of the growing season, depending on the farmer's preference. In other instances, farmers use pointed sticks to create planting holes – a common CA planting technique (Nyanga et al., 2012). The pointed stick is common due to its simplicity, and it does not require specialised CA implements. On the other hand, mechanised CA uses different implements such as Magoye rippers and jab-planters. The jab-planter directly plants seeds and applies fertilisers in the planting holes. The use of jab-planters and Magoye rippers is constrained by farmers' limited land-holding size and poorly defined property rights (Brinkman, 2017). Other farmers use an animal-drawn seeding system to plant seeds and apply fertiliser. Animal-drawn traction is better suited in areas with high ox-drawn animals and is more convenient than the jab-planter; however, it is hampered by poor livestock health after the dry season (Jaleta et al., 2014). Farmers using jab-planters, rippers, and animal-drawn traction have reported the improved timeliness of operations, which enhances earlier planting over manual CA systems. However, there is limited access to CA implements among farmers. It has been noted that CA projects support farmers with jab-planters, rippers, and other CA-complementary tools during the project period, but that this is not sustainable after the project period, and so farmers resort to conventional farming (Lai et al., 2012). It is necessary to institute policies and an enabling environment for locally-based and cost-effective CA machinery. This can include innovative approaches to a CA implement hiring service, developing local artisans who make CA implements, and a conducive market for CA machinery (Jaleta et al., 2014).

2.2 Relationship between conservation agriculture and livelihood outcomes

Livelihood is made up of people, capacities, and methods of earning a living such as income, assets, and food (Scoones, 2015). Climate change has increased the call for sustainable and resilient livelihoods. The Malabo Agreement committed countries to enhance resilient livelihoods and agricultural systems (Commission, 2014). Crop production, a major livelihood for most rural households, needs to be sustainable and therefore requires technologies that are climate-smart (Pittelkow et al., 2015). Farmers adopt CA with the goal of increasing crop yields and reducing production costs (Ng'ombe et al., 2017).Correspondingly, high crop yields are expected to improve food security and increase household income (Nkala et al., 2011b). Theoretically, CA adoption should have a positive impact on key livelihood outcomes, which, over time, should increase adoption rates among smallholder farmers in sub-Saharan Africa.

2.2.1 Impact of CA on agronomic outcomes

Agronomic theory suggests that CA improves the capacity to adapt to climate change and to reduce crop vulnerability through water retention in times of drought (Selejio et al., 2018).There have been different results for both experimental and field trials on CA's impact on soil quality, crop yields, and resilience in the face of drought, and this section outlines the different findings of CA's impact on agronomic outcomes. The study focused initially on CA's impact on total maize production, total agricultural yield, adaptation to the impact of climate change, and resilience in the face of drought.

There have been several debates on the premise that CA increases crop yield. Researchers have argued that most of the studies have been done on experimental trials, rather than on the normal and local conditions that farmers face (Edralin et al., 2017). Khonje et al. (2018) and Lai et al. (2012) found a positive statistically significant difference in crop yield between CA and conventional farming. On the other hand, study results from Zambia on CA's impact on farmers' welfare showed that the crop yields of CA adopters were not statistically significantly different from those of non-adopters. Likewise, another study in Zambia showed a negative CA impact on crop yields compared with conventional farming, with the study documenting management constraints as a possible failure of CA to produce positive results (Gatere et al., 2013).

Studies of specific CA technologies provide different results, based on the adoption conditions and locations. Khonje et al. (2018) and Ward et al. (2016) argue that, when farmers partially adopt CA technologies, this affects the performance of CA on crop yield. CA is also reported to have increased the maize yield if intercropped with legumes, compared with stand-alone cropping (Lai et al., 2012). Similarly, a meta-analysis of the effect of minimum tillage on crop yields found a negative impact; however, crop yields increased when combined with crop rotation and cover crops (Arslan et al., 2014, Corbeels et al., 2014). Mupangwa et al. (2017) reported that CA increased maize productivity in cases of systematic crop rotation. Importantly, CA performance has been shown to differ, based on agro-ecology and soil qualities. For example, an impact evaluation of CA on water infiltration in cotton and sorghum fields showed no statistically significant difference between CA and conventional farming on fine-textured soils, while the results were significantly different on coarse-textured soils (Baudron et al., 2012). This showed that the performance of CA also depends on soil quality. Ngwira et al. (2012) and Michler et al. (2019) found statistically insignificant results between maize yields for conventional farming and CA in normal rainfall conditions, but a positive statistically significant difference in times of drought. Likewise, Alfani et al. (2019) and Steward et al. (2019) reported a positive impact on maize production in periods of El-Niño in Malawi and Zambia. Mafongoya et al. (2016) highlighted that CA increases crop yields in dry areas.

However, Enfors et al. (2011) reported inconclusive results on CA's impact on crop yields in the dry land of Tanzania.

It has also been documented that the crop yield difference between CA and conventional farming differed over time. For instance, CA increased the maize yield with more years of experience (Thierfelder et al., 2018) and a meta-analysis of CA's impact on soil fertility and maize yields reported an improved maize production over time (Brouder and Gomez-Macpherson, 2014). CA requires technical skills in planting pits and herbicide use, and these skills are enhanced over time (Corbeels et al., 2015).This is comparable with agricultural production theory that states that efficiency of technologies improves over time (Smeets Kristkova et al., 2017).

Based on the documented impact of CA on crop yields, there is still no concrete and tangible conclusion on the benefits of CA on crop yields, adaptation to the impact of climate change, and resilience in the face of drought (Brouder and Gomez-Macpherson, 2014, Zheng et al., 2014). More studies agree that there is no clear trend in the performance of CA on crop yields in Africa (Stevenson et al., 2014). This indicates a literature gap on clear CA impacts on agronomic outcomes among smallholder farmers and require investigation to establish CA impacts. Considering that agronomic outcomes inform performance of other livelihood outcomes, it is important to provide farmers and other stakeholders concrete results on CA's impacts on agronomic outcomes to close the literature gap and inform the CA policy agenda

2.2.2 Impact of CA on food security and nutrition

Food security is defined by the FAO as "when all people have access to enough and sufficient food all the time for all bodily needs" (Pinstrup-Andersen, 2009). There are four dimensions to food security: food availability, access, stability, and use. *Food availability* focuses on the presence of food from different sources, such as own production and food aid; basically this is the supply side of food (Marivoet et al., 2017). *Food access* deals with all the capacities and systems that are needed for the availability and affordability of food for households. Food availability is different from food access, as food can be available but not accessible due to factors such as purchasing power and distribution (Perez-Escamilla et al., 2017). *Food use* is the ability of the household to use the food for household consumption. This is where food is translated into nutrition. The last dimension of food security, *food stability*, focuses on the household's ability to maintain food security over a long time. The adoption of climate-smart technologies such as CA has been shown to build resilient livelihoods and increase food stability (Campbell et al., 2016).

Africa still faces food insecurity, despite a reported global increase in food production (Denny et al., 2018).Over the past two decades, crop yields have increased, but increased crop production does not guarantee household food security (Conceição et al., 2016, Xu et al., 2019) However, higher crop yields have been shown to have a positive impact on household food security if women have both access to and control of the produce (Silvestri et al., 2015). Food security has been shown to be influenced by different factors, such as age, education, gender of the household head, and the adoption of agricultural technologies (Zhou et al., 2017). These factors are critical in understanding and formulating policies that are effective, and in using agricultural technologies that are nutrition-sensitive. Zambia and Tanzania still have a large percentage of households who depend on agriculture for food and income. Technologies that increase agricultural productivity have a direct impact on household food security. An increased crop yield ensures that households have adequate and nutritious food throughout the year, and reduces periods of food insecurity (Frelat et al., 2016). It has also been shown that increased crop yield increases household income, since SSA farmers get income from the sale of surplus crops, which increases the availability of micro-nutrient-rich food (Devereux, 2016).

There are different findings about CA's impact on household food security. The CA literature has documented the quantitative CA impact on food security and disregarded the qualitative part. Nevertheless, documentation that is both quantitative and qualitative is important in understanding CA's adoption and impact. For instance, the use of herbicides has been found to reduce the availability of local vegetables, and to reduce diet diversity and women's income (Nyanga et al., 2012). It is reported that the use of herbicides kills all the weeds in the fields, including those that are edible, thus increasing the burden on women searching for vegetables. Nonetheless, CA has the potential to contribute towards nutrition sensitive agriculture through the availability of legumes in household meals. SSA diets have been mono-cultured and full of starch (especially maize); and legumes have the potential to change this diet. Crop diversification has a positive effect on household food security status. The diversity of crops grown improves dietary diversity and improves household food security. In remote rural areas, households depend on their own production to enhance the availability of diverse foods (Adjimoti and Kwadzo, 2018). The challenge has been that most households sell legumes instead of using them for household consumption; for instance, Nkala et al. (2011b) found a positive CA impact on crop productivity, and an insignificant CA impact on the households' food security and nutrition. Nevertheless, CA could improve food security if incomes realised from the sale of surplus crops were managed by women (Doss et al., 2018). Regrettably, men overtake women in managing crops that are shown to be lucrative, thus worsening household food security (Nyanga et al., 2012).

There have been inconsistent results on CA's impact on household food security. This is attributed to numerous indicators, measured at individual, household, and national level, which use different metrics. The challenge in the differences between the outcomes can be attributed to the multi-dimensionality of the food security measurement indicators (Lele et al., 2016, Perez-Escamilla et al., 2017). A number of CA impact studies on food security used different food security indicators, such as the number of food-secure months, a food consumption score, and a dietary diversity score (Abdulai, 2016, Brown et al., 2018, Mango et al., 2017). Similarly, a study on the impact of the adoption of agriculture technologies on food security used different food security indicators, such as total consumption expenditure, household expenditure on food, calorie intake, and diet diversity (Magrini and Vigani, 2016). The study found a positive relationship between agricultural technologies and food security in Tanzania using principal component analysis. These studies provided different results, as the indicators used different food security dimensions. A study of the impact of agricultural technologies on food security supported the complexity of food security measurements, which need harmonisation rather than simple indices (Magrini and Vigani, 2016)

A CA impact study on household food security in Zimbabwe, Malawi, and Mozambique found different results for each country (Mango et al., 2017). The study used a food consumption score to quantify the impact of CA on household food security; a positive impact was reported in Mozambique, while Malawi and Zimbabwe had statistically insignificant results on food security. The study concluded that the results were different for each country, depending on the conditions for CA implementation, and it recommended a strong CA institutional framework (Mango et al., 2017). On the other hand, Jumbe and Nyambose (2016) reported that CA increased household food security, using the number of months of food provisioning and household maize per capita consumption in Malawi. Likewise, a study in Zimbabwe used the number of months of food provisioning, and reported a positive impact of CA on household food security (Siziba et al., 2019). A study of the impact of sustainable agriculture technology on food security used a household food insecurity access scale, and showed a positive impact on household food security (Yahaya et al., 2018).

Looking at the reviewed literature, there are conflicts and a gap in understanding CA impacts on food security and nutrition outcomes among smallholder farmers. It is therefore difficult for farmers and other stakeholders to make informed decisions regarding CA adoption to effect food security and nutrition outcomes. It is important that research be taken to close the literature gap of CA impacts on food security and nutrition. Additionally, there is limited literature on CA's impact on household food security, with most impact studies having been done on crop yield. Therefore, there is still a need to assess the impact of CA on food security, as increasing crop yield does not imply improved food security.

2.2.3 Impact of CA on household economic outcomes

There are different documented impacts of CA on household economic outcomes. This study focused on understanding CA's impact on household income, accumulation of household productive assets, addressing agricultural calendar bottlenecks, and agricultural production costs.

Household income is one of the critical livelihood outcomes that influence technology adoption. Farmers are interested in technologies that boost farm incomes, considering their multiplier effect. SSA farmers have both on-farm and off-farm income sources, and their dependency on on-farm income sources has a more direct relationship with CA. However, CA impact studies on farm income have provided different results. Nkala et al. (2011b) found a positive CA impact on crop productivity and an insignificant CA impact on household income. Khonje et al. (2018) found positive results when CA was combined with other agricultural technologies, such as improved seeds. Similarly, Khonje et al. (2018), Manda et al. (2016), Ng'ombe et al. (2017), and Ngwira et al. (2012) found a positive impact of CA on income when farmers comply and adopt the full CA package. In contrast, Nkala et al. (2011a) found statistically insignificant differences in household incomes between CA adopters and non-adopters. Further, CA has been found to be economically feasible among farmers in Zimbabwe, but the farmers mentioned a lack of supporting services, such as input and output markets to speed up adoption (Thierfelder et al., 2018).

CA has been shown to impact household income depending on the production conditions. For instance, Bravo-Ureta et al. (2006) found a positive CA impact on household income. Depending on the total land size under CA, incomes became significant when more land is devoted to CA. In addition, El-Shater et al. (2016) reported that net incomes from CA were significantly affected by the location of the farm, the distance to markets, and the inputs used. CA is also shown to have a positive impact on household income; with technical efficiency, greater experience, and more years of CA implementation, the greater the impact of CA on household income (Corbeels et al., 2014). It is expected that increased household income from CA impacts will result in accumulation of productive assets (Ogada et al., 2018).

Importantly, CA is reported to increase household income when agricultural production costs are reduced. There are different ideas about CA's impact on production costs. Edralin et al. (2017) reported that CA reduces production costs compared with conventional farming, through reduced weeding costs. Yet some literature argues that the use of herbicides increases agricultural production costs (Pittelkow et al., 2015). Agricultural labour adds a considerable cost to agricultural production. Smallholder farmers in Sub-Saharan Africa depend on family labour for farm labour, and this is not costed. However, family labour does not always meet the labour demands, and often requires external support. Labour costs vary across locations, and are determined by proximity to urban centres, time of seasons, and availability of other non-agricultural labour (Alasia et al., 2009).

There are different study results on how labour demands change when households change from conventional to conservation agriculture. Some studies have found hand-hoeing to need more labourers than planting basins and ripping (Mazvimavi and Twomlow, 2009). Similarly, CA adopters using crop residues from other farms have reported increased labour in transporting crop residues for mulching. The increase in labour reduces the time available for other non-farm incomes, resulting in low income among adopters. However, in cases of high herbicide use, CA has been reported to increase the time available for non-farm income activities (Muoni et al., 2013). In contrast, Lalani et al. (2017) reported the limited capacity of CA to decrease weeding time in the absence of herbicides. There are also reports that labour distribution in CA depends on the tillage method used. Umar et al. (2012) found that hand weeding in basins required more time and cost than conventional farming. This shows that weeding CA plots using hand hoes takes more time than conventional farming and, since specific CA-related implements are expensive, farmers opt for conventional farming. However, CA has been reported to decrease weed growth when all three CA principles are adopted and practised appropriately (Nichols et al., 2015). The particular challenge in labour costs calculation has been poor record-keeping among farmers.

Correspondingly, there are inconclusive results on the profitability of CA implementation. For instance, Lalani et al. (2017) have documented that net present values proved that the short- and long-term benefits depend on the opportunity costs of labour, crops grown, and location. Equally, Mupangwa et al. (2017) reported variations in maize profitability under CA across agro-ecological zones in Zimbabwe, with more profits recorded in medium-rainfall zones. In addition, TerAvest et al. (2019) found that high profits were recorded with no tillage, and the lowest profits were recorded with crop rotation. Further, Mafongoya et al. (2016) report inconclusive results on maize productivity and profitability, which might be attributed to the limited profitability methods used; CA studies have been limited to partial budgeting and net present value (Dalton et al., 2014, Lalani et al., 2017).

All the reviewed literature indicates and confirms that CA's impact on household economic outcomes is inconsistent and inconclusive. This points to a gap in the understanding of CA's impact on agronomic outcomes: agricultural yield, resilience in the face of drought, and adaptation to climate change impacts, and requires more scientific and robust research on CA impacts on household economic outcomes.

2.2.4 Impact of CA on social and gender outcomes

Studies of CA's impact on agronomic outcomes, food security and nutrition, household economic outcomes, community social cohesion, and environmental outcomes have been silent on the gender dimensions: they have assumed that CA's impact is equal across the genders. However, gender-responsive research has promoted an assessment of the impact on each gender dimension. Female farmers are reported to produce between 60% and 80% of the world's food, but no specific gendered research dimension has been given (Doss et al., 2018). There are varying results on the impact of CA on gender. For instance, Harman et al. (2015) and Wekesah et al. (2019) reported that CA increased labour for women farmers. Increased agricultural labour has negative impacts on female-headed households. There has been a high level of outward migration by men from rural agro-based areas, and women have been left alone to manage agricultural activities (Khatri-Chhetri et al., 2019). Worse still, there are cultures that restrict women from using farm machinery, forcing them to practise manual CA, which is burdensome (Farnworth et al., 2016). In most cases, manual CA implements require heavy labour. A good example is the Chaka hoe, used in Zambia, which is heavier for women to use (Mazvimavi, 2016, Nyanga, 2012).There are also reports that sprayers are heavy for women to operate, thus causing back pain and forcing them to hire spray services (Farnworth et al., 2016, Nyanga et al., 2012). In this context, all the options of machinery and herbicides have been shown to affect women adopters negatively. It is important, therefore, to advocate for gender-responsive labour-saving technologies (Doss, 2001, Teklewold et al., 2013).

There are also varying results on the factors affecting CA adoption among female farmers. Brown et al. (2017) reported that men dominate in CA adoption decisions. In contrast, a study in Zimbabwe found women to be managers of close to half of the CA fields (Kunzekweguta et al., 2017). Kahimba et al. (2014) found that CA adoption decisions varied in different conditions; for instance, in Arusha, Tanzania couples made the decisions to adopt, while in Dodoma, Tanzania the decision to adopt was exclusively made by men. Similarly, a study in Tanzania reported that married women were limited in their decision-making about coping strategies (Van Aelst and Holvoet, 2016). Limited information, land, and finance have constrained female farmers in respect of CA adoption (Jost et al., 2016, Makate et al., 2018).

The gender impact of CA has varied in different conditions. CA has been found to have a positive impact on food security and crop yields in relation to gender (Hove and Gweme, 2018, Nyanga et al., 2012).Given all the support that women have been shown to benefit from with CA, for instance, CA resulted in more food-secure months for female-headed households than for male-headed households in Zimbabwe (Siziba et al., 2019). Conversely, CA has been reported to affect women and livelihood outcomes negatively when men take over high-value crops (Beuchelt and Badstue, 2013, Nyanga et al., 2012) . Similarly, Teklewold et al. (2013) found that CA negatively impacted gender outcomes and yet, Wekesah et al. (2019) found mixed views of CA's impact on gender outcomes.

It is therefore difficult to reach a firm conclusion from the available literature on CA's gender-related impact on the defined livelihood outcomes: agronomic outcomes, food security and nutrition, household economic outcomes, and environmental outcomes. There needs to be a thorough analysis of the trade-off between CA, livelihood outcomes, and gender outcomes to provide a benchmark for understanding the gender impact of CA. Thus, this review concludes that CA's gender impact is inconsistent and unclear. This calls for more research on gendered impacts of CA to provide a strong basis for CA adoption and investment in CA.

2.2.5 Impact of CA on environmental outcomes.

Studies of CA's impact on environmental and natural resources have focused on soil health and soil carbon sequestration. There have been different results on CA's impact on soil health, carbon sequestration, and forest area cleared for cultivation.

Soil health is the soil's ability to act as a living system and to circulate air and nutrients to all living things (Lal, 2016). Soil health and soil fertility have been used interchangeably; however, they are different concepts. 'Soil fertility' is restricted to plant growth, while 'soil health' includes other living things and food safety (Drobnik et al., 2018, Rinot et al., 2019). Studies of CA's impact on soil health have been inconsistent and conflicting. Cheesman et al. (2016), Kimaro et al. (2016) and Powlson et al. (2016) reported positive CA impacts on soil health, while Esser (2017) found a negative impact of CA on soil water infiltration, retention, and overall soil health; and yet Martinsen et al. (2017) found insignificant differences for soil organic carbon and soil quality nutrient cycling between CA farmers and conventional farmers.

Similarly, there has been a contested debate on CA's impact on soil carbon sequestration. Primarily, 'soil carbon sequestration' is defined as the relocation of atmospheric carbon dioxide into the soil (Lal et al., 2015). No-tillage has been identified as the main means to carbon sequestration in CA (Govaerts∗ et al., 2009). Nichols et al. (2015), and Thierfelder et al. (2017) reported that CA sequestered soil organic carbon in the case of crop rotation. CA has also been shown to sequester carbon when CA is integrated with forestry management, and this has shown positive impacts in cases of integrated CA and agroforestry (Jindal et al., 2008). However, farmers have been unable to adopt agroforestry due to poorly defined tenure rights, policies, and opportunity costs with other short-term benefits (Luedeling et al., 2011). On the other hand, the ability of CA to sequester carbon and provide ecosystem services has been questioned, due to the use of herbicides and chemical fertilisers. For instance, Simone et al. (2017) reported insubstantial levels of carbon reduction and predicted that it would take close to 20 years for farmers to benefit substantially from CA's impact. Likewise, Palm et al. (2014) concluded that CA does not sequester carbon. This calls for other sustainable weed management and alternatives to chemical fertilisers to increase the potential of carbon sequestration in CA (Muoni et al., 2013). However, adoption rates of integrated weed management are reportedly low among smallholder farmers despite its documented benefits (Chauhan et al., 2012). All these studies and arguments confirm the debate on the potential of CA to sequester carbon and curb greenhouse gases. This, therefore, is evidence that CA's impact on carbon sequestration is inconsistent and that it is difficult to reach a conclusion.

All in all, the reviewed literature on CA impacts on environmental outcomes: soil health and forest area cleared per year is inconsistent and inconclusive. In this regard, the literature does not provide a good guidance for farmers and stakeholders to make CA related decisions on environmental outcomes. This leaves farmers and stakeholders to speculate conclusions of CA impacts on environmental outcomes. It is important to research further on the CA impacts related to environmental outcomes to provide a clear and concrete conclusion on the same.

2.2.6 Conclusion of CA's impact on livelihood outcomes

The debate about CA's impact on livelihood outcomes in Africa remains inconclusive, and thus more research is needed to add to the debate and provide a clear conclusion (Nkala et al., 2011b). There are different results relating to CA's impact on agronomic outcomes, food security and nutrition, household economic outcomes, gender and social cohesion, and environmental outcomes. There are also limited CA impacts on two or more livelihood outcomes, making it difficult to provide a comprehensive understanding of CA's impact. Considering that farmers assess and make adoption decisions based on multiple CA impacts, it is important to have a detailed understanding of how CA adoption affects all the predetermined livelihood outcomes.

2.3 Empirical and scientific impact evaluations

2.3.1 Impact evaluation

'Programme impact' is the change in an outcome of a treatment group that can be attributed to the programme intervention only. Impact evaluation takes account of other factors that might also change during the treatment period. This means that the impact must take into account the systematic differences between adopters and non-adopters (Bamberger, 2012). The difference between the two groups should only be due to the programme intervention. Specifically, impact evaluation must measure the difference using the best method that will attribute the difference to the programme intervention. Programme impacts measure the positive and negative and the intended and unintended impacts of the programme. 'Programme impact' differs from 'programme monitoring' in its level of measurement: programme monitoring focuses on tracking implementation, and mainly uses inputs and outputs. On the other hand, programme impact focuses on the causality between the intervention and the outcomes (Cameron et al., 2016).

The problem with impact evaluation is that individuals have only one characteristic; they are either adopters or non-adopters and this results in missing information. The best scenario for impact evaluation is to have baseline data as a benchmark for measuring results; however, baseline data is not always available. Thus, impact evaluation is faced with being counterfactual, which raises the question: What would have happened had one not participated in the intervention? Individuals and households may change even if there is no intervention, due to changing times and world patterns. There is a need to control for these changes if the results are to give a true reflection of the causality. The other critical problems in programme impacts are that programme areas are targeted using observable traits based on the targets of the programmes and the individuals self-selects to participate in the intervention. Therefore, literal comparisons of treated and controls group does not provide a true reflection of the programme impact.

There are basically two types of impact evaluation method: experimental design and quasi-experimental design. Experimental design is usually used in scientific laboratory experiments or field experiments, where the treated and the control are well-defined. The only difference between the two groups is the treatment variable. The quasi-experimental design is usually used in the social sciences to measure the impacts of interventions, and have different methodologies based on the available data and the specified characteristics of the two groups.

2.3.2 Impact evaluation methods

Impact evaluation seeks to establish causality between two variables. The problem with impact evaluation is missing data, which is counterfactual. The challenge with impact evaluation has been to establish counterfactual (Rosenbaum and Rubin, 1983). A lot of the literature has established a correlation between CA and livelihood outcomes, but there is only a limited literature on the causality between CA's impact and livelihood outcomes. There are numerous empirical methods for establishing causality between covariates, and these have been used in impact evaluations. These methods include propensity score matching, instrumental variables, regression discontinuity design, and differencing. These methods are specific to the type of data that can be used; for instance, panel data uses differencing, and cross-sectional data uses propensity score matching and regression discontinuity design.

Impact evaluation compares treated and controls: those who participated in the project and non-project participants. There are different types of control: randomised, shadow, generic, reflexive, constructed, and statistical (Anandajayasekeram, 2004). The differences between the various controls are sometimes obscure. Randomised controls differ from the other controls in that the assignment of treatment is purely random and the intervention is not available to controls. Constructed and statistical controls use matching with equal numbers of controls and treated but differ in that statistical controls hold the statistical differences between controls and treated constant. Conversely, in reflexive control, treated groups are compared with themselves in terms of before and after participation in the project. Finally, generic and shadow controls are similar: generic controls are compared with a well-known trend of change in a specified population, while shadow controls use experts' conclusions about change for the target group (Anandajayasekeram, 2004).

Numerous impact evaluation methods have been used on CA and livelihood in the literature. The empirical methods differ in the data they use; whether cross-sectional, time series, or panel data. The study of Mango et al. (2017) on food security in Southern Africa used propensity score matching (PSM) and applied all the PSM algorithms to check the robustness of the results. PSM has been used in impact evaluation for agricultural technologies, and the results have been shown to be robust (Ogunniyi et al., 2017). Likewise, Magrini and Vigani (2016) and Ogada et al. (2018) used both propensity score matching and a multinomial switching model to ensure consistent and robust results. Notably, PSM has been used in other impact evaluations beyond the agricultural context (Bluwstein et al., 2018, Habiyaremye, 2017, Haji and Legesse, 2017, Mango et al., 2017). Specifically, Haji and Legesse, (2017) used PSM on the impact of sedentarization on household livelihood outcomes. Other fields that have used PSM include microfinance, the adoption of improved seeds, and others (Bluwstein et al., 2018, Mango et al., 2017, Mchopa and Jeckoniah, 2018, Namwata et al., 2010, Ogundeji et al., 2018, Tesfaye et al., 2016).

Importantly, PSM has been blended with other impact evaluation methods as a robustness check and to validate results. Ogundeji et al. (2018) empirically estimated impacts of climate smart technologies with the propensity score-matching method, using the double-hurdle approach (the Probit and Tobit models). Similarly, the multinomial endogenous switching method has been used in evaluating the impact of treatment variables of more than two categories (Nkala et al., 2011b, Ogundeji et al., 2018, Ogunniyi et al., 2017). For example, the model was applied in evaluating the impact of adopting different packages of CA in Zambia (Ng'ombe et al., 2017). Owing to the cumbersomeness of the multinomial endogenous switching model, panel data CA impact studies have used the multinomial endogenous regression model (Manda et al., 2016).CA impact studies and labour productivity studies have estimated impacts using generalised methods of moments and the control function approach (Tsegaye et al., 2017). Basically, the results of PSM and the endogenous switching model have been shown to provide similar results, and one has commonly been used as a proof to validate the other.

The review of empirical methods unearthed multiple impact evaluation methods that have been widely used. These include propensity score matching, the multinomial switching model, the multinomial endogenous switching model, instrumental variables, and generalised methods of moments. Studies have used one or two of these impact evaluation methods for robust checks and the validation of results. Of the impact evaluation methods reviewed, propensity score matching, and the multinomial endogenous model have been widely used and have been shown to be robust.

2.4. Conclusion on all reviewed literature

The synthesis of the literature on CA's impact indicates conflicting and different results on smallholder farmers' livelihood outcomes across Africa. Results have shown that the impact of conservation agriculture differs across regions, policy environments, ecological zones, and gender, and therefore there are no conclusive results on the impact of CA on specific regions. CA has also been found to differ within the same area, depending on the set definition of the CA package and indicators.

The review found a substantial literature on the impact of CA on crop yield, although this did not provide a clear conclusion about agronomic outcomes, and these impacts varied in different environments. The review also found a considerable number of studies on the impact of CA on household income; however, the results are mixed and debatable, and therefore there is no tangible conclusion on the impact of CA on household income and asset accumulation. On other hand, the review found a very limited literature on the impact of CA on household food security, and it did not provide concrete results. The literature on food security cited the multi-dimensional nature of household food security as a challenge to making conclusions and recommended the use of different food security indicators.

Additionally, the literature review showed research gaps on the impact of CA on multiple livelihood outcomes: agronomic outcomes, food security and nutrition outcomes, household economic outcomes, gender and social outcomes, and environmental outcomes. Most studies on CA impacts on livelihood outcomes focused on one livelihood outcome, which does not relate well to livelihood outcomes, since the livelihood outcomes are interrelated. This demands more impact studies that focus on two or more predetermined livelihood outcomes. The review identified gaps in understanding a comprehensive CA impact on combination of the predetermined livelihood outcomes and recommended the implementation of CA impact studies on the identified livelihood outcomes. This study is important to closing the knowledge gap that exists on the causality of CA and livelihood outcomes: agronomic outcomes, food security and nutrition, household economic outcomes, gender and social cohesion, and environmental outcomes. The results of the study will inform policymakers in designing and promoting agricultural technologies that are efficient, that add value for smallholder farmers, and that are also gender responsive.

Chapter 3: Study Methods and Procedures

This chapter describes the area of study and outlines the research procedures followed in this study. The chapter is broken down into six main sections. Section 3.1 describes the background of the study area to give background to the whole study. The data sources and data analysis are presented in sections 3.2 and 3.3, respectively. The sample socio-economic characteristics are presented in section 3.4. Finally, sections 3.5 and 3.6 present the empirical methods and the chapter's conclusion, respectively.

3.1 Study area

The research used data collected for end-of-project evaluation by the African Conservation Tillage Network (ACT) under the flagship funding of the Common Market for Eastern and Southern Africa (COMESA). The project was a partnership with COMESA, and was implemented from 2010 to 2016 (COMESA, 2011). ACT promoted the adoption and practice of CA across different agro-ecological zones in Tanzania, Zambia, Zimbabwe, and Kenya by different ACT local partners. The study areas for Zambia were Mpongwe in Central Region and Mumbwa in the Copper Belt Region. In Tanzania, the study areas were Mbeya District in Mbeya Region and Babati in Manyara Region. All the study hot spots had different agro-ecological characteristics, making the study valuable and comparable.

3.1.1 Agro-ecological zones for Zambian sites

Mpongwe and Mumbwa fall under different agro-ecological zones: Mumbwa is under agro-ecological zone IIa, and Mpongwe fall under agro-ecological III. Agro-ecological zone IIa is a medium rainfall degradation plateau, where the annual rainfall ranges from 800mm to 1000mm, and Mumbwa itself receives 900mm of rainfall. The agro-ecological zone IIa growing season ranges from 100 to 140 days. The region is characterised by leached sandy loam soils, and has good cropping potential (Esser, 2017). On the other hand, Mpongwe receives the highest rainfall in Zambia, annually averaging 1000mm; the growing season ranges from 130 to 190 days; and the soils are leached acidic soils (Esser, 2017). Agriculture is the main source of livelihood, growing crops such as maize, millet, sorghum, cassava, and other legumes. Maize is the staple crop for the study areas.

3.1.2 Agro-ecological zones for Tanzanian sites

Mbeya and Babati have different agro-ecological characteristics. Mbeya is under the Plateaux western zone, which is characterised by a combination of sandy plains, flooded swamps, and clay soils. Annual rainfall ranges from 800 to 1500mm. On the other hand, Babati falls under the Southern zone, which is characterised by moderate fertile clay soils, and annual rainfall ranges from 1200 to 1500m. Part of Mbeya is semi-arid, and most of the farmers were once pastoralists. Overall, agriculture is the main source of livelihood, growing crops such as maize, millet, sorghum, cassava, and other legumes (National Bureau of Statistics and ICF, 2016).

3.2 Data sources

The study used secondary data from an end-of-project evaluation study for African Conservation Tillage Network project areas in Tanzania and Zambia. The data was collected in 2016 for 2015/2016 agricultural season.

3.3 Data analysis

The data collected through the semi-structured household questionnaire was transcribed and saved in a Microsoft Excel spreadsheet. The data analysis exported the data to STATA. Measures of central tendency and dispersion, such as mean, median, mode, maximum, and minimum, were used to identify outliers that might affect the correctness of the results. Data entry errors were identified and adjusted, but impractical observations were replaced by the average. Kernel density graphs were used to determine the extent of normality in the data and to identify more outliers. Thereafter the summary statistics and empirical estimations were computed to achieve the study objectives.

3.4 Socio-economic characteristics of sampled households

In a quest to understand the characteristics of the study population, the study investigated the households' socio-economic characteristics. Table 3.1 presents the results for Tanzania and Zambia. There are two types of entries: numbers and percentages. The numbers show the number of farmers, and the percentages in the entries are obtained by dividing the numbers in the table by the number of farmers in each category. The study captured the number of farmers under each of the following categories: per district, gender of household head, marital status of household head, household size, and literacy of household head. In addition, the table captured the farmers' participation in farmer organisations, off-farm income sources, land under cultivation in hectares, and access to credit.

Table 3.1 Socio-economic characteristics of sampled households

	Zambia			Tanzania		
Description	**Non-ACT** 71 **farmers)**	**ACT (13**3 **farmers)**	**Chi2/t**	Non- ACT (68 farmers)	ACT (135 farmers)	Chi2/t
			District			
Copper belt/Mbeya	22 (31%)	80 (60%)	15.8***	43 (63%)	58 (43%)	7.4 ***
Mpongwe/Babati	49 (69%)	53 (40%)		25 (34%0	77 (57%)	
			Gender of household head			
Female	32 (45%)	36 (27%)	6.8***	9 (13%)	23 (17%)	0.5
Male	39 (55%)	97 (73%)		59 (87%)	112 (83%)	
			Marital status of household head			
Not Married	11 (15%)	22 (17%)	0.8	6 (9%)	15 (11%)	0.26
Married	60 (85%)	111 (83%)		62 (91%)	120 (89%)	
			Household size			
Mean	9.2	12.7	3.5 ***	7.2	6.4	1.70*
			Literacy of household head			
Literate	63 (89%)	125 (94%)	1.77	66 (97%)	125 (93%)	0.203
Illiterate	8 (11%)	8 (6%)		2 (3%)	10 (7%)	
			Household head age			
Mean	42.2	52.4	5 ***	46.94	48.77	1.19
			Membership to farmer organization			
No	28 (85%)	43 (25%)	43.45***	56 (82%)	20 (14%)	80.07***
Yes	5 (15%)	128 (75%)		12 (18%)	115 (86%)	
			Off-farm employment			
No	45 (64%)	92 (69%)	0.74	49 (72%)	101 (75%)	0.67
Yes	26 (37%)	41 (31%)		19 (28%)	34 (25%)	
			Land under cultivation			
Mean	2.6	5.7	2.0**	1.7	2.2	2.0**
			Access to extension services			
No	37 (52%)	47 (35%)	5.38***	56 (82%)	14 (10%)	103***
Yes	34 (48%)	86 (65%)		12 (18%)	121 (90%)	
			Access to credit			
No	69 (97%)	121 (91%)	2.79*	59 (87%)	113 (84%)	0.33
Yes	2 (3%)	12 (9%)		9 (13%)	22 (16%)	

***significant at 1%, ** significant at 5% and * significant at 10%. Source: survey data

In Tanzania, male-headed households outnumbered female-headed households in adopting CA. The results are in line with those of Wekesah et al. (2019), who found that male-headed households are able to cope with the intensive farm workload needed for manual weeding. It is also easy to note that non-ACT farmers had larger households than ACT farmers. Further, the results indicate that ACT-project farmers had better access to extension services, credit services, and farmer organisations.

Likewise, the results for Zambia suggest that ACT-project farmers have more access to credit, extension services, and participation in farmer organisations than non-ACT farmers. ACT-project farmers in Zambia also had larger households than non-ACT farmers. On average, the household sizes for both Tanzania and Zambia are larger than their respective national household sizes (Central Statistical Office and International, 2014, National Bureau of Statistics and ICF, 2016) . Similarly, both Zambian and Tanzanian ACT farmers had older household heads than did non-ACT farmers. It is reported that younger farmers are interested in youth-friendly technologies (Adam and Quinhentos, 2018, Jean-Philippe et al., 2017), and the results suggest that CA does not appeal to young farmers in the two study areas.

3.5 Empirical approaches

The literature has found that project implementers do not randomly assign CA to areas, but rather that implementers identify study areas depending on specific criteria. Thus, CA projects are allocated randomly to smallholder farmers; as such, CA adopters tend to have specific traits that result in self-selection bias (Baylis et al., 2016). Normally, CA implementers consider certain attributes of communities that will appeal to farmers to adopt CA; in such cases, farmers who match the attributes self-select into CA adoption. The selection criteria may include labour availability, access to credit facilities, soil quality, and access to extension services. This means that smallholder farmers do not randomly participate in CA. Most of the selection criteria determine CA adoption, in which case a simple comparison of CA adopters and non-adopters can bias the impact of CA on livelihood outcomes. In particular, households' socio-economic characteristics influence decisions to self-select into CA.

The study therefore had to use a technique that deals with self-selection bias. Researchers apply different methods to address self-selection bias in impact assessment. The most often used include difference-in- difference, instrumental variables, and propensity score matching (Haji and Legesse, 2017). Owing to the absence of a baseline study, difference-in -difference was ruled out. Similarly, instrumental variables did not work out due to a failure to find suitable instrumental variables that meet set criteria. In this case, the study opted to use propensity score matching to address the self-selection bias in the impact assessment of CA on the identified livelihood outcomes.

3.5.1 Propensity score matching

Initially proposed by Rosenbaum and Rubin (1983), propensity score matching (PSM) is a procedure to address self-selection bias in impact assessment. PSM matches observable traits between treated groups and control groups. For this impact assessment, farmers participating in CA (treated) were matched with non-CA adopters (controls) having identical traits such as the age of the household head, land-holding size, household size, access to extension services, participation in farmer organisations, perception of soil fertility before the CA project, off-farm income, the gender of the household head, and the literacy level of the household head, given that these traits influence CA adoption in the two countries.

In this regard, PSM deals with self-selection bias and endogeneity. It takes into consideration the possibility of non-randomness in technology adoption; in this case, using means might have biased the comparison between CA adopters and non-adopters. The impact assessment results might have been biased if self-selection bias was not considered (Gatere et al., 2013). PSM is based on an assumption of counterfactual; the concept that data is missing which implies that it is not possible for a household to be a CA adopter and non-adopter at the same time. PSM provides an average treatment on the treated (ATT), which gives better comparison results than the usual average treatment effects (ATE) from the probit model (Rosenbaum and Rubin, 1983). PSM estimates ATT based on the estimation function below.

$$\mathrm{ATT} = \mathrm{E}[\upsilon_{1i}|\mathrm{D_i} = 1] - \mathrm{E}[\upsilon_{0i}|\mathrm{D_i} = 1] \quad (3.1)$$

v_{1i} and v_{0i} are outcome variables (crop yield, household income, asset accumulation) before and after adoption of CA, D_i is the binary outcome for being an adopter or non-adopter.

As mentioned earlier, PSM is chosen for its ability to counter sample selection bias, since CA adopters may be different from non-adopters, thus affecting the comparison results. PSM identifies and compares CA adopters and non-adopters who are closely similar in observable characteristics, and reduces the systematic bias (Dehejia and Wahba, 2002). PSM uses scores to construct comparable households with similar scores from the treated group and the control group. These scores are used to calculate the average outcomes for the treated and the control. The ATE of the treated households is the difference in the outcomes for the treated and the control variables. The outlined PSM procedure provides good estimates of the treatment effect and allows for a comparison of the outcomes between CA adopters and non-adopters with similar observable characteristics. However, PSM does not address selection bias in unobservable characteristics (Baser, 2006).

Specifically, when using PSM in STATA, impact assessment theory requires the imposition of the conditional independence assumption (CIA), which holds that, given a set of observable covariates **X**, the probable outcome in the case of non-adoption should be autonomous of treatment assignment. Fundamentally, CIA requires the analyst to use statistical measures to mimic complete randomisation in treatment allocation. In this regard, CIA requires that the treatment and control observations should be made as similar as possible with respect to the statistically significant covariates. STATA delivers on this objective by estimating a propensity score equation and confirming that the balancing property of the propensity score is satisfied prior to matching. In STATA, the balancing property ensures that assignment to treatment is 'random', which implies that the treatment and control units are observationally identical on average.

3.5.2 Model estimation

A probit model was used to estimate the propensity score using several covariates that define adopters and non-adopters. The covariates included the gender of the household head, membership of farmer organisations, the age of the household head, land-holding size, household size, access to extension services, , perception of soil fertility before the CA project, off-farm income, the gender of the household head, the literacy level of the household head, access to credit, and access to extension services.

The dependent variables for the study were predetermined livelihood outcomes: agronomic benefits, food security, household income, and environmental and gender impacts, for Tanzania and Zambia. The agronomic outcomes assessed were total agricultural yield, the farmer's ability to adapt to the impact of climate change, the farmer's resilience in the face of drought, and total maize production. The food security and nutritional outcomes assessed were the number of food-insecure months per year, and the number of meals per day. The economic outcomes assessed were household income, accumulation of productive assets, household's ability to address agricultural calendar bottlenecks, and total agricultural production costs. The gender and social outcomes assessed were gender disparities and social cohesion. Finally, the environmental outcomes assessed were the impact of CA on soil health and forest area cleared per year.

In this case, the outcome variables were the dependent variables, and the household characteristics and the other covariates were the independent variables. The programme evaluation used procedures stipulated by econometric methods (Maddala, 1986):

$$y = \beta_0 + X_1\beta_1 + X_2B_2 + \cdots X_nB_n + u \quad \text{………………………………..……………} (3.2)$$

in which y represents the livelihood outcomes under evaluation, such as total yields, number of food-insecure months, household income, and asset accumulation. Xs' represents the vector of household characteristics, the treatment variable that may have an impact on the outcome variable, and u represents the disturbance that may not be explained by the vector of the explanatory variables. PSM estimates are valid if they are able to balance the covariates, and there should be no heterogeneity in the farmers due to unobservable characteristics (Caliendo and Kopeinig, 2008, Dehejia and Wahba, 2002). PSM balance is tested using the Rosenbaum bounds test, which checks for hidden bias due to unobservable factors (Rosenbaum and Rubin, 1983).

Important to impact assessment is the accuracy of the independent and dependent variables in determining causality. The next section provides a brief background to, and the expectations of, the covariates used in determining CA adoption and impact assessment.

(i) Age of household head

Age of household' has been used in the literature as a proxy for understanding technology adoption. It has been determined that young farmers and older farmers prefer different technologies, in that young farmers are early adopters (Radeny et al., 2018). For the past two decades (2000 to present), technology promoters have deliberately altered technologies to attract young farmers into adoption. It is expected that an increase in the age of the household head will reduce the probability of CA adoption.

(ii) Land holding size

The ownership of land and the size of land have an impact on CA technologies adoption. Manda et al. (2016) and Teklewold et al. (2013) reported the size of land to be a determining factor in technologies adoption. We consider that CA requires more land for cultivation than conventional farming. We hypothesise that a greater land-holding size will have a positive influence on CA adoption.

(iii) Household size

Household size has been defined as a determinant of household labour in Africa (Sims and Kienzle, 2015). This means that a household's size affects its decision to adopt agricultural technologies. Specifically, household size determines the technologies adopted in proportion to the labour demands. The study hypothesises that bigger households will positively increase CA adoption relative to smaller households.

(iv) Literacy

Being able to read and write has shown to facilitate information transfer and technology adoption (Brown et al., 2017). The study incorporated literacy to explain the role of education in influencing CA adoption. It is expected that households with literate household heads will make more calculative and climate-smart decisions to adopt CA. It is therefore expected that literate households will positively influence CA adoption.

(v) District of residence

This is a dummy for farmers residing in Mbeya or Babati for Tanzania, and those residing in Mpongwe or Mumbwa for Zambia. Studies have shown geographical region to influence technology adoption; for instance, CA may appeal more to residents in low rainfall areas than those in high rainfall areas. It is expected that residing in a low rainfall or dry area will positively influence CA adoption.

(vi) Gender of household head

The gender of the household head affects a household's decision on technology adoption. Manda et al. (2016) and Murray et al. (2016) have suggested a low likelihood of female-headed households adopting these technologies. Gender studies on CSA adoption have attributed the low adoption of CSA technologies to limited access to and control of land, credit, and farm machinery, and have advocated for gender-responsive research into CSA technologies (Doss et al., 2018, Doss, 2001, Murray et al., 2016). It is expected that male-headed households will positively influence CA adoption.

(vii) Access to agricultural extension services

Agricultural extension services provide smallholder farmers with technology and production information, farming skills, and access to market information. In that regard, agricultural extension is expected to have a bearing on the level of CA adoption (Shinbrot et al., 2019). It is expected that access to extension services will positively influence CA adoption.

(vii) Access to credit

Access to credit determines the capacity of farmers to access quality and certified seeds and fertilisers (Aku et al., 2018). Access to credit may be from either formal or informal institutions. CA needs specific implements that require capital investments. It is expected that access to credit will positively influence CA adoption.

(viii) Participation in farmer organisations

Participation in farmer groups increases the possibility of CA adoption. Adong (2014) and Olawuyi and Mushunje (2019) have reported a positive relationship between participation in farmer groups and technology adoption. Farmer groups are critical social capital and facilitate technology transfer. Husen et al. (2017) and Tamako and Thamaga-Chitja (2017) have shown that farmers participate in farmer groups to broaden their economic network and to exchange knowledge. It is expected that participation in farmer organisations will positively influence CA adoption.

(ix) Marital status of household head

The marital status of the household head has been shown to influence technologies, since it defines labour availability in the household. In addition, the marital status of the household head influences adoption decisions for technologies. Considering that communities have specific gender roles for men and women, it is expected that a married household head will positively influence CA adoption.

(x) Engagement in off-farm income

The availability of and level of engagement in off-farm income sources determines technology adoption. Normally, households with a high engagement in off-farm income activities have limited time for on-farm activities. A high dependence on on-farm activities motivates farmers to engage in more rewarding technologies relative to a high dependence on off-farm incomes. It is expected that engagement in off-farm income activities will negatively influence CA adoption.

(xi) Perception of soil fertility before CA project

Farmers' perceptions of CA's benefits for soil fertility have been reported to motivate CA adoption (Lalani et al., 2016). Similarly, a reasoned action approach to discover the factors of CA adoption reported attitudes and perceptions as key drivers of CA adoption in Kenya (Van Hulst and Posthumus, 2016). Specifically, Abdulai and Huffman (2014) showed that farmers who perceive that CA improves fertility are very likely to adopt CA. It is expected that farmers who perceive their land as infertile will positively influence CA adoption.

(xii) Benefit from a CA-related project

Shrestha and Ligonja (2015) showed that there is a relationship between benefitting from a CA-related project and CA adoption. The benefits may be in terms of training participation, extension support, farm input support, among others. It is expected that farmers who have benefitted from CA-related projects will positively influence CA adoption.

3.5.3 Description of the PSM algorithms

The study used four PSM algorithms: kernel matching, nearest neighbour matching, radius matching, and stratification matching.

'Nearest neighbour matching' matches treated units and control groups with the nearest propensity score. One can match either without replacement or with replacement. Matching with replacement allows multiple matching of control units with the treated units, while matching without replacement only allows one-to-one matching between the control and treated units. Nearest neighbour matching risks bad matches if the closest neighbours are not sufficiently similar. This is avoided by imposing a tolerance level called the 'calliper'. Most studies use a calliper from 0.001 to 0.1. Nearest neighbour matching matches adopters and non-adopters with the closest propensity scores. This algorithm imposes the common support condition.

'Kernel matching' uses the weighted average of control and treated groups to construct counterfactuals for the treated units. The weights depend on the distance between the control group and the estimated unit of the treated. The kernel functions assign higher weights to observations with very close propensity scores, and lower weights to those with a big difference in the weights.

'Radius matching' deals with bad matches by limiting an acceptance mark on the propensity scores. This is like the matching with replacement in nearest neighbour matching. The calliper allows matching between treated and control groups within the calliper category. The main challenge with radius matching is that it is difficult to know the realistic acceptable level (Rosenbaum and Rubin, 1983).

'Stratification matching' groups observations in strata with similar propensity scores to ensure that treated and controls are balanced within a particular stratum (Rosenbaum and Rubin, 1983). The treatment effect is then estimated by accumulating specific stratum treatment effects. The stratum methodology deals with bias in the observations.

It is best practice in propensity score matching to evaluate the matching algorithms. The best algorithm is determined by a large matched sample size, high numbers of insignificant variables after matching, a lower standardised mean bias, and a low pseudo R-squared (Haji and Legesse, 2017). The algorithm that meets those characteristics suits the data well, and results and conclusions from the results can be made using the algorithm. Finally, it is always necessary to conduct the Rosenbaum bound tests to measure whether the matching method and results best fit with the outcome variable. The results of the sensitivity analysis determine the validity of the results.

3.6 Conclusion

This chapter provided an overview of the study methods and procedures used in this research. The study used end-of-project evaluation data obtained from ACT study areas in Tanzania and Zambia. Specifically, the study applied PSM to assess the impact of CA on livelihood outcomes: agronomic outcomes, food security and nutrition, household economic outcomes, gender and social cohesion, and environmental outcomes. The study then compared the outcome variables for CA adopters and non-adopters respectively to understand CA's impact.

Chapter 4: Results and Discussions

This chapter summarises and presents the study results in the light of the objectives set out in Chapter 1. Section 4.1 discusses the overall adoption of CA technologies in Tanzania and Zambia, while section 4.2 discusses the impact assessment of CA adoption in Tanzania (section 4.2.1) and Zambia (section 4.2.2). Finally, section 4.3 provides an overall summary of the results.

4.1 Adoption of CA technologies in Tanzania and Zambia

The ACT defines CA adopters as farmers who dedicate a portion of their land to any CA practice. Using this definition, the study interviewed 68 non-adopter and 135 adopter farmers in Tanzania (a total of 203 farmers). In Zambia, the study interviewed 71 non-adopter and 133 adopter farmers (a total of 204 farmers). The results for the intensity of CA adoption in Tanzania and Zambia are presented in Table 4.1.

Table 4.1: Intensity of CA adoption in Tanzania and Zambia

Technology type	Tanzania (203 farmers)		Zambia (204 farmers)	
	Non-ACT (68 obs.)	ACT (135 obs.)	Non-ACT (71 obs.)	ACT (133 obs.)
Adoption of minimum tillage practices				
Ripping land preparation	2 (3%)	120 (89%)	3 (4%)	128 (96%)
Sub-soiling land preparation	0 (0%)	9 (7%)	0 (0%)	12 (9%)
Animal drawn no-till seeding	0 (0%)	42 (31%)	0 (0%)	18 (14%)
Tractor drawn no-till seeding	0 (0%)	1 (1%)	0 (0%)	5 (4%)
Jab planter no-till seeding	0 (0%)	3 (2%)	0 (0%)	0 (0%)
Adoption of continuous soil cover practices				
Leave crop residues in field after harvesting	29 (43%)	127 (94%)	7 (10%)	123 (92%)
Used manure for fertilizer	43 (63%)	92 (68%)	5 (7%)	77 (58%)
Mulching (imported from other fields)	0 (0%)	2 (1%)	1 (1%)	18 (14%)
Shallow weeding (weed scrapper)	1 (1%)	58 (43%)	1 (1%)	18 (14%)
Uprooting weeds (not cutting)	0 (0%)	19 (14%)	0 (0%)	1 (1%)
Adoption of crop diversity practices				
Crop rotation	8 (12%)	55 (41%)	20 (28%)	129 (97%)
Intercropping	42 (62%)	71 (53%)	2 (3%)	58 44%)

****Source: survey data*

Following the CA definition adopted by the FAO (Reicosky, 2015), Table 4.1 groups the CA practices captured in this study into three broad categories: minimum tillage, continuous soil cover, and crop diversity. The study captured two minimum tillage land preparation practices;

sub-soiling and ripping, and three no-till seeding practices; animal drawn, tractor drawn and jab planter. The study captured five continuous soil cover practices: leaving crop residues in the field after harvesting, use of manure for fertiliser, mulch imported from other fields, shallow weeding, and uprooting rather than cutting weeds. Finally, the study recorded whether farmers practised crop rotation or intercropping. The number of farmers practising a particular technology and adoption rates is recorded in Table 4.1, with the latter being the percentage of farmers practising a particular technology relative to the total ACT or non-ACT project participants interviewed.

Table 4.1 shows that, in both countries, ripping (compared with sub-soiling) is by far the most important land preparation technology. Ripping, which may be done by hand or be animal-drawn, is affordable and easy to implement for smallholder farmers (Hodson, 2016). Sub-soiling, on the other hand, requires the use of plow chisel technology, which is not readily available and so constrains adoption (Andersson and D'Souza, 2014). Table 4.1 shows that the levels of no-till seeding adoption in both countries are very low, with only 31% of ACT-project farmers in Tanzania and 14% of ACT-project farmers in Zambia practising animal-drawn no-till seeding. The number of farmers practising tractor-drawn no-till seeding or jab planter no-till seeding is negligible. Although the no-till seeding technologies are efficient, many farmers cannot afford them. In a follow-up question (question C4 in the appendix), the study established that smallholder farmers preferred to use manual seeding techniques such as planting in lines, sowing in a hole with a machete, or planting zai-basins as alternatives to the promoted no-till technologies. Using Table 4.1's presentation style, Table 4.2 summarises the manual seeding techniques used in Tanzania and Zambia. Planting Zai-basins are common in Zambia, while sowing in a hole is common among ACT-project farmers in Tanzania. In a further follow-up question (see question I1), the study also established that farmers preferred manual techniques because they are considered more sustainable and durable than jab-planters.

Table 4.2: Adoption of manual planting techniques

Type of planting technique	Tanzania (203 farmers)		Zambia (204 farmers)	
	Non-ACT (68 obs.)	ACT (135 obs.)	Non-ACT (71 obs.)	ACT (133 obs.)
planting -zai basin	0 (0%)	0 (0%)	0 (0%)	29 (21%)
sow in a hole	5 (7%)	76 (56%)	0 (0%)	0 (0%)

Source: survey data

With respect to the adoption of continuous soil cover, Table 4.1 generally shows that leaving crop residues after harvesting and using manure for fertiliser are preferred by ACT-project farmers in both countries. A follow-up question (see QI1, appendix) showed that manure for fertiliser was considered durable and sustainable, which could be attributed to manure availability, since 67% and 43% of farmers in Tanzania and Zambia respectively practised mixed farming (see Qc8, appendix). Crop residues are used for livestock feed, which explains the negligible adoption of mulching that is imported from other fields. Although the ACT promoted cover crops, they were not preferred for continuous soil cover. Table 4.1 shows that there is a low uptake of shallow weeding and uprooting of weeds by ACT-project farmers in both countries, although shallow weeding was more common in Tanzania than in Zambia. As a follow-up question on the low adoption of uprooting weeds (see QI1, appendix), 85% of the ACT-project farmers in Tanzania and 79% of the ACT-project farmers in Zambia regarded uprooting weeds as both unsustainable and not durable. In a subsequent follow-up question (QC5, appendix), 73% of the farmers in Zambia and 56% of farmers in Tanzania stated that they used herbicides in managing weeds, even though the use of herbicides does not comply with CA standards (Kimaro et al., 2016).

Finally, Table 4.1 shows that crop rotation is very high among ACT-project farmers in Zambia, while intercropping is relatively higher among ACT-project farmers in Tanzania. In a follow-up question to understand other crop rotation techniques (QC7, appendix), 42% of the ACT-project farmers in Zambia stated that they practised agroforestry (*Faidherbi albida*), while agroforestry was negligible in Tanzania.

Table 4.1 allows us to draw two important conclusions. In both countries, most ACT-project farmers adopt and use at least one CA technology. It is also clear that, within a country, the proportion of ACT farmers adopting and using CA technologies far outweighs the non-ACT farmers. These results are in line with impact evaluation practice, which shows that projects are targeted and implemented in areas where interventions will attract more participants and will have a strong positive impact.

To gain an even better understanding of CA adoption in the two countries, the study analysed the number of farmers who adopted at least one of the five minimum tillage practices listed in Table 4.1, at least one of the five continuous soil cover practices listed in Table 4.1, and practised either intercropping or crop rotation (Table 4.3). One can see from Table 4.3 that the adoption of at least one CA practice among ACT-project participants is very high.

Table 4.3 :Adoption of at least one CA practice

CA technology adoption	Tanzania (203 farmers)		Zambia (204 farmers)	
	Non-ACT (68 obs.)	ACT (135 obs.)	Non-ACT (71 obs.)	ACT (133 obs.)
At least one minimum tillage practice	2 (3%)	126 (93%)	3 (4%)	128 (95%)
At least one continuous soil cover practice	46 (67%)	131 (97%)	15 (21%)	125 (93%)
Either inter-cropping or crop rotation	50 (73%)	120 (89%)	20 (28%)	129 (96%)

Source: survey data

The study proceeded to analyse the number of farmers who combined at least one minimum tillage and one continuous soil cover practice, at least one minimum tillage practice and either crop rotation or intercropping, and at least one continuous soil cover practice and either crop rotation or intercropping (Table 4.4). Since farmers could combine at least two technology categories, the column totals in Table 4.4 are double those of Table 4.1. In contrast to the results reported in Table 4.3, the number of ACT-project farmers who adopted at least two CA practices drops significantly.

Table 4. 4: Farmers adopting at least two CA practices

CA technologies	Tanzania (203 farmers)		Zambia (204 farmers)	
	Non-ACT (136 obs.)	ACT (270 obs.)	Non-ACT (142 obs.)	ACT (266 obs.)
Minimum tillage and continuous soil cover	2 (1%)	123 (46%)	2 (1%)	121 (45%)
Crop rotation and minimum tillage	2 (1%)	113 (42%)	3(2%)	125 (47%)
Crop rotation and continuous soil cover	42(31%)	117 (43%)	5 (4%)	124 (47%)

Source: survey data

Finally, the study analysed the number of farmers who adopted the full suite of CA practices: at least one minimum tillage practice, at least one continuous soil cover practice, and either crop rotation or intercropping (Table 4.5). In contrast to Tables 4.3 and 4.4, the number of ACT-project farmers who adopted and practised the full suite of promoted CA technologies drops even further, which is consistent with the observation that adoption of the CA suite is still low in Sub-Saharan Africa (Arslan et al., 2014, Glover et al., 2016, Kaonga and Oliver, 2016, Ndah et al., 2015).

Table 4.5: Farmers adopting the suite of CA technologies

Adoption of CA technology	Tanzania (203 farmers)		Zambia (204 farmers)	
	Non-ACT (204 obs.)	**ACT (406 obs.)**	**Non-ACT (213 obs.)**	**ACT (399 obs.)**
	2 (1%)	110 (27%)	2 (1%)	120 (30%)

Source: survey data

In the light of Tables 4.3–4.5, it is pertinent to investigate why one observes the proportion of farmers adopting CA reducing from the adoption of one promoted technology to the full suite. Thus, the study investigated the underlying constraints on CA technologies adoption among farmers who participated in the CA project (Table 4.6) and those who did not (Table 4.7). Tables 4.6 and 4.7 group the challenges into those related to CA inputs (tools, seeds, and equipment), CA mind-sets, tradition and culture, and CA knowledge and policy.

The study captured four challenges related to CA inputs: the high costs of CA tools and equipment, the lack or inaccessibility of appropriate CA equipment, the widespread use of crop residues for livestock feed and fuel and burning crop residues. Two challenges were registered with respect to CA mindset, tradition, and culture: the fixed mindset of agriculture leaders, extension agents and farmers, and their traditions and culture. Finally, two challenges were captured under CA knowledge and policy: lack of knowledge about the potential benefits of CA, and lack of government policy support for a CA-enabling environment.

Tables 4.6 and 4.7 have three entries: numbers, percentages, and Pearson chi-square statistics. The numbers are for farmers who reported a constraint as the most challenging. The percentages were obtained by dividing the numbers in the tables by the total number of farmers interviewed by category. The chi-square statistics in Table 4.6 and Table 4.7 test the null hypotheses that CA adoption constraints among ACT farmers (and non-ACT farmers) in Tanzania are equivalent to those of Zambia.

Table 4.6: Most challenging constraints to CA adoption among ACT- project farmers

Adoption constraints	**Tanzania**	**Zambia**	
	ACT (135 obs.)	**ACT (133 obs.)**	**Chi-2**
High costs of CA tools and equipment	39 (29%)	14 (11%)	14.24***
Lack or inaccessibility of appropriate CA equipment	40 (12%)	1 (1%)	43.12***
Availability of cover crops seeds	0 (9%)	6 (5%)	6.23**
Widespread use of crop residues for livestock feed and fuel	8 (6%)	4 (3%)	1.33
Burning of crop residues	7 (5%)	8 (6%)	0.09
CA related mindset, traditions and culture			
Fixed mindset of agriculture leaders, extension agents and farmers	1 (1%)	8 (6%)	5.74**
Traditions and culture	15 (11%)	3 (2%)	8.39***
CA related knowledge and policy support			
Lack of knowledge about the potential benefits of CA	2 (1%)	4 (3%)	0.713
Lack of government policy support for CA-enabling environment	0 (0%)	3 (2%)	3.08*

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.6 shows that the high costs of CA tools and the lack of appropriate CA tools are the main challenges to CA adoption among ACT-project farmers. These results are consistent the with CA literature, which shows that the lack of appropriate CA equipment is a challenge to CA adoption (Grabowski et al., 2016). Likewise, Table 4.6 indicates that crop residue-related challenges constrain ACT-project farmers in adopting CA. Similarly, much of the CA literature has found crop residue burning and competition for crop residues for either livestock feed or fuel to be a constraint on CA adoption (Andersson and D'Souza, 2014, Arslan et al., 2014, Nkala et al., 2011b, Tumbo et al., 2019, Valbuena et al., 2012, Van Hulst and Posthumus, 2016). In both countries, farmers prevented crop residue burning by setting firewalls; and this was regarded as sustainable (see QI1, appendix). Table 4.6 suggests that the constraints on CA adoption among ACT-project farmers in Tanzania outweighed the challenges among ACT-project farmers in Zambia. As expected, ACT-project farmers in both countries have a good knowledge of CA's benefits. This suggests that the ACT project did a good a job in building knowledge of CA's benefits among ACT-project farmers in both countries. We conclude that ACT-project farmers in Tanzania and Zambia are constrained in adopting CA by different factors. It is important, therefore, that the challenges be addressed in relation to the context of the specific country. In the light of the low figures in Table 4.6, we are inclined to deduce that the listed challenges are not perceived as constraints on CA adoption among ACT project farmers.

Similarly, Table 4.7 indicates that non-ACT farmers in Zambia are highly constrained in adopting CA by mindset, tradition, and culture than are non-ACT farmers in Tanzania. A study by Chinseu et al. (2019) showed that this mindset, and the traditions and culture held by those that regard CA as being against traditional farming, delay crop emergence and other outcomes. Further, Table 4.7 indicates that most non-ACT farmers in Zambia are more constrained in adopting CA due to a lack of knowledge about CA's benefits and a lack of government policy for a CA-enabling environment than are non-ACT farmers in Tanzania. However, these were not statistically different. Surprisingly, Zambia strategically promoted and pioneered CA among its farmers through the Conservation Farming Unit (Hodson, 2016), and that country was expected to have more awareness and knowledge of CA than Tanzania. In conclusion, Table 4.7 indicates that non-ACT farmers in the two countries are constrained in adopting CA by different factors. It is important, therefore, that the challenges be addressed in relation to the context of the specific country.

Table 4.7: Most challenging constraints to CA adoption among non-ACT farmers

	Tanzania	**Zambia**	
Adoption constraints	**Non-ACT (68 obs.)**	**Non-ACT (71 obs.)**	**Chi-2**
CA related inputs: tools, seeds and equipment			
High costs of CA tools and equipment	9 (13%)	19 (27%)	3.13*
Lack or inaccessibility of appropriate CA equipment	8 (12%)	21 (30%)	6.23**
Availability of cover crops seeds	6 (9%)	8 (11%)	6.65**
Widespread use of crop residues for livestock feed and fuel	7 (10%)	12 (17%)	6.37**
Burning of crop residues	7 (10%)	14 (20%)	4.87**
CA related mindset, traditions and culture			
Fixed mindset of agriculture leaders, extension agents and farmers	7 (10%)	21 (30%)	1.65
Traditions and culture	8 (11%)	3 (4%)	26.77***
CA related knowledge and policy support			
Lack of knowledge about the potential benefits of CA	6 (9%)	19 (27%)	1.05
Lack of government policy support for CA-enabling environment	6 (9%)	16 (23%)	1.98

***significant at 1%, ** significant at 5% and * significant at 10%. Source: survey data

Following our observation that the listed challenges were not perceived as constraints on CA adoption among ACT and non-ACT project farmers, it is our view that there might be unknown constraints on CA adoption that the study's strategy was not able to uncover. A research strategy that builds on farmers' participatory approach to understanding low adoption may produce more conclusive results.

4.2 Impact assessment of CA technology adoption in Tanzania and Zambia

Section 4.2.1 reports on the impact assessment of CA adoption in Tanzania, while section 4.2.2 reports on the impact assessment of CA adoption in Zambia.

4.2.1 Impact assessment of CA adoption in Tanzania

4.2.1.1 Outcome variables

Table 4.8 presents the outcome variables used to assess the impact of CA adoption in Tanzania. Except for the number of food-insecure months and the number of meals per day, which were continuous variables, the rest were discrete ordinal variables. The entries in Table 4.8 are medians for the discrete variables and means for the continuous variables.

Table 4.8: Outcome variables

Outcome variable	ACT (n=135)	Non-ACT (n=68)	$P > T(\chi^2)$
Agronomic outcomes			
Total agricultural yield[1]	3	1	0.000***
Adaptation to climate change impacts[1]	3	1	0.000***
Resilience to drought[1]	3	1	0.000***
Total maize production[1]	3	1	0.000***
Household food security and nutritional outcomes			
Food security[1]	3	1	0.000***
Number of food insecure months[3]	3.5	5	0.5821
Number of meals per day[4]	2.904	1.176	0.000***
Household economic outcomes			
Household income (US$)[1]	3	1	0.000***
Accumulation of productive assets[1]	3	1	0.000***
Addressing agricultural calendar bottlenecks[1]	1	1	0.0013***
Total agricultural production costs[2]	3	1	0.0246**
Gender and social outcomes			
Gender disparities[1]	2	1	0.000***
Social cohesion[1]	3	1	0.000***
Environmental outcomes			
Soil health[1]	3	1	0.0042***
Forest area covered (ha)[1]	3	1	0.000***

1 (3= increased, 2 = constant, 1= decreased), 2 (3 = decreased, 2= constant, 1=increased), 3(continuous 1-12 months), 4 (continuous 0-3 meals).

Table 4.8 shows that there were statistically significant differences between the treatment and control observations on all outcome variables, except for the number of food-insecure months, which leads us to suspect that the CA intervention might have had an impact on the outcome variables.

4.2.1.2 The case for self-selection bias

The first step in an impact assessment study is to establish whether there are systematic pre-treatment differences between the treated and controls in the sample which requires to establish whether there is evidence for self-selection bias. Following Rosenbaum (1983), Table 4.9 presents the results for the equality of means tests between the treated and control observations.

Table 4.9: Equality of means tests

Variable	**ACT**	**Non-ACT**	**Abs. T-value**
Age	48.70	46.90	1.1885
Land holding size	2.42	1.96	1.4325
Benefited from CA project (1= benefited, 0 otherwise)	0.98	0.04	36.9581***
Household size	6.20	7.01	1.8346*
Literacy (1= can read and write, 0 otherwise)	0.93	0.97	1.2723
Off- farm income in $US (= yes, 0= otherwise)	0.25	0.28	0.4201
Married (1= married, 0 =otherwise)	0.89	0.91	0.5029
Participates in farmer groups (1= yes, 0 =otherwise)	0.85	0.18	12.4105***
Residence in Mbeya (1= yes, 0 =otherwise)	0.43	0.63	2.7642***
Household head gender of (1= male, 0 =otherwise)	0.83	0.87	0.6990
Access to credit (1= yes, 0 =otherwise)	0.16	0.13	0.5699
Perception of soil fertility before the CA project (1=low, 0 =otherwise)	0.93	0.07	22.7070***
Access to extension services (1= yes, 0 =otherwise)	0.89	0.18	14.4904***

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.9 shows that there are no systematically and statistically significant pre-treatment differences between the treated and controls, based on the following covariates: the age of the household head, the land-holding size, whether the household head is literate, the levels of off-farm income, the marital status of the household head, the gender of the household head, and whether the household has access to credit. It follows that, pre-treatment, the above covariates cannot distinguish the treated from the controls. However, Table 4.9 shows the existence of systematically and statistically significant pre-treatment differences between the treated and controls, thus establishing a case for self-selection bias based on the following covariates: whether the household has benefitted from any CA project before, the household size, whether the household has membership in a farmer group, whether the household is in Mbeya, the household’s perception of soil fertility before the introduction of the CA project, and whether the household has access to extension services.

4.2.1.3 Impact assessment

To identify the impact of CA in the presence of self-selection bias, impact assessment theory requires the imposition of the conditional independence assumption (CIA), which stipulates that, for a given number of observable variables **X**, the possible outcome in the case of non-adoption should be autonomous of treatment assignment. Essentially, CIA requires the analyst to use statistical procedures to mimic complete randomisation in treatment allocation. To this end, CIA requires that the treatment and control observations be made as similar as possible with respect to the statistically significant covariates in Table 4.9. STATA delivers on this objective by estimating a propensity score equation and confirming that the balancing property of the propensity score is satisfied prior to matching. In STATA language, the balancing property ensures that assignment to treatment is 'random', which implies that the treatment and control units are observationally identical on average.

The results from the estimating model (4.1) using PSCORE (calliper 0.001) are reported in Table 4.10. An extensive literature review and comparisons of different model specifications in attempting to satisfy the balancing property informed the variables included in the model (4.1).

$$\text{PCAadop} = \beta + \beta_1\text{HHage} + \beta_2\text{Landsize} + \beta_3\text{HHsize} + \beta_4\text{Literacy} + \beta_5\text{Mbeya} + \beta_6\text{HHgender} + \beta_7\text{Extens} + \beta_8\,\text{cre} \qquad (4.1)$$

Table 4.10: Probit model for CA adoption

Variable	Co-efficient	Standard error	Z	p>|z|
Age of household head	-0.0108	0.0131	-0.83	0.407
Land holding size	0.1871**	0.0829	2.25	0.024
Household size	-0.0574	0.0511	-1.12	0.262
Literacy (1=Yes, 0= No)	-0.0969	0.5933	-0.16	0.870
Residence in Mbeya (1=Yes, 0=Otherwise)	-0.0860	0.2723	0.32	0.748
Gender of household head (1= Male, 0=Female)	0.0583	0.3407	0.17	0.864
Access to extension services (1=Yes, 0=Otherwise)	2.4037***	0.2723	8.83	0.000
Access to credit (1=Yes, 0=Otherwise)	0.7201**	0.3529	2.04	0.041
Constant	-0.58444	0.92096	0.63	0.526
Summary statistics				
Number of observations	203			
LR Chi-square	119.09			
Prob > chi2	0.0000			
Pseudo-R2	0.4600			
Log-likelihood	-69.89967			

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.10 shows that there were no statistically significant differences between the treated and control observations for the following variables: the age of the household head, household size, whether the household head is literate, whether the household is in Mbeya, and the gender of the household head. Similarly, Nkala (2011) found the age of the household head, household size, education levels, and the gender of the household head statistically insignificant in determining CA adoption in Tanzania. However, the land-holding size, access to extension services, and access to credit were significantly different in determining CA adoption. The observation that households with access to extension services have a relatively higher probability of CA adoption is consistent with studies by Abdulai (2016), Namwata et al. (2010), and Tumbo et al. (2019). Namwata et al. (2010) found that credit access positively influences the adoption of improved agricultural technologies in Mbeya, Tanzania. Manda et al. (2016) and Teklewold et al. (2013) found that households with higher land holdings are more likely to adopt CA than are land-constrained households, which is consistent with the observations made by Chinseu et al. (2019).

In addition to the CIA, successful impact identification requires the imposition of the common support or overlap condition, which guarantees that, for every adopting household, there are non-adopting households with the same observable covariates. The model presented in Table 4.10 not only satisfied the balancing property; it also had a 0.116405 and 0.999999 region of common support. With the balancing property and region of common support satisfied, the theory of impact assessment allowed us to conclude that any differences we might subsequently observe between the treatment and the controls could be causally attributed to the CSA project intervention.

Consequently, the estimated propensity scores of Tables 4.10 were used to estimate the average treatment effect of adopting CA on the treated (ATT) with respect to the outcome variables reported in Table 4.8. We used the nearest neighbour, kernel, and radius matching strategies to provide robustness and consistency. Caliendo and Kopeining (2005) reviewed the advantages and disadvantages of these matching strategies. Table 4.11 reports the causal effect estimates of CA on agronomic outcomes.

Table 4.11: Impacts of CA on agronomic outcomes

Matching algorithm	**# treated obs.**	**# control obs.**	**ATT**	**SE**	**t-stats**
Total agricultural yield					
Nearest neighbour	135	23	1.481	0.285	5.205***
Kernel Matching	135	50	1.332	0.204	6.530***
Radius matching	135	50	1.361	0.213	6.397***
Adaptation to climate change impacts					
Nearest neighbour	135	23	1.526	0.310	4.926***
Kernel Matching	135	50	1.218	0.275	4.429***
Radius matching	135	50	1.224	0.270	4.609***
Resilience to drought					
Nearest neighbour	135	23	1.444	0.329	4.393***
Kernel Matching	135	50	1.336	0.220	6.058***
Radius matching	135	50	1.373	0.167	8.203***
Total maize production					
Nearest neighbour	135	23	1.052	0.257	4.087***
Kernel Matching	135	50	0.808	0.246	3.282***
Radius matching	135	50	0.828	0.204	4.066***

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Let ATT be the average treatment effect on the treated, υ_{1i} (υ_{0i}) indicate individual i received (or did not receive) the treatment ($D_i = 1$), and E be the expectations operator. In line with Chapter 3, the ATT is calculated using equation (4.2):

$$ATT = E[\upsilon_{1i}|D_i = 1] - E[\upsilon_{0i}|D_i = 1] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

Responses to the discrete outcome variables in Table 4.8 were coded as increased (3), constant (2), or decreased (1), it follows that a positive ATT in Table 4.11 implies that, on average, CA adoption improves the outcome of interest, and the bigger the ATT value, the stronger the view. A negative ATT, on the other hand, implies that CA on average decreases the outcome. Table 4.11 shows that the respondents on average perceived CA adoption as having a positive and statistically significant impact on total agricultural yield, which is consistent with Brown et al. (2018) and Lai et al. (2012). Table 4.11 also shows that the respondents on average perceived CA adoption as having a positive impact on climate change adaptation and resilience in the face of drought (Kimaro et al., 2016), and on total maize production.

Table 4.12 reports the causal effect estimates of CA on food security and nutrition outcomes.

Table 4.12: Impacts of CA on food security and nutrition outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
		Food security			
Nearest neighbour	135	23	1.570	0.365	4.303***
Kernel Matching	135	50	1.266	0.285	4.447***
Radius matching	135	50	1.329	0.269	4.940***
		Number of food insecure months			
Nearest neighbour	135	5	0.065	0.830	0.078
Kernel Matching	135	50	-0.169	0.495	0.341
Radius matching	-	-	-	-	-
		Number of meals per day			
Nearest neighbour	135	23	2.430	0.509	4.777***
Kernel Matching	135	50	1.768	0.330	5.358***
Radius matching	135	50	1.848	0.380	4.861***

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Household food security and nutrition outcomes are indicators of household well-being. Table 4.12 shows that CA had positive and significant impacts on perceived food security and nutrition outcomes, and on the number of meals per day (a measure of household food availability). The increase in household food availability may be attributed to the perceived increase in maize production, which defines food availability in the study areas. Contrary to studies by Jumbe and Nyambose (2016) and Siziba et al. (2019), which show that CA has positive and significant impacts on increasing the number of food-provisioning months, this variable is statistically insignificant in Table 4.12.

Table 4.13 reports the causal effect estimates of CA on household economic outcomes.

Table 4.13 : Impacts of CA on household economic outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Household income					
Nearest neighbour	135	23	1.548	0.343	4.513***
Kernel Matching	135	50	1.224	0.295	4.217***
Radius matching	135	50	1.307	0.277	4.716***
Accumulation of productive assets					
Nearest neighbour	135	23	1.274	0.391	3.261***
Kernel Matching	135	50	1.034	0.281	3.679***
Radius matching	135	50	1.090	0.206	5.290***
Addressing agricultural calendar bottlenecks					
Nearest neighbour	135	23	0.319	0.153	2.079**
Kernel Matching	135	50	0.119	0.250	0.476
Radius matching	135	50	0.108	0.212	0.511
Agricultural production costs					
Nearest neighbour	128	23	-0.096	0.084	1.144
Kernel Matching	135	50	-0.120	0.094	1.278
Radius matching	135	50	-0.102	0.132	0.773

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.13 shows that households perceived CA as having positive and statistically significant impacts on both household income and the ability of households to accumulate productive assets. Similarly, Khonje et al. (2018), Manda et al. (2016), Ng'ombe et al. (2017), and Ngwira et al. (2012) reported positive impacts of CA on household income. The positive impacts can be attributed to increases in maize and overall crop yield. We noted earlier that CA adopters are highly dependent on on-farm income. Thus, the increased maize production increases their farm incomes, with spill-over effects on their capacity to accumulate productive assets.

Table 4.13 generally shows that households perceived CA as having no impact on their ability to address agricultural calendar bottlenecks. It is only the nearest neighbour algorithm that shows that CA has a positive and statistically significant impact on this variable, which is consistent with Nichols et al. (2015). The ATT for the kernel and radius matching algorithms is statistically insignificant, implying that we cannot conclude whether CA has a positive or a negative impact. Since the production costs outcome was coded as decreased (3), constant (2), increased (1), Table 4.13 shows that households perceived CA adoption as increasing total agricultural costs, consistent with Pittelkow et al. (2015), who reported that an increased use of herbicides in CA increased labour costs; but this impact is statistically insignificant.

Table 4.14 reports the causal effect estimates of CA on social and gender outcomes.

Table 4.14 : Impacts of CA on social and gender outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Community social cohesion					
Nearest neighbour	135	23	1.341	0.358	3.750***
Kernel Matching	135	50	1.098	0.285	3.849***
Radius matching	135	50	1.156	0.230	5.019***
Gender disparity					
Nearest neighbour	135	23	0.881	0.362	2.437***
Kernel Matching	135	50	0.750	0.225	3.332***
Radius matching	135	50	0.805	0.220	3.649***

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.14 shows that households perceived CA as having positive and statistically significant impacts on community social cohesion and on reducing gender disparity. The positive impact on community social cohesion can be attributed to higher numbers of CA adopters' participation in farmers groups, which increases social cohesion through knowledge-sharing and group-building initiatives (Adong, 2014). Participation in farmer organisations provides more time for CA adopters to engage in community activities, and thus strengthens social cohesion. FAO (2019) reports that, in theory, CA adoption should reduce agricultural labour and provide time for off-farm operations and social activities. Although the positive and significant impacts of CA on gender outcomes are consistent with Siziba et al. (2019), who reported that CA improved gender outcomes by increasing food security for female-headed households, the adoption of CA technologies such as herbicide spraying and other CA equipment is biased towards male farmers.

Finally, Table 4.15 reports the causal effect estimates of CA on environmental outcomes.

Table 4.15 : Impacts of CA on environmental outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Soil health					
Nearest neighbour	135	23	2.281	0.429	5.316***
Kernel Matching	135	50	2.019	0.284	7.116***
Radius matching	135	50	2.070	0.259	7.987***
Forest area cleared					
Nearest neighbour	135	23	-0.319	0.140	2.282**
Kernel Matching	135	50	-0.188	0.197	0.953
Radius matching	135	50	-0.186	0.170	1.094

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.15 shows that households perceived CA as having positive and statistically significant impacts on improving soil health, consistent with results reported by Cheesman et al. (2016), Kimaro et al. (2016), and Powlson et al. (2016). Table 4.27 is also consistent with our earlier findings that CA increases resilience in the face of droughts, and corresponds with the requirements of CSA technologies. Table 4.15 further shows that households perceived CA as having no statistically significant impact on reducing the forest area cleared. Although it is erroneous to attach meaning to the statistically insignificant ATT for the forest area cleared, Luedeling et al. (2011) documented the failure of CA to reduce the forest area cleared per year through agroforestry due to poor land tenure policies and rights. Table 4.15 appears to support Govaerts et al. (2009), who questioned the potential of CA to sequester carbon and provide ecosystem services.

4.2.2 Impact assessment of CA adoption in Zambia

4.2.2.1 Outcome variables

Table 4.16 presents the outcome variables used to assess the impact of CA adoption in Zambia. All the variables were discrete ordinals, except for the number of food-insecure months and the number of meals per day, which were continuous variables. The entries in Table 4.16 are medians for the discrete variables and means for the continuous variables.

Table 4.16: Outcome variables

Outcome variable	ACT (n=133)	Non-ACT (n=71)	$P > T(\chi^2)$
Agronomic outcomes			
Total agricultural yield[1]	3	1	0.000***
Adaptation to climate change impacts[1]	3	1	0.000***
Resilience to drought[1]	3	1	0.000***
Total maize production[1]	3	1	0.000***
Household food security and nutritional outcomes			
Food security[1]	3	2	0.000***
Number of food insecure months[3]	2.071	3.44	0.000***
Number of meals per day[4]	2.969	2.519	0.000***
Household economic outcomes			
Household income (US$)[1]	3	2	0.000***
Accumulation of productive assets[1]	3	2	0.000***
Addressing agricultural calendar bottlenecks[1]	3	2	0.000***
Total agricultural production costs[2]	3	3	0.0415**
Gender and social outcomes			
Gender disparities[1]	3	2	0.000***
Social cohesion[1]	3	2	0.000***
Environmental outcomes			
Soil health[1]	3	1	0.0005 ***
Forest area covered (ha)[1]	2	1	0.1318

1 (3= increased, 2 = constant, 1= decreased), 2 (3 = decreased, 2= constant, 1=increased), 3(continuous 1-12 months), 4 (continuous 0-3 meals).

Table 4.16 shows that there were statistically significant differences between the treated and control observations on all outcome variables except for forest area cleared per year, which makes us suspect the likelihood of a CA intervention impact.

4.2.2.2 The case for self-selection bias

As required in an impact assessment study, Table 4.17 checks the presence of systematic pre-treatment differences between the treated and controls in the sample as evidence of self-selection bias. Following Rosenbaum (1983), Table 4.17 presents the results for the equality of means tests between the treated and control observations.

Table 4.17: Equality of means tests

Variable	ACT	Non-ACT	Abs. t stats
Age	52.361	42.197	5.1203***
Land holding size	14.631	8.829	1.4480
Benefited from CA project (1= benefited, 0 otherwise)	0.849	0.014	19.0549***
Household size	8.977	7.042	3.1390***
Literacy (1= able to read and write, 0 otherwise	0.939	0.887	1.3285
Off- farm income	0.308	0.366	0.8365
Married (1= Married, 0 =otherwise)	0.835	0.845	0.1928
Participation in farmers groups	0.962	0.606	7.3940***
Residence in Mpongwe	0.398	0.690	4.1108***
Gender of Household head	0.729	0.549	2.6294***
Access to credit	0.090	0.028	1.6733*
Perception of soil fertility before CA	0.985	0.183	21.8529***
Access to extension services	0.645	0.479	2.3285**

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.17 suggests that there were no systematically and statistically significant pre-treatment variances between the treated and controls, based on the following covariates: land holding size, whether the household head is literate, the levels of off-farm income, and whether the household head is married. This means that, for pre-treatment, these variables cannot differentiate the treated and controls. However, there are systematically and statistically significant pre-treatment differences between the treated and controls, based on the following covariates, which establishes a case for self-selection bias: the gender of the household head, the age of the household head, whether a household has benefitted from any CA project before, whether a household has access to credit, household size, whether a household is a member of a farmers' group, whether a household is in Mpongwe, the household's perception of soil fertility before the introduction of the CA project, and whether a household has access to extension services.

4.2.2.3 Impact assessment

Impact assessment in the case of the existence of self-selection bias necessitates the imposition of the conditional independence assumption (CIA), which states that, given a set of observable covariates **X**, the potential outcome in the case of non-adoption should be independent of treatment assignment. Fundamentally, CIA requires the use of statistical procedures to imitate complete randomisation in treatment allocation. In that regard, CIA requires that the treatment and control observations be made as similar as possible with respect to the statistically significant covariates in Table 4.17. As mentioned earlier, the statistical package (STATA) delivers CIA by estimating a propensity score equation and satisfaction of the balancing property prior to matching. In such a case, the balancing property ensures that assignment to treatment is ‘random’, which suggests that the treatment and control units are observationally identical on average.

The results from the estimating model (4.3) using PSCORE (calliper 0.001) are reported in Table 4.18. A widespread literature review and comparisons of different model specifications in attempting to satisfy the balancing property informed the variables included in the model (4.3).

$$\text{PCAadop} = \beta + \beta_1\text{HHage} + \beta_2\text{Landsize} + \beta_3\text{HHsize} + \beta_4\text{Literacy} + \beta_5\text{Marital} + \beta_6\text{HHgender} + \beta_7\text{soilfert} + \beta_8\,\text{credit} + \beta_9\text{Offarminc} \quad (4.3)$$

Table 4.18: Probit model for CA adoption

Variable	**Coef.**	**SE**	**Z**	**p-value**
Age of household head	0.0239**	0.0117	2.06	0.040
Land holding size	0.0068	0.0124	0.55	0.580
Household size	0.0506	0.0431	1.17	0.240
Being married (1= Yes, 0= No)	-0.5991	0.5853	-1.02	0.306
Literacy (1=Yes, 0= No)	0.8571	0.5354	1.60	0.109
Gender of household head (1= Male, 0=Female)	-0.0198	0.3802	-0.05	0.959
Off-farm income (1 = Yes, 0= No)	0.0895	0.3191	0.28	0.779
Perception of soil fertility before CA project (1=Low, 0=high)	3.1635***	0.3706	8.54	0.000
Access to credit (1=Yes, 0=Otherwise)	-0.0789	0.5837	-0.14	0.892
Constant	-3.6584***	0.9074	-4.03	0.000
Summary statistics				
Number of observations	204			
LR Chi-square	172.60			
Prob > chi2	0.0000			
Pseudo-R2	06546			
Log-likelihood	-45.528455			

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Table 4.18 shows that there were no statistically significant differences between treated and control observations in the following variables: land-holding size, household size, whether a household head is married, whether the household head is literate, the gender of the household head, off-farm income sources, and access to credit. Still, the age of the household head and the perception of soil fertility before the CA project were statistically significant in influencing CA adoption in Zambia. Table 4.18 indicates that the perception of low soil fertility increases the propensity for CA adoption. Consistently, Abdulai (2016), Lalani et al. (2016), and Van Hulst and Posthumus (2016) show that farmers’ perception of CA’s capacity to improve soil fertility influences CA adoption. In addition, Table 4.18 indicates that the age of the household head increases the probability of CA adoption in Zambia. Similarly, Jumbe et al. (2016) show that the age of the household head increases CA adoption in Malawi.

As a CIA requirement, the PSM model in Table 4.18 satisfied the balancing property within a region of common support of 0.00386349 and 0.9997959. Upon satisfying the balancing property and region of common support, the impact assessment allows us to conclude that any differences between the treatment and the controls should be attributed to the CSA project's intervention. We used the PSM model of Table 4.18 to estimate the average treatment effect of adopting CA on the treated (ATT), regarding the outcome variables in Table 4.16. We used the nearest neighbour, kernel, and stratification matching strategies to provide robustness checks within the strategies (Caliendo and Kopeinig, 2008).

As specified in Table 4.16, responses to the discrete outcome variables in Table 4.16 were coded as decreased (1), constant (2), increased (3), it follows that a positive ATT implies that, on average, CA adoption improves the outcome of interest, and the bigger the ATT value, the stronger the view. A negative ATT, on the other hand, implies that CA on average decreases the outcome.

The estimates of the causal effect of CA on the outcomes in Table 4.16 are reported in Tables 4.19 to 4.23. As with the interpretation of ATT for Tanzania, we interpret the impact of CA on the outcome variables presented in Table 4.16.

Table 4.19 reports the causal effect estimates of CA on agronomic outcomes.

Table 4.19 : Impacts of CA on agronomic outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Total agricultural yield					
Nearest neighbour	133	11	1.075	0.243	4.423***
Kernel Matching	133	68	1.315	0.284	4.628***
Stratification	133	68	1.412	0.236	5.981***
Adaptation to climate change impacts					
Nearest neighbour	133	11	1.075	0.245	4.381***
Kernel Matching	133	68	1.262	0.269	4.690***
Stratification matching	133	68	1.374	0.226	6.087***
Resilience to drought					
Nearest neighbour	133	11	1.068	0.244	4.381***
Kernel Matching	133	68	1.301	0.283	4.605***
Stratification matching	133	68	1.397	0.233	5.997***
Total maize production					
Nearest neighbour	133	10	0.329	0.435	0.756
Kernel Matching	133	68	0.734	0.368	1.994**
Stratification matching	133	68	0.773	0.407	1.899*

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Specifically, Table 4.19 suggests that CA had a positive and significant impact on the total agricultural yield; this is confirmed by a positive and significant impact on maize production. Consistent with this, Brown et al. (2018) and Lai et al. (2012) show a positive CA impact on agricultural yield. Specifically, Abdulai (2016) reports that an increased maize yield can be attributed to CA adoption. The increase in maize production may be attributed to the fact that farmers in Sub-Saharan Africa practise CA on maize fields more than on other crops (Corbeels et al., 2015). In addition, consistent with the findings of Alfani et al. (2019) and Mulenga et al. (2017), Table 4.19 indicates that CA enhanced households' resilience in the face of droughts and their adaptation to the impact of climate change.

Causal impacts on food security and nutrition are presented in Table 4.20.

Table 4.20: Impacts of CA on food security outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Food security					
Nearest neighbour	133	12	0.714	0.350	2.041**
Kernel Matching	133	68	0.626	0.205	3.050***
Stratification matching	133	68	0.618	0.259	2.388***
Number of food insecure months					
Nearest neighbour	133	9	-2.933	1.260	2.328**
Kernel Matching	133	68	-2.089	0.900	2.323**
Stratification matching	133	68	-2.022	0.720	2.809***
Number of meals per day					
Nearest neighbour	133	9	0.823	0.140	5.897***
Kernel Matching	133	68	0.755	0.134	5.652***
Stratification matching	133	68	0.796	0.061	13.129***

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Looking at Table 4.20 indicates that there are statistically significant differences in food security and nutrition outcomes between CA adopters and non-adopters in Zambia. Consistent with the findings of Jumbe et al. (2016) and Siziba et al. (2019), CA reduced the number of food-insecure months. The reduced number of food-insecure months is evidenced by the increased number of meals per day. Jumbe and Nyambose (2016) also documents an increased maize consumption per capita with CA adoption.

Causal CA impacts on economic outcomes are presented in Table 4.21.

Table 4.21: Impacts of CA on economic outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Household income					
Nearest neighbour	133	12	0.714	0.347	2.056**
Kernel Matching	133	68	0.623	0.206	3.019***
Stratification matching	133	68	0.702	0.205	3.414***
Accumulation of productive assets					
Nearest neighbour	131	12	0.568	0.355	1.598
Kernel Matching	131	68	0.465	0.202	2.298**
Stratification matching	133	68	0.456	0.221	2.066**
Addressing agricultural calendar bottlenecks					
Nearest neighbour	133	11	1.029	0.242	4.254***
Kernel Matching	133	68	1.169	0.279	4.191***
Stratification matching	133	68	1.297	0.269	4.823***
Total production costs					
Nearest neighbour	133	10	-0.298	0.067	4.464***
Kernel Matching	133	68	-0.277	0.062	4.453***
Stratification matching	133	68	-0.283	0.069	4.122***

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Causal CA impacts on gender and social outcomes are presented in Table 4.22.

Table 4.21 shows that CA increased household income and ultimately enhanced households' capacity to accumulate productive assets and to address agricultural calendar bottlenecks. Similarly, Khonje et al. (2018) and Manda et al. (2016) report increased household income with CA adoption. The improved household income is evidenced by an accumulation of household productive assets and corresponds with the results of Ogada et al. (2018). However, Table 4.21 suggests a negative CA impact on agricultural production costs. Since the production costs outcome was coded as decreased (3), constant (2), increased (1) Table 4.21 suggests that CA increased the total agricultural costs, which is consistent with the documentation of Pittelkow et al. (2015). All in all, considering the overall impact on economic outcomes in Zambia, we consider that the positive CA impacts outweigh the negative CA impacts, and conclude that CA positively impacted household economic outcomes.

Table 4.22: Impacts of CA on gender and social outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Gender outcomes					
Nearest neighbour	133	12	0.637	0.335	1.901*
Kernel Matching	133	68	0.585	0.239	2.453***
Stratification	133	68	0.570	0.253	2.249**
Social cohesion					
Nearest neighbour	133	12	0.578	0.351	1.646*
Kernel Matching	133	68	0.474	0.227	2.089**
Stratification matching	133	68	0.467	0.247	1.894*

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Specifically, Table 4.22 indicates that CA positively and significantly impacted gender outcomes. Consistent with this, Siziba et al. (2019) reported a positive effect of CA on gender outcomes by increasing food security for female-headed households compared with male-headed households. In addition, Table 4.22 shows a positive impact on social cohesion outcomes. Adong (2014) showed that membership of farmer organisations increased social cohesion; and this study also attributed increased social cohesion to participation in farmer organisations.

Finally, causal CA impacts on environmental outcomes are presented in Table 4.23.

Table 4.23: Impacts of CA on Environmental outcomes

Matching algorithm	# treated obs.	# control obs.	ATT	SE	t-stats
Soil health					
Nearest neighbour	133	12	-0.932	0.287	3.248***
Kernel Matching	133	68	-0.956	0.242	3.956***
Stratification matching	133	68	-0.907	0.289	3.139***
Forest area cleared per year					
Nearest neighbour	133	10	0.168	0.375	0.447
Kernel Matching	133	68	-0.078	0.245	0.319
Stratification matching	133	68	-0.038	0.254	0.151

***significant at 1%, ** significant at 5% and * significant at 10%. **Source: survey data**

Tables 4.23 indicates a negative impact of CA on environmental outcomes. Specifically, CA negatively impacted soil health in Zambia, which is in line with the findings of Esser (2017). In addition, Table 4.23 indicates a negative and insignificant CA impact on the forest area cleared per year; and therefore we cannot reach a conclusion on CA's impact on the forest area cleared per year. Curiously, the results connect with those of Cheesman et al. (2016), Kimaro et al. (2016), and Powlson et al. (2016) in questioning the capacity of CA to provide positive ecosystem services.

Chapter 5: Conclusion and recommendations

5.1 Introduction

This chapter presents a summary of the findings on the impact of CA on livelihood outcomes: agronomic benefits, food security, household income, and environmental and gender impacts in Tanzania and Zambia. The agronomic outcomes assessed were total agricultural yield, farmers' ability to adapt to the impact of climate change, farmers' resilience in the face of drought, and total maize production. The food security and nutritional outcomes assessed were the number of food-insecure months per year and the number of meals per day. The economic outcomes assessed were household income, accumulation of productive assets, households' ability to address agricultural calendar bottlenecks, and total agricultural production costs. The gender and social outcomes assessed were gender disparities and social cohesion. Finally, the environmental outcomes assessed were the impact of CA on soil health and the forest area cleared per year. The study was relevant in providing policy-makers and CA promoters with clear information on the impact of CA on these outcomes, thus helping them to shape the CA agenda for Africa. Specifically, the study was important in the light of the fact that most projects lack capacity to do impact assessments, which is a critical planning tool. Based on the findings, conclusions were reached and translated into policy recommendations in the arena of CA policy.

5.2 Summary of the findings

The major objective of the study was to test whether CA is delivering positive livelihood outcomes for farmers in Tanzania and Zambia. This was done using propensity score matching for CA adopters and non-adopters in Tanzania and Zambia. In addition, the study assessed the adoption of CA technologies by country, the underlying factors for CA technology preferences, and constraints on CA adoption. In both countries, most ACT project farmers adopt and use at least one CA technology; but there were significantly low adoption rates for the whole CA suite.

The study hypothesised that there are no statistically significant differences in all the pre-determined livelihood outcomes between CA adopters and non-adopters. In Tanzania, the impact assessment results showed that CA had positive and significant impact on all the predetermined livelihood outcomes excerpt for the number of food-insecure months, the total agricultural costs, and the forest area cleared per year, which produced statistically insignificant results. Similarly, the impact assessment results for Zambia showed that CA had a positive and significant impact on all the predetermined livelihood outcomes except for the total agricultural production costs and soil health, which produced negative and significant impacts. On the other hand, CA's impact on the forest area cleared per year showed statistically insignificant differences between CA adopters and non-adopters in Zambia.

5.3 Conclusions

The study revealed that CA has the capacity to improve livelihood outcomes for participating farmers in the two countries. It is imperative to conclude that CA has the potential to improve agronomic outcomes such as crop yield, enhancing households' capacity to be resilient in the face of drought, and thus increasing household food security outcomes. In addition, the study showed that CA has the capacity to improve gender and social cohesion outcomes. We therefore conclude that CA has the potential to fight the negative impact of climate change, enhance gender and social outcomes, and increase agricultural productivity in Tanzania and Zambia. However, in both countries the forest area cleared per year was statistically insignificant between CA adopters and non-adopters. Specific to Zambia, CA had a negative and significant impact on soil health. Based on these findings, we conclude that CA's impact on environmental outcomes is inconclusive.

5.4 Policy recommendations

In the light of the assessment, study findings, and conclusions, we consider that, on average, the CA benefits outweigh the negative impacts. CA should therefore be viewed as a tool to address the impact of climate change and to enhance households' resilience in the face of drought. Nonetheless, the study highlighted notable and important points for CA policymakers to consider in ensuring the best outcomes from CA.

The study revealed that there were statistically significant differences in socio-economic characteristics between CA adopters and non-adopters. CA promoters may take these differences in defining adoption rates and strategizing how best to engage farmers inclusively to adopt CA. In addition, the study showed that the gender of the household head, access to extension services, access to credit, benefitting from a CA project, participation in farmers' groups, and a perception of low soil fertility before CA are critical in determining CA adoption. These findings inform policy-makers about the need to capitalise on these variables to increase CA adoption and contribute towards the achievement of the SDGs and Africa Agenda 2063. Specifically, CA promoters may concurrently promote participation in farmers' groups and access to credit and extension services among smallholder farmers. Considering the potential of the perception of low soil fertility to influence CA adoption, CA promoters should also consider stressing the capacity of CA to improve soil fertility and so enhance CA adoption. Despite the confirmed positive and significant impact of CA on gender outcomes, PSM for Zambia confirmed that CA adoption was biased towards male-headed households. The study questions the application of gender-responsive research to CA technologies and to CA promotion and policies. It is important, therefore, to revise and devise strategies to ensure that female farmers are given a better chance to adopt CA technology, considering the high percentage of such farmers.

Finally, the assessment of CA technologies indicated preferences for and alterations of CA practices across the two countries. This indicates that CA technologies are not 'one size fits all': adopters alter the technologies according to the available resources and cultivation practices. Similarly, the constraints on CA adoption vary, and so require country-specific arrangements to address them. We therefore recommend comprehensive assessments of the current cropping practices before CA is implemented, to draw on specific practices and identify the possible constraints.

5.5 Areas of further study

The study provided a detailed account of CA's impact on livelihood outcomes for Tanzania and Zambia. The study's results feed into the CA literature and inform CA practitioners and policymakers on the impact of CA. Nonetheless, the study identified limitations in the design set out in Chapter 1. To deal with these limitations, the study recommends that future research makes changes to obtain more robust results.

1) Considering that the study used discrete outcomes, which are not usually metrically measured, we recommend that future studies use scientifically proven measurements on the outcomes. For instance, we consider that metrically measured soil health is more robust than farmers' perceptions.
2) Given that the study focused on multiple outcomes, we accept that the assessment was not as comprehensive as a study that focused only on one or two outcomes. We therefore recommend specific studies focusing on each outcome for a comprehensive assessment.
3) Given that the study's findings and literature confirm that CA's impact improves over time, we consider that panel data analysis would give much a better picture of CA's impact. We therefore recommend that future studies use panel data more than cross-sectional data. We consider that long-term data will provide more robust and detailed

information on CA's impact and qualify what the CA literature says about CA's impact over time.

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Chapter 7: Appendix

7.1 Study questionnaire

African Conservation Tillage Network

"Turning Conservation Agriculture Knowledge into Action"

Conservation Agriculture Impact Evaluation Study: Questionnaire for Household In-depth Interviews in CA 'Hot spots' in Eastern and Southern Africa.

Name of Respondent: ……………………………………..

Name of the enumerator: ……………………………………...

Date of Interview: ……………………………… Start time………………… End time………………

Country ………………………………………… County/Region...

District / Sub-County ……………………..…… Ward/Location: ....

Village: ....GPS coordinates: Longitude: ………..……… Latitude: ……………………..

SECTION A: BASIC INFORMATION

A1. Age of the Household head (Decision maker) …………….. (Years)

A2. Gender of the Household Head (Decision maker) 1=Male ☐ 2=Female ☐

A3. Level of education of the household head

1=No formal education	2 = Primary	3=Secondary	4 =University	5=Other (specify)___________

A4. Do you know how to read? Yes……. No ……….

A5. People living in homestead

Children (0-17)	*Adults (18-59)*	*Elderly (>60)*

M_______   F_______   M_______   F_______   M_______   F_______

A6. Have you been a beneficiary of any CA project? ☐Yes ☐ No

A7. Identification: When did you join the project? (Indicate the year) __________________

A8. When did the project end? (Indicate the year) __________________

A9. Marital status: Married ☐ Never married ☐ Widowed ☐

Separated/Divorced ☐

A10. What is the total size of your land? (In hectares) …………………………………….

A11. Number of animals in the household

a. Cows........ b. Goats....... c. Sheep......... d. Pigs ……e. Chicken …… f. Ducks....... g. Others (specify)

A12. Do you belong to a farmers group? 1=Yes ☐ 0=No ☐

A13. What are the major sources of household income? Choose three most important.

a. Crop production; b. Livestock production ; c. Business; d. Casual labour; e. Remittances; f. Employment; g. Others (specify)……………..

SECTION B: EMPOWERMENT

B1. Have you attended any type of training organized by CA promoters? ☐1=Yes, ☐ 2=No

B2. If yes, please provide the following information.

Type of training	Received?		Type of skills gained (Recall)	Ever used the skills gained?		Are you still practising the gained skills?	
	Yes	No		Yes	No	Yes	No
1. Land preparation							
2. Seeding							
3. Weed control							
4. Cover Crops							
5. Harvest							
6. Environment conservation							

Type of training	Received?		Type of skills gained (Recall)	Ever used the skills gained?		Are you still practising the gained skills?	
	Yes	No		Yes	No	Yes	No
7. Farmers Group dynamics							
8. Produce marketing							
9. Agribusiness/Entrepreneurship							
10. Other:							

B3. If you have not been able to use the knowledge and skills gained, list the three major reasons/ constraints?

(a) ……………………………………………………………………….………..……………….

(b)……………………………………………………………………………………………………

(c) ………

SECTION C: ADOPTION OF TECHNOLOGIES

C1. What is the total size of your land in hectares?

1) Area under cultivation (hectares) _______________
2) Area under CA (hectares) ______________________

C2. How have you been managing crop residues/weeds/cover crops in your farm prior to planting? ☐ Slashing with machete or slasher ☐ Mulching ☐ Uprooting weeds (not cutting) ☐ Using knife roller ☐ Use of herbicides

☐ Other (specify)…………..

C3. How do you prepare your farm for planting? ☐ Basin/Zai pit method ☐ Hand ripping ☐Animal Drawn ripping

☐ Tractor drawn ripping ☐ Animal Drawn sub-soiling ☐ Tractor drawn sub-soiling

☐ Others, specify……………………………..

C4. During planting, how do you to carry out planting? ☐ Sow in hole with machete / dibble stick ☐ planting basins / Zai pits ☐ Jab planting ☐ Animal Drawn Direct planting ☐ Tractor Drawn Direct planting ☐ Other (specify)…………..

C5. How have you been controlling or managing weeds in your farm? ☐ Early sowing just after slashing ☐ Mulching ☐ Uprooting weeds (not cutting) ☐ Early weeding ☐ Use of herbicides ☐ Other (specify)…………..

C6. How do you create or maintain organic soil cover in your farm? ☐Prevent burning ☐ Set firewalls/fire breaks ☐ Slash natural vegetation-and mulch ☐ Slash & leave crop residues in the field ☐ Sow cover crop after main crop (Name of cover crops (specify) ..…………………… ☐ Slash cover crops at flowering stage ☐ Leave cover crop in field after harvesting the grain

C7. How do you practice crop diversification or associations? ☐ Crop rotation ☐ Inter-cropping ☐ Relay cropping ☐ Agroforestry (Faidherbi albida)

C8. Are you a mixed farmer ☐Yes ☐No,

If yes, how do you integrate crop with livestock? ☐ Used manure for fertilizer ☐ Used crop residues for livestock feed ☐ Protection of fields from animals (specify how)……………………………………………………………

☐Other (specify) ………………………………………………………………………………………………..

C9. Where is the main source of knowledge and information about the above technologies you have adopted or use?

☐1=CA Project; ☐2=Government Extension; ☐3=Neighbours; ☐4=Other Specify ………………………………….

C10. How do you rate your level of mastery or understanding of the above mentioned technologies of practices?

☐ (1=Low (Need more adaptation); 2=Average; 3=High (Well adapted))

C11. Please indicate the extent in terms of land size to which each technology below has been adopted and practiced in your farm?

Type of technology /practice	**Year Started**	**Beginning (land size started with) (Hectares)**	**Year ended**	**Presently (land size currently under each) (Hectares)**
Land Preparation				
Sub-soiling (Animal or Tractor)				
Ripping (Hand, Animal or Tractor)				
No-Till Seeding				
Animal Drawn Direct planting				

Tractor Drawn Direct planting				
Jab planter				
Soil Cover				
Leave crop residue in field after harvesting				
Mulching (imported from other fields)				
Uprooting weeds (not cutting)				
Shallow weeding (Weed Scrapper)				
Crop Rotation/Associations				
Crop rotation				
Inter cropping				
Area under Cover crops				
Used manure for fertilizer				

SECTION D: CHALLENGES OF ADOPTION

D1. Score the challenges facing the adoption of CA technologies (Score in a scale of 1 to 5, where 1 is the least challenging and 5 is the most challenging) as listed below.

	Challenges facing adoption of CA technologies	Score
1.	Fixed mind-set of agriculture leaders, extension agents and farmers	
2.	Lack or inaccessibility of appropriate CA equipment	
3.	High costs of CA tools and equipment	
4.	Wide spread use of crop residues for livestock feed and fuel	
5.	Burning of crop residues	
6.	Lack of knowledge about the potential benefits of CA	
7.	Lack of government policy support for CA –enabling environment	
8.	Traditions and culture	
9.	Availability of cover crops seeds	
10.	Others (specify) ….	

SECTION E: OVERALL IMPACT

E1. How did the CA interventions (in the project you were involved in) impact on the below listed areas? (Use 1=Improved, 2= Static and 3= Decreased)

Aspects under CA	1=Improved, 2= Static & 3= Decreased
Food security	
Income	
Health and nutrition	
Assets	
Environment	
Social	
Gender disparity	

E2. How has the CA impacts been realized in terms of timelines (Use 1=short term, 2=medium term or 3=long term

Aspects under CA	1=Short term, 2=Medium term & 3=Long term	Beneficiary (M=Male, F=Female or B=Both)
Food security		
Income		
Health and nutrition		
Assets		
Environment		
Social		
Gender disparity		

E3.What is your observation on the following aspects as regard to adoption or involvement on CA at your household level?

Would you say that the total ...	... has increased or decreased after getting involved in CA project (1=Increased, 2=Stagnated 3=Decreased)	Value before CA	Current value (after CA)
At Household Level			
Total cultivated area (hectares)			
Area under CA (hectares)			
Soil fertility			
Total Maize production (kg)			
Total Sorghum production (kg)			
Total Beans production (kg)			
Total Cowpeas production (kg)			
Total Pigeon Peas production (kg)			

Total Dolichos Lablab production (kg)			
Product sales (value in USD)			
Total Production Costs (value in USD)			
Profit (sales minus production costs)			
Food security			
Access to credit			
Savings capacity			
At the Community Level			
Forest area cleared per year (hectares)			
Number of farmers practicing CA in the village			
Solidarity, social cohesion and group work			

E4. How reliable is income obtained from CA project enterprise?

1=Very reliable, 2=Somehow reliable, 3=Less reliable, 4=Not reliable at all ☐

E5. What are the top 3 benefits that can be attributed to the CA projects?

Description	Rank the top three in order of importance (1 = most important, 3 least important)
1. Increase revenue	
2. Improving food security	
3. Purchase of assets/goods	
4. Increases in CA inputs and service provision and usage	
5. Policy changes supportive of CA	
6. Start a new business (specify):	
7. Increase in awareness, knowledge, skills	
8. Changes in community capacity	

9. Other (specify):	

E6. What other impacts, positive and negative, did CA and the CA project(s) produce?

1. ___________________________________

2. ___________________________________

3. ___________________________________

SECTION F: FOOD AND NUTRITIONAL SECURITY

F1. What is the change in food and nutritional security since you started using CA (1=Improved, 2= Static and 3= Decreased) ☐

F2. What is the cause of this change in the food and nutritional security?

1. _____________________________

2. _____________________________

3. _____________________________

F3. What is the yield status after using CA (1=Improved, 2= Static and 3= Decreased)

F4. Rank the sources of food in your household before CA and with CA in order of importance (Most important =5, Least Important=1)

Source of food	**Before CA**	**Presently with CA**
Own farm		
Purchase		
Given by neighbours/friends/relatives		
Government		

F5. On average, how many meals per day can your household provide to its members?

	Before the CA	With CA
Number of meals / day		
Number of months food insecure		

SECTION G: POLICY INTERVENTION ON CA

G1. Are you aware of any policy intervention that governs the CA technologies 1=Yes ☐ 2=No ☐

If yes, has it worked and what changes has it brought

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

G2. What kind of policy was it?

....

....

....

G3. Do you understand the policy? 1=Yes ☐ 2=No ☐

SECTION H: INSTITUTIONAL FACTORS

H1. What is the major role of the following institutions?

Institutions **Key roles**

Local government office

Local institutions (Churches, Mosques,)

Private sector agro-dealers

Local NGOs

Research institutions

Extension services,

Farmers' communities

1=Provision of seeds, 2=Provision of extension services, 3=Provision of tools, 4=others Specify..........

H2. Has the frequency of meeting the agricultural extensionist increased or reduced after the end of CA project you were involved in? (1=increased, 2=decreased) ☐

H3. How often were/are you meeting the agricultural extensionist from the project?

(1=weekly, 2= bi-monthly, 3= monthly, 4= a few times a year, 5 = never) ☐

H4. The contact time with the extensionist was/is adequate? ☐Yes ☐ No

H5. How often are you participating in your farmers' group meetings? (1=weekly, 2= bi-monthly, 3= monthly 4= a few times a year, 5 = never)

SECTION I: AFFORDABILITY AND SUSTAINABILITY

I1. How durable are the adoption of CA practices

Type of technology /practice	**Durability** (1=Durable 0=Not durable)	**Sustainability** (1=Sustainable 0=not sustainable)
Direct planting in lines		
Sow in hole with machete / stick		
Jab planter		
Early sowing just after slashing		
Mulching		
Uprooting weeds (not cutting)		
Early weeding		
Set firewalls		
Slash cover crops at flowering stage		
Soil permanently covered		
Leave crop residue in field after harvesting		
Crop rotation		
Inter cropping		
Cover crop during dry season		
Use manure for fertilizer		
Use crop residues for livestock feed		

I2. What is the effect on the listed parameters on households adopting CA?

Parameters	**1= Decreased; 2 = Static; and 3 = Increased**
Soil health	
Resilient to drought	
Agricultural yield	
Adaptation to impacts of climate change	
Addressed agricultural calendar bottlenecks	

SECTION J: LABOUR AND GENDER

J1**.** Based on your experience and observation which of the following CA technologies requires more time to implement compared to conventional/traditional system? Indicate also who the doer/implementer of the activity is.

CA TECHNOLOGY	**Tick the technique that takes more time to implement <u>on one hectare</u>**		**Mostly done by who** **(**Use 1=Male 0=Female)
	CA	**Traditional**	
Digging planting basins			
Ripping (Hand, Draft animal or Tractor)			
Direct planting in lines			
Sowing in hole with machete / stick			
Jab planting			
Early sowing just after slashing			
Mulching			
Uprooting weeds (not cutting)			
Shallow weeding (scrapping)			
Setting firewalls			
Planting of Cover crops			
Application of manure for fertilizer			
Home preservation of crop residues for mulching			

J2. Has CA reduced labour and agricultural workload? Use 1=Yes or 0=No ☐

J3. If yes, whose labour is reduced? Use 1= Men; 2= Women; and 3 = Both ☐

SECTION K: ACCESS TO RESOURCES

K1. Did you use any inputs obtained outside the household in the current/last cropping season? 1=yes, 2=no

K2. If yes, how did you access the inputs and tools you used?

Input type (specify the items in the case)	Granted by project (name the project & NGO)		Own Purchase (full cost)		Own Purchase (subsided)	
	What input / tool	**Price total**	**What input / tool**	**Price total**	**What input / tool**	**Price total**
Main crop seed						
Cover crop seed						
Fertilisers						
Insecticide						
Herbicides						
Hoes						
Machetes and sticks						
Jab planters						
Other (specify)						

K3. Do you have access to an agro-dealer (inputs suppliers) from your area? ☐ 1=Yes; 0=No

K4. What is the source of money for purchase of inputs? ☐ 1=Sale of crops, 2=Sale of livestock, 3=CA project 4=remittance, 5=Sale of labour, 6=other (specify) …………..

SECTION L: SUSTAINABILITY

L1. Have you ever provided CA services to other farmers? ☐ Yes ☐ No

L2. If yes, what type of services? List maximum of three services offered………………………………………………

L3. To how many farmers? ……………………………………

L4. Were you paid for it? ☐ Yes ☐ No If yes, how much? ....

L5. Would you say that the area under CA in the community have increased or decreased after the end of the project? ☐

1 = Increased, 2 = Stagnated, 3 = Decreased, 4 = Do not know

L5. Have you learnt anything new after the CA project related to the project? ☐ 1=Yes, 2=No

If yes, list a maximum of three

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

SECTION M: DIFFUSION OF CA INTERVENTIONS

M1. Which of the following items in your household can be attributed to CA project? (Both CA and non-CA respondents)

Item	**Rank the appropriate ones** **(1= more important, to the last, cross if no)**
1.Increase household income	
2.improve food security	
3.Increase children’s education	
4. Purchase assets (specify): ………………....	
5.Improved house	
6.Start a new business	
7. Other (specify):	

For Non-beneficiaries of the CA project:

M2. Are you aware of CA Project activities in your village or nearby villages? ☐ 1=Yes, 2=No

M3. If yes, where did you get information about the Project? ☐

1=Village leaders, 2=Extension workers, 3=Farmers in the village, 4 = radio broadcast 4=others (specify)

M4. Are there other related projects in your area promoting CA? ☐ 1=Yes, 2=No

M5. Have you learned any new thing that was introduced by CA project? ☐ 1=Yes, 2=No

M6. If yes, mention how you heard of it

………
………
………………………………

SECTION J: ACCESS TO CREDIT

Has the access to credit increased or decreased since the introduction of CA project?	1 = increase, 2 = stagnate, 3 = decrease 4. Do not know
Have you ever accessed credit?	☐ yes ☐ no
If yes, for what?	☐ agricultural production ☐ health/domestic issue ☐ running of business ☐ construction investments ☐Other (specify)……………………………………………
If no, what is the reason?	☐ lack of awareness ☐ high interest rates ☐ fear or risk averseness ☐Other (specify)……………………………………………
What was the value of the credit (Value in USD)	....
What was the source of credit?	....
How far is the nearest financial institution?	……………. kilometres
What forms of savings do you practice? *(tick all appropriate options)*	☐ cash saving ☐ livestock investments ☐ labour exchange ☐ cereal storing ☐Other (specify)……………………………………………

NOTES:

- 2.5 acres = 1 hectare; or multiply "y" acres by 0.4 to get hectares.

THANK YOU VERY MUCH FOR YOUR TIME AND COOPERATION

7.2 African Conservation Tillage Network consent letter

ACT AFRICAN CONSERVATION TILLAGE NETWORK

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10 September 2019

Linda Sankhulani

University of Pretoria

South Africa

RE: AUTHORITY TO USE ACT - COMESA DATA IN PREPARING A DISSERTATION TOWARDS FULFILLMENT OF A MASTER'S DEGREE IN AGRICULTURAL ECONOMICS

I acknowledge of your letter on the above subject dated 2nd September 2019.

I am pleased to inform you that African Conservation Tillage Network (ACT) has granted you authority to use the ACT-COMESA data as per your request. We look forward to your adherence to the specifications of the Memorandum of Understanding between ACT and you (Linda Sankhulani).

Attached is the Memorandum of Understanding.

Engineer Mkomwa

Executive Director

Memorandum of agreement between Linda Sankhulani and African Conservation Tillage Network in preparing a dissertation towards the fulfilment of Linda Sankhulani's Masters Studies.

I, Linda Sankhulani pursuing master's studies in Agricultural Economics at University of Pretoria have requested ACT secretariat for the provision, access and use of ACT-COMESA Zambia and Tanzania data for my master's thesis. The memorandum signed by me, serves as an undertaking of the following;

1.The ACT-COMESA data and information will only be used for my research and studies and for no other purpose.

2. I will not disseminate the ACT-COMESA data or information to any other party.

3. I will keep ACT-COMESA data and information for my research confidential.

4. I will not disseminate the results of my research to any other party other than for the purposes of research.

5. I will share my results with ACT before publishing and accept comments.

6. I will acknowledge ACT as the source of data and information in my research dissertation.

7. The views and opinion expressed in my dissertation will be mine and will not in any way represent policies and position of ACT.

8. ACT has no liability of any errors or omissions in my research dissertation. Errors or omissions in my research dissertation remain my sole responsibility.

Signed by:

Name: Linda Sankhulani

Signature

Date: September 2019

Accepted by:

Name: Eng. Saidi Mkomwa

Signature

Date: 10 September 2019