Does conservation agriculture work as advertised? Implications on labor and farm returns in sentinel sites in Malawi and Zambia

A report produced for the ACASA project and the CGIAR Regional Initiative, Ukama Ustawi: Diversification in East and Southern Africa

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Table of Contents

List of Figures

List of Tables

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Abbreviations

CA	Conservation Agriculture
CARD	Centre for Agricultural Research and Development
CIMMYT	International Centre for Maize and Wheat Improvement
CP	conventional Practices
IITA	International Institute for Tropical Agriculture
SSA	Sub-Sahara Africa

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Abstract

Sub-Sahara Africa (SSA) has degraded soils, epitomized by decades of loss of valuable topsoil caused by continuous cultivation, monocropping, excessive run-off, and the absence of effective conservation-based farming practices. Conservation Agriculture (CA) offers several opportunities to restore land and arrest soil degradation in smallholder farming systems of SSA. This study assessed labor productivity and farm returns associated with CA in Malawi and Zambia using household survey data collected from 500 and 616 farmers in Zambia and Malawi, respectively. Half of the sample was drawn from areas known to have had intense CA promotion over the last 10 years since 2023, hereafter called treatment areas. The other half came from control areas where there was no known institutional CA promotion. We studied the effects of CA on maize, groundnut, and soybean. The study found yield under CA statistically higher than under conventional, suggesting that CA improves yield. The study also observed that CA saves farmers' time, where households in the non-CA areas allocate 26.00 and 21.59 more personal days per season per hectare than households in the treatment areas in Malawi and Zambia, respectively. Based on the two-stage robust stochastic frontier analysis, study findings revealed that CA enhances labor productivity by 3.72% and 2.75 % in Malawi and Zambia, respectively. Likewise, CA improves farm productivity by 13.90 % and 8.80 % in Malawi and Zambia, respectively. Gross margin analysis results suggest farmers in the treatment areas have higher gross margins of US$ 1,474.6 per ha than farmers in control areas with US$ 813 per ha in Malawi. Similarly, farmers in the treatment areas in Zambia had higher gross margins at US$ 764 per ha compared to US$ 394 per ha in control areas. These positive economic benefits in this paper render credence to continued support for CA promotion but more multi-location and multi-year research building on panel surveys is required to further assess the socioeconomic benefits of CA. More work remains on understanding appropriate policy and economic incentives that can be used to spur adoption and how to effectively strengthen extension systems to better support CA promotion and scaling.

Keywords: Labor productivity, gross margin, long-term experiments

1. Introduction

Farmers in Sub-Sahara Africa (SSA) rely heavily on decades of unsustainable farming practices, leading to declining soil fertility and dwindling agricultural land productivity (Wawire et al., 2021; Vanlauwe et al., 2015; Okyere and Kornher, 2023). Over eight million hectares of arable land in the region is degraded, with annual costs of land degradation estimated around US$320 million in Malawi alone (Serraglio et al. 2021). Land degradation has led to a reduction in ecosystem services, leading to deterioration in food availability, soil fertility, carbon sequestration capacity, wood production, and groundwater recharge (Serraglio et al., 2021). This has significant social and economic effects on countries in sub-Saharan Africa (SSA) (Lal, 2015; Munoz et al., 2017). Thus, in their commitment to the African Land Restoration Initiative (AFRI100), countries in SSA, including Malawi and Zambia, have submitted their Nationally Determined Contributions (NDCs) and land restoration through integrated and sustainable land management intensification practices are some of the strategies to mitigate or adapt to climate change and to redress increasing land resource degradation (Magar et al., 2022; Lal, 2009).

Conservation Agriculture (CA) presents several opportunities to arrest and reverse the downward spiral of resource degradation, which leads to high costs of production and inefficient, un-competitive, and unsustainable agriculture (Lee and Gambiza, 2022; Ayyam et al., 2021; Thierfelder et al., 2012, 2015, 2016 and 2017). The fundamental goal of CA is to optimize yields and profits while maintaining a balance between agricultural, economic, and environmental outcomes (Nyanga, 2012). The claim that CA increases yield over time is insufficient to attract investment and, therefore, there is need for data-driven economic assessments (Giller et al., 2015).

As a sustainable cropping system that can help reverse soil degradation, increase land productivity, and reduce labor requirements while producing high net returns (Jew et al., 2020a; Ngwira et al., 2012; Thierfelder, Bunderson, et al., 2016; Thierfelder et al., 2012, 2015, 2016 and 2017; Rodenburg et al., 2021), CA encompuses three core principles: i) minimum soil disturbance, ii) mulching, and iii) crop diversification (Thierfelder et al., 2018; Rodenburg et al., 2021). Historically, the adoption of CA has been low despite several investments targeting CA adoption in Sub-Southern Africa (SSA). Nevertheless, households in SSA are vulnerable to climate change and are affected by low land productivity, challenges that CA is designed to help address. For instance, in Zambia and Malawi, farmers depend on rainfed agriculture, which is negatively impacted by climate change and weather variability (Pangapanga-Phiri et al., 2021). Projections indicating a 3% and 0.6% decrease in rainfall by 2050 and an anticipated temperature rise of 1.9^{o}C to 2.3^{o}C during the same period (Hamududu and Ngoma, 2020) emphasize the urgency of the need to adopt sustainable farming practices.

CA has several agronomic benefits, such as improved soil health through maintaining a permanent or semi-permanent organic soil cover through crop residues and cover crops (Nyamangara et al., 2013), thereby fostering the accumulation of organic matter, a crucial component for soil fertility and microbial activity. It enhances nutrient cycling and soil health (Lal, 2009; Six et al., 2002). Cover crops and residue mulches increase soil organic matter, and improve water-holding capacity. This minimizes evaporation and allows crops to utilize water more efficiently, especially during dry periods (Lal, 2010; Molden and Molden, 2009). Diverse crop rotations and reduced soil disturbance associated with CA promote efficient nutrient cycling and mineralization within the soil profile. This makes nutrients more readily available for crop uptake, minimizing losses and improving overall nutrient use efficiency (Lal, 2007; Pretty et al., 2003). These agronomic benefits contribute to increased crop yields, improved farm resilience, and environmental sustainability (Hobbs et al., 2008; Lipper et al., 2014; Mosquera et al., 2019; Stamations et al., 2023). In addition, CA has been shown to reduce soil erosion by up to 80% and improve water infiltration by up to

30% (Lal, 2010), thereby improving soil health, increasing crop yields, and reducing production costs for farmers (Mosquera et al., 2019; Cárceles et al.,2022).

Furthermore, CA can reduce production costs, an important economic benefit at farm level (Lal, 2003). By minimizing soil disturbance, CA helps to conserve soil organic matter, which improves water infiltration, nutrient retention, and overall soil fertility (Lal et al., 2010; Palm et al., 2014; van der Ploeg et al., 2017; Stamations et al., 2023). Additionally, CA practices, such as mulching and cover cropping, help maintain the integrity of soil structure and moisture content, leading to more stable yields (Devkota et al., 2022). This is particularly beneficial in regions with variable or extreme weather conditions. The benefits of CA extend beyond immediate production cycles. By preserving soil health and fertility, CA can contribute to long-term profitability for farmers. Healthy soil can better support crop growth and withstand climate variability, ensuring farmers can produce high yields (Veni et al., 2020). Besides, CA can also help to reduce off-site costs, such as those associated with soil erosion and water pollution (Devkota, 2022 and Verchot et al., 2007). By minimizing soil erosion, CA helps to protect water resources, infrastructure, and the environment. For instance, in a meta-analysis of 370 studies in 25 countries, CA practices increased crop yields by an average of 6.2% and reduced production costs by 14.9% (Tittonell and Giller,2012; Pretty et al., 2003).

While CA offers several agronomic and economic benefits, challenges and limitations associated with its implementation remain. Implementing CA requires knowledge and skills regarding residue management, cover crop selection, and weed control strategies. Farmers might need training and support to adapt to these new practices (Morris et al., 2013; Chikowo et al., 2003). Stakeholders led by the Ministries of Agriculture, NGOs, and research institutions have provided such information and training to farmers through workshops, demonstrations, or agricultural fairs. However, Lal (2015) argues that in some cases, CA initially increases labor needs for activities like residue management and manual weed control. This can be challenging for farmers with limited labor resources. Tittonell and Giller, (2012)., and Pittelkow et al. (2015) noted that in the short term, transitioning to CA sometimes reduces yields compared to conventional tillage, especially if management practices need to be optimized. Managing weeds under CA can be more challenging than under traditional tillage, depending on the context. As such, farmers may face yield penalties in the early adoption years. Erenstein (2003) and Faver et al. (2023) found that most farmers resort to using herbicides or manual methods to address the challenge of weeds and pests associated with CA.

Thus, while CA provides a valuable approach to sustainable agriculture, more evidence is needed to support its implementation. Hence, in this study, we askwhether CA works as advertised and use data from Malawi and Zambia to assess labor and farm returns and the economics of CA at the household level. We add to the literature in two ways. First, we assess whether farmers practicing CA have higher gross margins than farmers that use conventional methods based on large cross-country survey data involving more than 1,000 households. Second, we extend the literature and compare labor productivity between CA and non-CA farmers.

1.1 Problem statement

Several agronomic benefits such as better soil health, less erosion, soil water conservation, and increased organic matter are associated with full and partial CA (Giller et al., 2009; Thierfelder, Bunderson, et al., 2016; Thierfelder et al., 2012, 2015, 2016 and 2017; Tufa et al., 2023; Magar et al., 2022). These and other benefits contribute to improved yields over time. However, farmers enjoy these benefits only partially, given low and partial adoption. Some farmers adopt CA practices, then drop out due to various constraints, tradeoffs and different realities. Magar et al. (2022) report that CA-based practices have been adopted by only 8-10% of smallholder farmers, corresponding to only 13.9 million hectares in Asia and 1.5 million hectares in Africa. Several factors are attributed to low adoption of CA. For instance, while minimum tillage reduces labor costs in the medium to long term, it involves higher labor outlays at the start, and it increases herbicide expenditure at the farmer level. Mulching, on the other hand, can increase pest infestation since natural decomposition creates a perfect breeding ground for pests. Consequently, farmers incur higher expenditures in controlling such pests. Further, crop rotation must align with market demand for profitability. Therefore, sustainable adoption is only possible through carefully considering and balancing these tradeoffs. Notwithstanding, CA is promoted as a farming approach that optimizes resource use, improves land and labor productivity, enhances resilience to climate shocks and is climate smart. CA is often advertised to offer higher returns and more stable yields, and that it generates higher farm returns at the household level than does conventional practices (Omnivore, 2023). Evidence to back these claims is mixed at best or absent in some contexts. For instance, Giller et al. (2015) report that CA does not always improve yield. Pittelkow et al. (2015) highlight that minimum tillage in itself results in a yield reduction of about 10%. Kirkegaard et al. (2014) argue that CA only increases yield under conditions of timely sowing, early crop establishment, and weed control rather than improving soil health. Rockstrom and Barron (2007) note that full yield benefits of CA are only realized when other nutrient deficiencies common in soils are adequately addressed. In the short run, it is noted that under normal to below rainfall, CA has the same yield as conventional practices (Giller et al., 2009). In addition, literature suggests that CA is more profitable among farmers who have adopted it for a long period of time (Thierfelder et al., 2012, 2015, 2017).

Tervest et al. (2019) argue that most CA assumptions at the smallholder level do not undergo rigorous evaluation or detailed testing. For instance, farmers do not till the land compared to convection tillage practices. As a result, the frequency of weeding on CA fields increases. CA results in labor burdens, especially when minimum tillage is practiced without herbicides (Grabowski and Kerr, 2014). Giller et al.

(2009) highlight that when herbicides are not available, hand weeding under CA is arduous. In the case of mulching, the literature suggests that farmers observe an increase in pests, therefore improving production costs through the acquisition of pesticides.

In some instances, with limited economies of scale, smallholder farmers obtain low returns (Rusinamhodzi et al., 2011). Kirkegaard et al. (2014**)** show that repeated reliance on specific herbicides such as glyphosates leads to the rapid evolution of herbicide-resistant weeds, suggesting that strategic tillage has more benefits in managing biotic stresses like weeds, pests, and diseases (Giller et al., 2015). Thierfelder et al. (2014) note that surface crop residues infected with gray spots result in acute infection of the next crop and further increase the production cost for farmers.

Given the complex decision-making environment that farmers face coupled with resource scarcity, there is a need to better understand the economic case for CA, especially at a farm level and among resource-poor farmers. This study contributes towards filling these gaps by assessing economic returns to CA and labor productivity under CA. Hence, we ask: are long-term economic outcomes between CA adopters and non-adopters statistically different. We specifically investigate and compare labor and farm returns among CA and non-CA adopters across various crops in Zambia and Malawi using large household data collected from a wide range of smallholder faring households.

2. Methodology

2.1 Farm Household Survey

We used farm household survey data collected in Malawi and Zambia (Figure 1) between August 13 and September 09, 2023. In both countries, the study employed a multi-stage stratified sampling strategy. In the first step, the study adopted purposive sampling of areas where the Ministries of Agriculture, Total Land-Care, other NGOs and CIMMYT promoted CA interventions for at least 10 years. In contrast, in control areas, no institutions actively promoted CA. In Zambia, these areas included Vuu and Hoya in Lundazi, Mtaya in Kasenengwa, Mtenguleni in Chipata, Manungu B and Malende in Monze, Chikalawa A and Chafulu in Sinda, as well as Chanje and Kapara Camps in Chipangali district. In Malawi, the study subjectively selected Linda Extension Planning Area (EPA) in Nkhotakota; Chinguluwe EPA in Salima; Chipeni in Dowa; Lemu, Phalula and Herbert in Balaka; Mtandika in Machinga; as well as Songani EPA in Zomba. Second, the study randomly sampled two agricultural sections or wards from each Camp or EPA; one section was from the treatment group, while the other section was from the control group.

Third, the study randomly sampled farmers from treatment and control areas within each section. About 200 and 300 farmers were sampled for treatment and control areas in Zambia, respectively. While in Malawi, 616 farmers were randomly chosen, with 256 and 360 farmers from treatment and control areas, respectively.

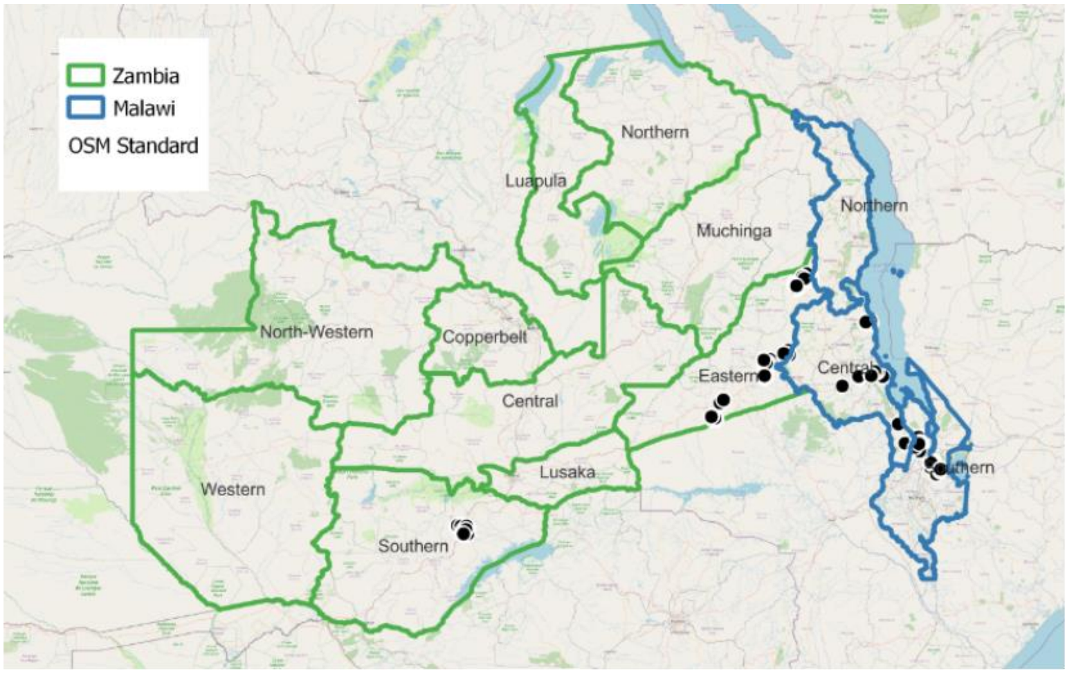

Figure 1: Map of the study sites in Malawi and Zambia

In addition, the study conducted focus group discussions (FGDs) to unearth factors explaining the labor productivity gains of CA adoption or non-adoption in the study sites. About 40 FGDs were done in the entire study, with half from each of Zambia and Malawi. The FGDs were disaggregated by gender, where half were for female farmers. Each FGD session lasted between 1 to 2 hours.

2.2 Theoretical and Estimation Strategy

Farmers are rational beings; hence, they only adopt a technology like CA if it presents higher returns in terms of land, labor, etc., or saves costs of production. As such, even if farmers have enough information through training, demonstrations, exchange visits, and practical self-experience, farmers either adopt, dis-adopt, or do not adopt a technology based on whether their expectations are met or not. Failure to meet farmers' expectations, especially regarding farm returns, is one of the major determinants of long-term adoption of a technology like CA. In addition, benefits or returns to CA are often observed after two or three years, while other farmers may realize the benefits of CA after five to ten years.

Hence, the first objective of this study is to assess whether CA improves farm returns or not. This was because CA is advertised to offer higher returns and more stable crop yield, thereby generating higher farm returns at the household level than does conventional practices (CP) farms (Omnivore, 2023). However, evidence on this at household or farm level remains mixed. Accordingly, we assess whether farmers who have adopted CA over a long period of time, such as ten years, have higher economic returns than those who have adopted it for less than ten years. To choose what test to use, we first run a normality test like kernel density and Shapiro Wilk (Wilcoxon and Wilcox, 1964), which suggests that the data is not normally distributed. Hence, we employ non-parametric-based approaches to examine the differences in economic returns between farmers in the treatment and control areas. Specifically, we adopt the Mann-Whitney U, sometimes called Wilcoxon rank-sum, and Krussi Wallis tests to identify the differences between the two groups. The Mann–Whitney U tests a null hypothesis that two independent samples of any variable are obtained from the same population; this includes all quantitative and nominal variables with values that can be ranked (Micheal and Edwardes, 2001).

In the second objective, we ask whether CA farmers have higher gross margins than CP farmers. The study estimates gross margins by first accounting for the total value of harvests obtained from a CA farm minus the total variable production costs. Because farmers cultivate several crops on the same land, the study sums physical products from all crops using a standard unit of measurement that converts the physical product into one currency, like the United States of America Dollars (US$). Total variable costs in the study included the following inputs: i) seeds, ii) inorganic fertilizers, iii) organic fertilizers, iv) herbicides, v) pesticides, vi) labor, and vii) transport from the farm to the storage place. Labor cost accounted for adult equivalents for labor supplied by female and male household members. It also included hired labor.

In our last objective, the study questions the agronomic argument that CA results into cost reduction. Hence, in this study, we estimate labor productivity between CA and non-CA farmers . Descriptively, the study tests the null hypothesis of no significant differences between the labor productivity between CA and non-CA farmers using Mann-Whitney U and Krussi Wallis tests.

In addition, the study attempts to isolate the effect of CA on labor productivity through a non-parametric regression analysis (Magar et al., 2022, Kumbhakar et al., 2015). Several parametric regression analyses have been applied to assess either farm or labor productivity. In this study, following Kumbhakar et al. (2015), we adopt a stochastic frontier framework of a Cobb-Douglas type to assess the effects of CA on farm or labor productivity as in equation 1.1.

$$lnlp^{ik} = \tau^0 + \tau^j \sum ln\, x^{ijk} + \gamma \hat{A}^i + \varepsilon^{ik} \qquad (1.1)$$

$lnlp^{ik}$ stands for natural log of labor or farm productivity for each farmer interviewed in this study. Scholars like Jayne et al. (2019) have used farm productivity or returns to measure output per unit of land. Similarly, this study defines labor productivity as output per personal day. As previously discussed, output is a sum of the total value of all crops cultivated from the same land. lnx^{ijk} is a vector of natural logs of other production inputs like land, inorganic fertilizer, labor, pesticides, and others. $\hat{A}^i$ denotes predicted values of CA adoption as estimated through the selection equation 1.2. Wooldridge (2010) defines $\widehat{CA}^i$ as generalized residuals or inverse mills ratios (IMR) predicted from an estimated regression of equation 1.2. τ^j and γ are unknown parameters that the study will estimate; γ is the most important unknown parameter in this study as it measures the effect of CA on labour productivity and the ε^i is the white noise. CA adoption is prone to self-selection as some farmers may have priori information incentivizing their participation in CA related interventions and these factors need to be known to the researcher. To address this, the study adopts a two-stage model to capture unobservable factors affecting farmers' adoption of CA using a selection regression, and, after that, isolate the effect of CA on labor productivity as in equation 1.1. We present a selection regression for the study as in equation 1.2, where A^i is as prior defined, where a farmer undertaking CA is assumed an adopter, otherwise, not; Z^{ij} stands for factors which may affect CA adoption such as farmers age, gender, education in years, CA training, and others; $\aleph^j$ is a vector of unknown parameters; and ϵ^i is the white note.

$$A^i = \aleph^0 + \sum \aleph^j Z^{ij} + \epsilon^i \qquad (1.2)$$

3. Results

3.1 Household characteristics

Conservation Agriculture (CA) adopting households in both Malawi and Zambia have higher household sizes than non-CA-adopting (also stated as Conventional Practice (CP)) households (Table 1). Zambian families have much larger household sizes, averaging 6 members across all groups than Malawian households, which had an average of 5 members. The average age of Malawian household heads is consistently high, with an average of 42 years for CA adopter and 38 years for non-CA adopter. In Zambia, an average of 40 years is observed among household heads' ages who adopted CA, compared to 35 years among non-CA adopters. CA adopters in both Zambia and Malawi have older household heads. Farmers in treatment areas of Zambia (US$ 22) pay double daily wage paid in Malawi (US$ 11). In the control areas of Zambia, farmers pay US$34, and in Malawi, they pay only US$ 16. Farmers in Zambia have more land than farmers in Malawi. For instance, in treatment areas, farmers reported to have 2.12 and 4.3 hectares in

Malawi and Zambia, respectively. In terms of labor days per season per hectare, households in Malawi allocate 39.40 and 65.40 total personal days in treatment and control areas, with households in the control areas using more personal days. The same labor days pattern is observed between treatment (29.84 days) and control (51.43 days) areas in Zambia, where control areas are also allocating more personal days per season per hectare in their farm. Both in Malawi and Zambia, the study notes that women dedicate more personal days per season per hectare. The labor descriptive statistics agree with the notion that CA reduces labor cost as farmers do not have to allocate more of their time in other farming activities like land preparation, weeding, and others, especially, when we consider herbicides application.

Zambia has a lower prevalence of female-headed households, with less than 21 percent in all groups, in contrast to Malawi, where female-headed households exceed 28 percent. In addition, a higher percentage of female-headed households is observed from among non-CA adopters in both countries. This suggests that male-headed households are likely to adopt CA than their female counterparts, which is also consistent with Nkhoma et al. (2017). Furthermore, Zambia exhibits a higher average education level of 7.9 years for both CA and non-CA adopters, compared to 7.1 years in Malawi. In both countries, the year of education is slightly higher among CA adopters than non-CA adopters. Household heads in Zambia has been living in the areas where they are now for 29 and 25 years in the treatment and control areas, respectively. In Malawi, household heads have lived in the treatment and control areas for 35 and 30 years, respectively. Zambia distinguishes itself through larger household sizes, and a younger population of household heads. Conversely, Malawi, on the other hand, has a higher proportion of female-headed households and a slightly higher number of years of education overall among non-CA adopters.

Table 1: Descriptive statistics of the socioeconomic variables between control and treatment areas in Malawi and Zambia.

	Malawi					Zambia				
	Treatment		Control			Treatment		Control		
Variable	Mean	SD	Mean	SD	Pvalue T-C	Mean	SD	Mean	SD	Pvalue T-C
Age_in_years_HHD (#)	42.23	13.92	38.73	14.87	0.00	40.00	12.85	35.78	14.04	0.00
Sex_HHD (Male=1)	71.00	0.45	62.00	0.49	0.01	83.00	0.38	79.00	0.41	0.35
Education_in_years_HHD (#)	7.31	3.17	6.95	3.56	0.20	8.27	3.82	7.57	3.96	0.05
Married_mogamous_HHD (Yes)	0.70	0.46	0.63	0.48	0.06	0.76	0.43	0.68	0.47	0.05
Married_polygamous_HHD (Yes)	0.05	0.21	0.04	0.20	0.76	0.04	0.21	0.10	0.30	0.02
Never_married_HHD (Yes)	0.00	0.06	0.01	0.09	0.50	0.00	0.07	0.02	0.13	0.24
Household_size (#)	5.43	2.34	5.25	2.28	0.33	6.97	2.75	6.56	2.96	0.12
Years_in_the_village (#)	35.28	17.92	30.44	17.84	0.00	29.61	15.42	25.23	14.57	0.00
Relatives_within the village (#)	4.43	4.51	3.55	3.71	0.01	3.23	4.05	3.14	3.63	0.78
Relatives_outside_the_village(#)	4.56	5.00	3.72	3.98	0.02	5.31	7.23	5.24	9.98	0.93
Non_relatives_within_the_village(#)	3.92	5.16	2.94	4.36	0.01	4.02	6.98	4.75	13.03	0.47
Non_relatives_outside_the_village(#)	0.51	0.50	0.50	0.50	0.78	0.51	0.50	0.48	0.50	0.41
Related_to_Member_of_Parliament (Yes)	0.05	0.23	0.07	0.26	0.38	0.03	0.18	0.03	0.17	0.75
Wage_per_day (US $)	10.69	12.07	11.87	15.86	0.53	22.45	31.50	20.53	34.12	0.61
Total_area_hectares (HA)	2.12	9.95	1.02	0.87	0.04	4.30	3.82	3.44	4.71	0.03
Area_cultivated_hectares (HA)	1.91	9.57	0.96	0.79	0.06	3.25	2.59	2.66	3.69	0.05
Total_personal_days_per HA (#)	39.40	39.34	65.40	41.65	0.00	29.84	25.71	51.43	34.81	0.00
Adult_male_personal_days_per_HA	17.91	21.64	28.01	26.69	0.00	14.78	14.83	24.39	19.97	0.00
Adult_female_personal_days_per_HA	21.48	22.88	37.39	25.40	0.00	15.06	13.95	27.03	21.77	0.00

Source: Survey data

3.2 Yield from Conservation Agriculture and Conventional Practices farms

Prior to diving into any analysis, the study run some basic normality diagnostic tests to check whether the data conform to production data needs or not as advocated by Kumbhakar et al. (2014). Figure 2 shows that the data distribution is line in with production data which is supposed to be negatively skewed. Hence, all the analysis in this study will be based on non-parametric statistical tests like the Kruss Wallis for the descriptive analysis and Stochastic Frontier Analysis for the regression.

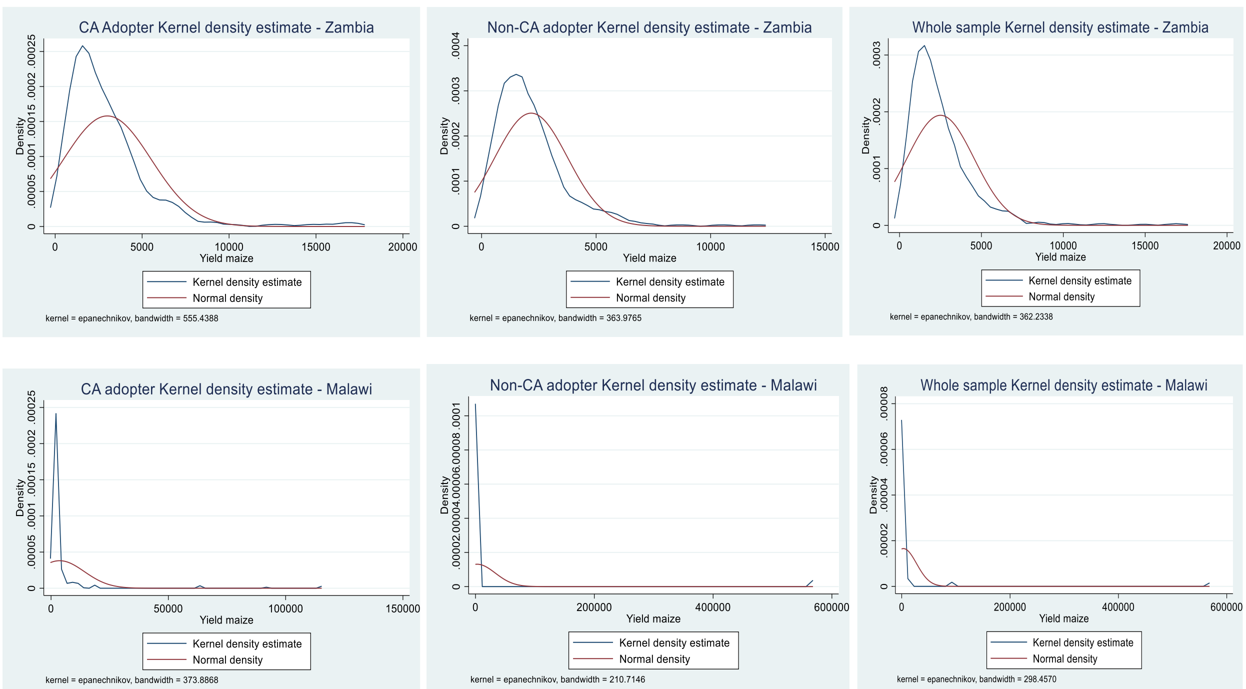

Figure 2. Testing for normality using Kernel density plots for land productivity

Source: survey data

The Figure 3 shows the mean yields (kg/ha) of three crops (soya beans, maize, and groundnuts) in Zambia and Malawi, under conservation agriculture (CA). The results suggest that CA treatment has the highest mean (>500 kg/ha) yield for all three crops in both Zambia and Malawi. For instance, in Malawi, farmers reported yield of 3.6 and 2.8 tons per hectare of maize in treatment and control areas, respectively. In Zambia, farmers reported maize yields of 3.0 and 2.2 tons per hectare in the treatment and control areas, respectively. Accordingly, Liu et al. (2019) highlight that the sustainability of CA depends on crop yield stability. In addition, soybeans have the second highest mean, averaging 0.7 tons per hectare in Zambia, and this may be attributed to the growing demand for their use in animal feed, human consumption, and biofuels. In Malawi, groundnuts have the second-highest mean yield, averaging 1.2 tons per hectare. This can be attributed to the high market value of groundnuts, coupled with their ability to thrive in regions characterized by low rainfall and poor soils prevalent in the region. Furthermore, groundnuts have the lowest mean yield, averaging 0.5 tons per hectare in all categories for Zambia, while Malawi has soya beans, averaging 0.7 tons per hectare. CA treatment has the highest mean yield for all three crops in both Zambia and Malawi. We find statistically significant differences in maize and groundnuts yields in Zambia and Malawi, respectively . Notably, CA control had lower yields suggesting that CA practices are essential for achieving high crop yields. However, the mean yield for Malawi is higher than Zambia due to several factors, such as differences in soil quality, climate, and agricultural practices (Jayne et al., 2019).

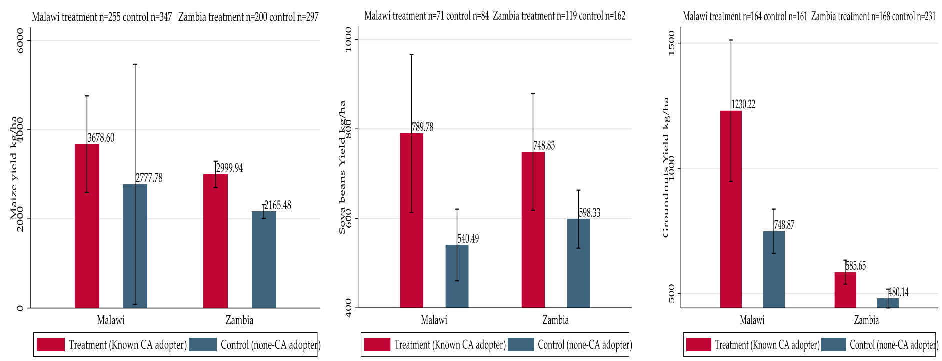

Figure 3 : Differences in maize, soya bean and groundnuts yield (kg/ ha) under Conservation Agriculture and Conventional Practices

Source: Survey data

3.3 Profitability Analysis of Conservation Agriculture

To provide insights into the profitability of CA, we compare farm-level gross margins for treatment households against those of control per hectare. Likewise, Mendiburu and Yaseen (2020) used economic analysis to compare the performance of CA against CP yield, while all calculations were based on a per hectare basis, and monetary values were expressed in a single currency, that is, USD. Figure 4 shows gross margins, total revenues, and total costs per hectare in US$ for Maize, Soya beans and groundnuts in Malawi and Zambia. Notably, the gross margins in both countries indicate significant differences between the treatment and the control.In this study, labor days were calculated by summing up labor days for all production-related activities based on 8 daily working hours per person, as purported by Magar et al. (2022). The descriptive statistics show that the treatment had higher mean gross margins than the control group in both countries. This could be due to improved soil health, reduced costs and improved yields associated with adopting and using CA, especially over a relatively long time. These results are consistent with what Magar et al (2022) found, where net returns across all crops in CA-based systems were higher than in CP-based systems. In addition, the results are in line with sentiments from FGD participants in Malawi and Zambia, highlighting the benefits of CA in improving soil health, moisture, and nutrients.

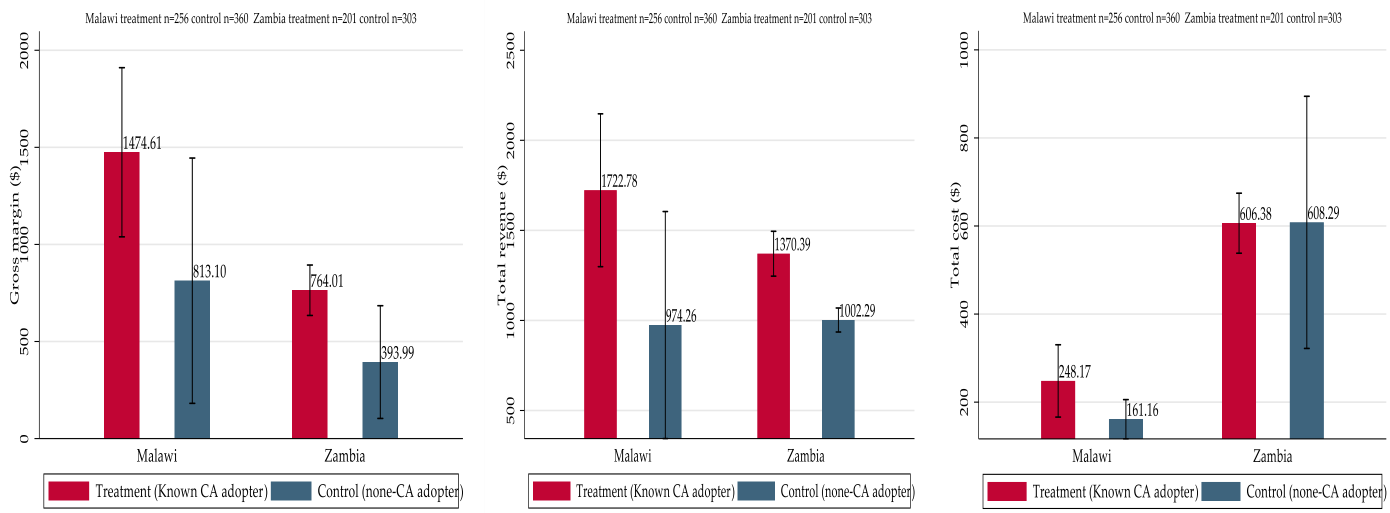

Figure 4 : Gross Margins, Total revenue, and Total cost at farm level in US$ or USD per hectare for Zambia and Malawi

Source: Survey data

Although farm-level analysis is best for mixed cropping where most inputs for production are shared across all crops at the plot level (Jayne et al., 2019), we examine gross margins individual crop level. We compare three top crops, namely, maize, groundnuts, and soybeans, for Malawi and Zambia to evaluate variability in gross margins at the crop level. Figure 5 shows that the gross margins for the treatment are consistently higher than the control across all the three crops: soya beans, groundnuts, and maize. This is confirmed from the MW p-values <0.05 for maize and groundnuts and a marginal result for soya beans. We find comparable results for Zambia. The treatment exhibits higher gross margins than the control for all the three crops: Maize, Soya beans, and Groundnuts. The MW tests p-value <0.05, once again confirm the statistically significant differences with all gross margins for the three crops, indicating robust statistical significance. These results show that adopting of CA, indicated by the treatment group, is associated with higher gross margins across agricultural crops in both Zambia and Malawi.

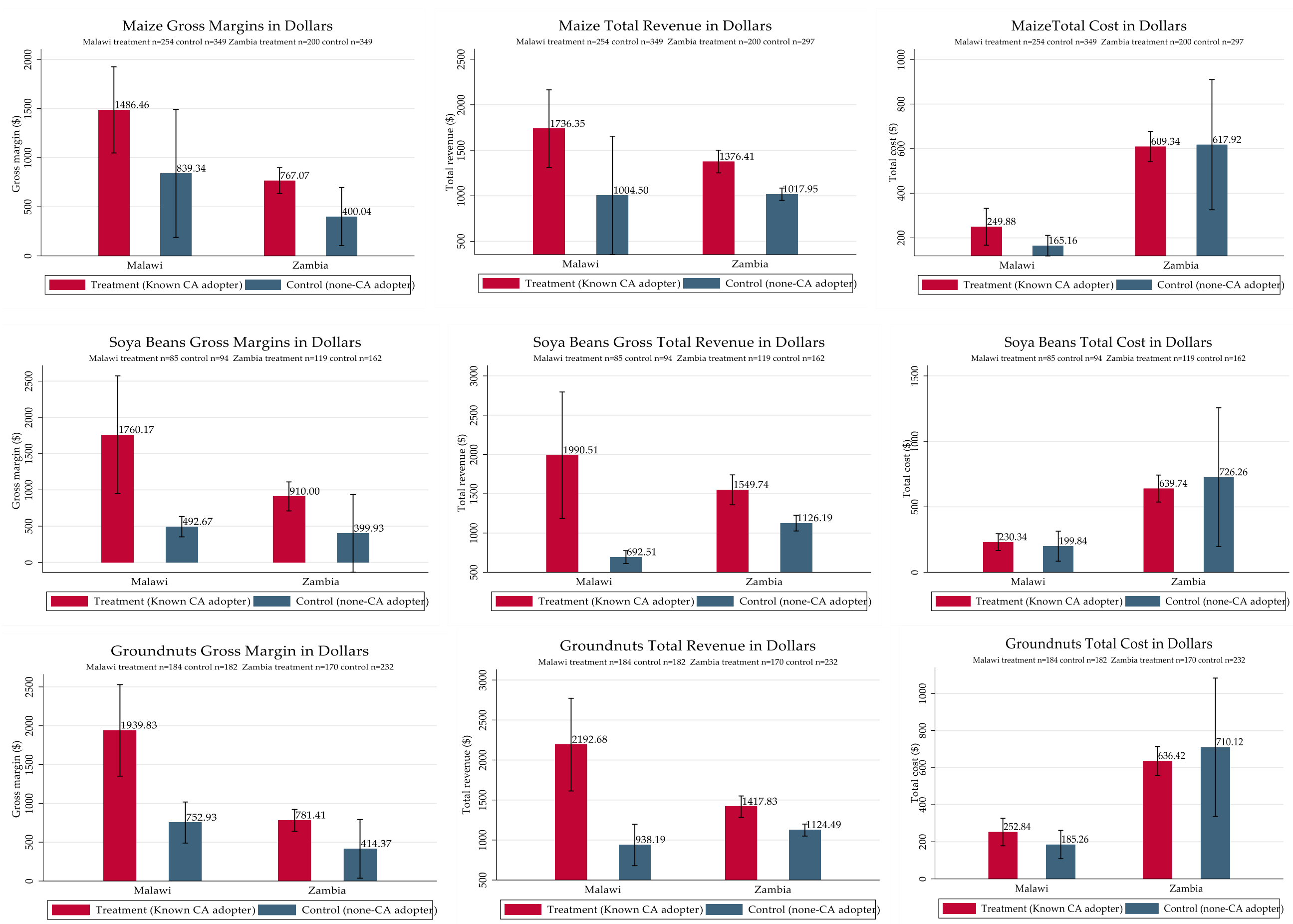

Figure 5:Gross Margins in USD per hectare for common crops in Zambia and Malawi

Source: Survey data

3.4 Labor productivity between in Zambia and Malawi

Figure 6 presents labour productivity between the treatment (CA adopters) group and compared to the control (non-adopters of CA). We define labor productivity as output per personal days per hectare. We determine the amount of total variable product to the unit of labor used. The results showed that both countries have a significantly higher labour productivity for the treatment group than the control group ($p < 0.05$). For instance, in Malawi, farmers in the treatment areas (154.42) have labor productivity that is 3.35 times higher than farmers in the control areas (46.13). Likewise, the study observed that farmers in treatment areas (388.72) of Zambia have labor productivity that is 3 times higher than farmers in the control areas (129.45). This means the adoption of CA by smallholder farmers has a positive impact on labor productivity for both Malawi and Zambia.

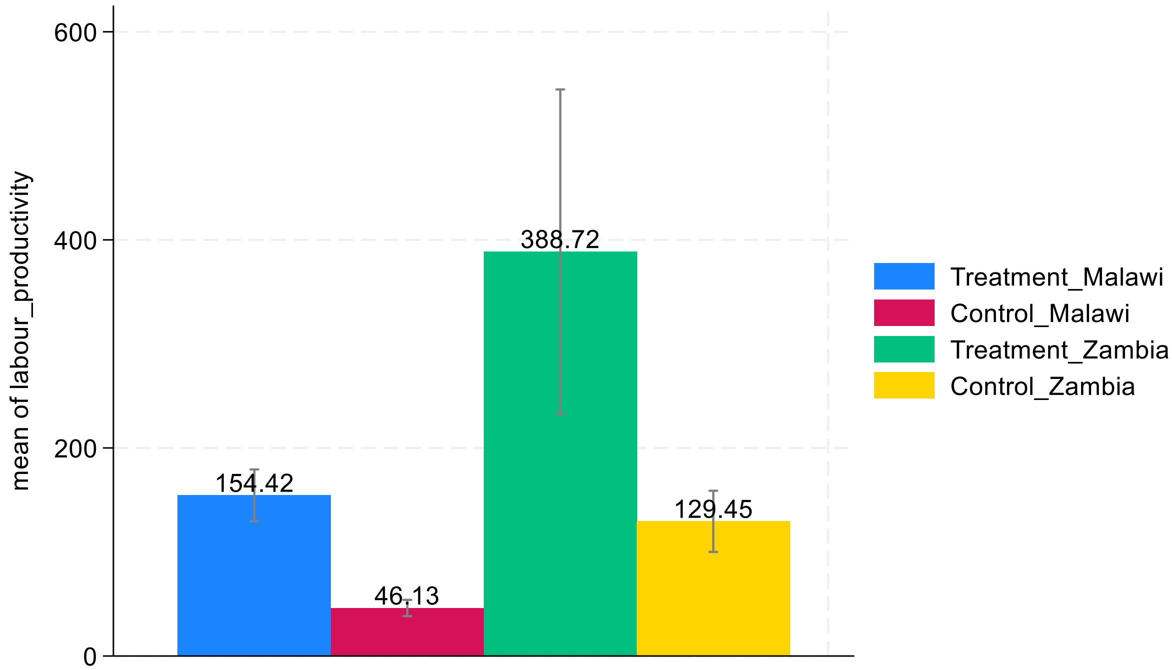

Figure 6: Labor productivity between treatment and control for maize soyabeans and groundnuts

Source: Survey Data

3.5 Regression analysis of labor productivity gains from adoption

Table 2 presents the estimated effects of CA, inorganic fertilizers, pesticides, herbicides, and land on labor productivity between treatment and control areas in Malawi and Zambia. We express labor productivity as yield per person days. The conservation agriculture (CA) coefficient is positive and significant (p=0.005), signifying a positive association between CA adoption and enhanced labor productivity, and with improved productivity in both Malawi and Zambia. Adoption of CA is associated with increased labor productivity by 3.72% and 2.76% in Malawi and Zambia, respectively (Table 2). Table 2 further shows the estimated effects of CA on farm productivity, where CA adoption enhances farm productivity by 13.90% and 8.80% in Malawi and Zambia, respectively. Similarly, we note positive effect of herbicides on labor productivity in Malawi and Zambia treatment areas by 52.7% and 60.0%, respectively.

Table 2: **Two-stage stochastic frontier analysis for the effect of CA on labor productivity**

Outcome_equation →	**Labor Productivity**		**Farm Productivity**	
	Malawi	**Zambia**	**Malawi**	**Zambia**
Conservation Agriculture (Yes)	3.533***	2.663***	13.86***	8.678***
	0.284	*0.285*	*0.383*	*0.916*
ln_land_in_HA	0.214**	0.287*		
	0.078	*0.138*		
ln_fertilizer_in_kg	0.137*	0.282***	0.0454	0.143
	0.057	*0.056*	*0.074*	*0.175*
ln_personal_days_per_HA			-0.347*	0.459
			0.175	*0.322*
ln_land_HA_square	-0.011	0.0143		
	0.031	0.065		
ln_personal_days_per_HA_sq			0.0457	-0.457***
			0.138	*0.116*
Apply_pesticides (Yes)	0.0121	0.127	0.0118	-0.251
	0.153	*0.119*	*0.177*	*0.132*
apply_herbicides (Yes)	0.530***	0.662***	0.176	-0.117
	0.140	*0.114*	*0.150*	*0.134*
Usigma (cons)	-1.897*	-24.27***	-26.62***	-30.14***
	0.905	*1.288*	*0.307*	*0.475*
Vsigman(cons)	0.454***	0.0299	0.683***	0.249*
	0.059	*0.081*	*0.096*	*0.119*

Selection_equation: Dependent_variable: CA_Adoption	**Coefficient**	**SE**
Cultivated_area_in_HA	0.00422	*0.0358*
Total_personal_days_per_HA	-0.00736*	*0.0041*
Top_dressing_kg	-0.000146	*0.000235*
Basal_dressing_in_kg	-0.000297	*0.000761*
Seed_rate_in_kg	0.00243	*0.00179*
Years_living_in_the_village	0.0311*	*0.0123*

Age_HHD	0.00787	*0.014*
Gender_HHD	0.0415	*0.406*
Education_HHD	0.0817*	*0.0487*
Constant	1.713	*0.884*

Note: Italicized values are standard errors; underlined values are estimated coefficients; ***, **, and * significant at 1%, 5%, and 10%. Source: Survey data

3.6 Insights from focus group discussions

Farmers in FGDs reviewed several reasons for adoption and non-adoption of CA. On CA benefits as reasons for adoption, farmers reported that CA plots had high yields compared to conventional (CP) plots. They also added that other CA benefits include prevention of soil erosion, improving soil drainage and water-holding capacity, retaining soil moisture even during dry spells, and enhancing soil fertility. In Southern Zambia, specifically in Malende camp, farmers reported that the use of rippers has led to an increase in optimal seed rates which in turn, has resulted in higher crop yields under CA compared to conventional farming. In Malawi, Machinga-Matandika section, one FGD participant said: "*After having poor soils on my farm, I started CA in 2014; since then, soil fertility on my farm has been restored and I have been harvesting more produce than when I used to cultivate under CP; because of this, I can never stop practicing CA*". In Balaka-Lijirima section FGD, male farmers explained: "*CA improves soil texture compared to CP farms. Residues are effective as they add manure to the soil, and when farmers adopt all CA practices on the same farm, the soils become virgin again, which is more fertile. When farmers plant crops, crops do very well*". In Eastern Zambia, Youth FGD participants from the Mtenguleni camp shed more light on the advantages of CA, where they said that intercropping improves soil fertility through nitrogen fixation.

In Nkhotakota Mwala wa Tongole Section, one female farmer explained that: *"I heard from a local agricultural extension farmer who visited my place, through informal conversation, he talked about how less expensive zero tillage is and how the use of herbicides helps to control weeds, which reduce labor requirements under zero tillage"*. In Balaka, Kanyumbaaka section, male farmers reported that they started CA farming because they were motivated by fellow farmers in the area*; "our fellow farmers practicing CA got more harvest from the same piece of land"*. Besides, one farmer in Balaka, Kanyumbaaka section narrated*: "Since 1990s, I was using regular CP, I envied what my fellow farmers were harvesting from intercropping that's when I decided to attend training that was offered by CIMMYT in 2013. After the training, I asked lead farmers in the area to visit my field to advise and recommend what methods I could use in my field. Initially, I harvested very low yield from CA field. However, after undertaking CA, I can now produce more yield and intercrop several crops on the same field"*. Same remarks were also made in the Balaka-Lemu section FGD where a female farmers narrated*: "people practicing CA seemed to be yielding more than us practicing CP; this motivated me to start practicing CA on my farm".*

In Machinga, Matandika, section FGD, female farmers explained*: "Lack of farm inputs like fertilizers forces people to practice rotation. They divide the parcel to 2 plots and plant crops that requires fertilizer to do well in one plot and legumes in the other plot; the following year they swap the crops on the plots".* In Zomba, Songani section FGD, one woman explained that we lack enough land for cultivating different crops; hence, intercropping has become a convenient CA practice for our needs. However, in the Balaka-Lemu section FGD, one farmer reported: "*one local organization, PROSPER, trained fellow farmers on mulching and after the training, farmers were given start-up seeds, fertilizers, and Mk 24,000 cash for pesticides. However, after the project, most fellow farmers stopped mulching on their farms*". CA practices have generally been shown to improve soil health, water infiltration, and water retention, leading to increased crop yields in Southern Africa.

In terms of non-adoption or dis-adoption, it was noted CA requires more labor among first-time adopters to deal with weed pressure, especially when practicing minimum tillage. In addition, farmers noted that they could not adopt CA in low laying areas as it promotes water logging. For instance, in Balaka-Kanyumbaaka FGD, male farmers explained: "*There is water logging in low-lying farms when using planting basins; in the past, most of us used planting basin in such farms, but we later stopped due to water logging because of heavy rains*". Farmers in the Eastern and Southern provinces of Zambia cited several challenges to CA adoption, like labor intensiveness while weeding in fields with zero-tillage, lack of necessary pro-CA machinery, and lack of knowledge. In Malawi, farmers also highlighted the shortage of pesticides or herbicides as another factor that acts as a barrier to CAadoption among early adopters, especially when practicing zero tillage or mulching.

Picture1. One of the CA farmers in Mthipo village, TA Nkula, Matandika Section, Machinga District in Malawi, in his field covered by mulch

Furthermore, due to limited or unavailability of inputs, farmers are advised to practice CA components on a small piece of land, which makes it harder for farmers to later practice CA on larger pieces of land. For intercropped farms, farmers complained of competition among crops for sunlight. For instance, in Balaka FGDs, farmers stated that in 2016/2017 season, some farmers stopped practicing CA because when they intercropped maize and pigeon peas, pigeon peas overgrew maize, providing shedding to maize that needed sunlight for its growth. Small land holding is another bottleneck to farmers adopting crop rotation. In Machinga-Matandika FGD, male farmers reported: "*the majority of farmers have 1 acre and use only 0.5 acres for cultivation so they are forced just to cultivate maize or engage in intercropping of maize-legume for subsistence or consumption only*".

3.7 Discussion

The findings from this study have important implications for labour and farm returns in CA production systems in Zambia and Malawi. Our study findings show that CA is associated with significantly higher labor and farm productivity of maize, groundnuts and soybeans. The higher gross margins for CA fields than non-CA fields suggest that CA could be economically viable; for instance, in Malawi, gross margins were higher in CA areas, with values of US$ 1474.6 per ha compared to US$ 813.1 per ha in the control areas. We observe the same pattern in Zambia, where farmers' gross margins in the treatment areas were higher at US$ 764 per ha compared to US$ 394 per ha in the control areas. These findings are consistent with findings from Ngwira et al., (2013), who reported 3 to 33 times higher gross margins for conservation agriculture farmers than conventional farmers. These results are in line with Nyirenda et al., (2021) who found 11 to 21 times higher gross margins for CA farmers compared to CP farmers.

In addition, we found that CA adoption improved labor productivity by 3.72% and 2.75 % in Malawi and Zambia, respectively. This improvement was measured by yield per person-day, indicating a more efficient allocation of personal days to CA farms at the household level. This is in line with Magar et al. (2022), who found higher labor productivity and a significant reduction in production cost by 245−369 USD per ha and increased net gain of 188−223 USD per ha in CA-based systems. Chakraborty et al. (2017), Erenstein (2009), and Thind et al. (2019) also found similar patterns where CA-based systems had higher returns than CP-based systems. We also found positive productivity effects, with farmers adopting CA obtaining 13.90% and 8.80% more yield in Malawi and Zambia, respectively. This is in line with Derpsch et al., (2011) who found that CA increased yields by 22% on average compared to conventional tillage (CT). Our results are supported by literature. In addition, these findings are in line with Thierfelder and Wall (2000) who found that CA increased maize yields by 72% in a low-yielding environment in Zimbabwe. Similarly, Mupangwa et al. (2007) found that CA increased maize yields by 38% and wheat yields by 20% in Zimbabwe. In Mozambique, Mapfumo et al. (2014) found that adopting CA increased yields by 16% and soybean yields by 6%. Furthermore, Chikowo et al. (2012) noted that CA increased maize yields by 23% and soybean yields by 22% in Malawi. When considered collectively, the foregoing evidence suggests that when effectively managed, CA can significantly contribute to increased crop yields and gross margins across different crops.

Although some literature (Giller et al., 2015) contend that CA fields are associated with high levels of costs for pests and diseases, our findings imply that CA has more benefits that outweigh the costs. This was confirmed by farmers in Balaka Lemu section who argued that CA practices like crop rotation reduce the costs of pests and diseases by minimizing pest transmission. For example, pests or diseases that attack maize cannot attack legumes. This makes rotation beneficial. In the Zomba-Songani section FGD, female farmers explained that less labor is required when using mulch because of the ground cover that suppresses weed growth. This allows farmers more time to engage in other equally productive or socially fulfilling activities. Moreover, youth farmers in Mtenguleni camp added that CA allows them to prepare land early and plant crops as soon as rains commence. Farmers in Nkhotakota, Mwala wa Tongole section FGD, reported that intercropping allows farmers to produce diverse types of crops on a small piece of land. One farmer in the same FGD explained, *"I received less than 5 kg of pigeon peas from government affordable input program (AIP); after planting, I harvested 5 kg of pigeon peas through intercropping"*.

A complex interplay of factors influences the effects of CA on crop yield in Southern Africa. While CA can lead to significant yield improvements and resilience to rainfall variability, its effectiveness is site-specific. It depends on soil type, rainfall patterns, and agronomic practices (Devkota et al., 2022; Nouri et al., 2021). Continued extension efforts are needed to promote the adoption of CA among smallholder farmers in Southern Africa and maximize its potential benefits for sustainable agricultural production (Rudel et al., 2016). More research is needed to understand the specific conditions under which CA is most effective.

Notwithstanding, the study noted several challenges that hinder CA adoption. For instance, in the study area, farmers indicated that minimum tillage practices did not adequately support proper growth of large maize stalks, resulting in lower yields. The tropical climate, characterized by high temperatures, also pose a challenge and reduces the efficacy of herbicides if sprayed at wrong times. In addition, farmers reported that more farms or fields are situated in steep areas, contributing to challenges in implementing certain CA practices, such as pit planting, which can exacerbate run-offs and soil erosion. In line with the literature (Giller et al., 2015; Erenstein, 2003), farmers noted that continued spraying of herbicides or pesticides on the same farms leads to resistance. Farmers cited termites as damaging to the crop roots in farms where pesticides are not applied, further discouraging farmers from sustained adopting CA.

4. Conclusion

Sub-Sahara Africa is grappling with degraded soils, the effects of climate change, low crop productivity and rising demand for food. This heightens the need for climate-proof production methods that can also help restore soil. Conservation Agriculture (CA) has been touted and promoted as one such potential option that can increase crop productivity, resilience, climate adaptation while delivering economic co-benefits of improved labor productivity and profitability. However, its uptake remains slower than anticipated. This paper asks: does CA work as advertised? We focused only on economic outcomes and assessed labor productivity and farm returns associated with CA using household survey data collected from 500 and 616 farmers in Zambia and Malawi, respectively. Half of the sample was drawn from areas known to have had intense CA promotion for at least 10 years before 2023, herein called treatment areas. The other half came from control areas where there is no known institutional CA promotion. Descriptive statistics shows that households in the control (non-CA) areas significantly employed more personal days per season per hectare, i.e., 26 days in Malawi and 21.59 days in Zambia, than in the treatment areas, suggesting that CA saves farmers time which can be allocated to other productive activities.

Based on the two-stage non-parametric stochastic frontier analysis, we found that CA is associated with higher labor and farm productivity in Malawi and Zambia. Specifically, in Malawi, CA is associated with a 3.72 % increase in labor productivity and a substantial increase of 13.90 % in farm productivity. Similarly, in Zambia, adoption of CA is associated with a 2.76 % boost in labor productivity and a 8.80 % enhancement in overall farm productivity. Regarding gross margins, the study found that the treatment areas had higher gross margins. For example, in Malawi, have the gross margins in treatment areas averaged US$ 1474.6 per ha compared to US$ 813 per ha in the control areas. In Zambia, treatment had higher gross margins of US$ 764 per ha compared to control areas at US$ 394 per ha, signifying the economic benefits of CA. The positive economic benefits in this paper lead us to conclude that for the study context, CA works as advertised. Albeit based on cross sectional data, these findings render credence to continued support for CA promotion but more multi-location and multi-year research building on panel surveys is required to further assess the socioeconomic benefits of CA. More work remains on understanding appropriate policy and economic incentives that can be used to spur adoption and how to effectively strengthen extension systems to better support CA promotion and scaling.

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