

*Full Length Research Paper*

# **Redefining conservation agriculture through appropriate use of herbicides and fertilisers to improve crop production in Mozambique**

**Inacio M. Cipriano<sup>1,2\*</sup>, Didy O. Onautsu<sup>2</sup>, Titki D. Tarassoum<sup>1</sup>, Idris I. Adejumobi<sup>2,3</sup> and Bily A. Bolakonga<sup>4</sup>**

<sup>1</sup>Department of Agrarian Sciences, ESUDER, University of Eduardo Mondlane, Mozambique.

<sup>2</sup>Department of Biotechnology, University of Kisangani, Republic Democratic of Congo.

<sup>3</sup>International Institute of Tropical Agriculture (IITA), Nigeria.

<sup>4</sup>Department of agricultural economics, Yangambi Institute of Agronomic Sciences, Republic Democratic of Congo.

Received 9 December, 2021; Accepted 31 January, 2022

The effects and applicability of conservation agriculture in different farming contexts are highly contested. Yet, there has been limited attempt to adapt the conservation agriculture system to the conditions of resource-poor farmers, focusing primarily on the existing farmers' capacity and objective to practice conservation agriculture. The study assessed the factors that influence adoption and dis-adoption of conservation agriculture as well as the impact and identified prospective components for successfully implementing it in rain-fed agriculture in Angonia (Mozambique). A structured questionnaire was randomly administered to 192 conservation agriculture farmers to collect data through a multistage sampling process. The study employed descriptive statistics, multinomial logistic regression to examine possible causal relationships among variables and literature review. The result shows that farmers are motivated to use conservation agriculture because of the increased yield, soil fertility and improved soil moisture. Lack of herbicides and reduced tillage equipment are two major challenges to implementing conservation agriculture. Regression analysis reveals that farmers would likely use minimum soil disturbance over other approaches. The study then proposes the appropriate use of herbicides to address the weed control issue; the use of fertilisers to generate immediate outcomes and enough vegetative cover; and the design of locally available and affordable reduced tillage equipment to accommodate resource-poor farmers. The government and stakeholders should work together to address market imperfections, including the establishment of agricultural input facilities. The study identifies the contextualised conditions required for designing and implementing conservation agriculture in pro-poor farming systems.

**Key words:** Adoption, factors, constraints, yield impact, herbicides, fertilisers.

## **INTRODUCTION**

Conservation agriculture (CA) has been promoted by governments and international organisations as a farming

\*Corresponding author. E-mail: [cipriano12cipriano@gmail.com](mailto:cipriano12cipriano@gmail.com). Tel: +258826905168.

method to resolve the problems that affect the world, including poor soil outcomes and profitability, soil erosion, climate change mitigation and food insecurity while safeguarding the environment to secure long-term crop productivity (Bouwman et al., 2021). In developing countries, CA has mainly been donor-driven because of a lack of policy and resources for implementation. Common principles that define CA have been namely no or reduced tillage, soil cover with crop residues and use of crop rotation or association (Bouwman et al., 2021; Vanlauwe et al., 2014). An overview of the literature on CA identifies the Americas and Australia as good examples of successful implementation of CA (Bouwman et al., 2021; Ndah et al., 2018). Farmers have embraced CA because it meets their needs, especially in productivity, profitability and enhanced environmental outcomes (Anghinoni et al., 2021). For this reason, CA is claimed to increase yields, reduce labour requirements and improve soil fertility. In some parts of Africa, results showed an increase in yield in Zambia (Ngoma et al., 2021), Malawi (Bouwman et al., 2021), and Tanzania (Kimaro et al., 2016). However, increased yield has not been unequivocally confirmed throughout sub-Saharan Africa (SSA).

Scholars have questioned the effects and applicability of CA to small and resource-poor farmers, particularly in sub-Saharan Africa (Bourne et al., 2021). Scheba (2017) has observed decreased yields and increased labour requirements. In addition, comprehensive meta-analyses of paired observations from studies revealed that no-till results in a yield penalty of around 10% overall (Giller et al., 2015; Ng'ombe et al., 2020; Pittelkow et al., 2015). Further, despite that CA is claimed to mitigate climate change by stimulating carbon (C) sequestration in the soil, the studies of Pittelkow et al. (2015) and Powlson et al. (2016) argue that it is erroneous and inconsistent to estimate increased soil carbon stock attributed to CA. The studies showed that CA accumulated soil carbon at the surface because of a lack of soil mixing. The studies also showed that experiments did not show an increase in soil organic carbon stocks except in locations where increased biomass production and crop residue retention existed in Brazil. Moreover, it was observed that the increased organic carbon stock was not significant (Pittelkow et al., 2015; Powlson et al., 2016). It once more seems that the impact of CA on the increased carbon stocks is contested. CA is also claimed to help manage pest and diseases through the crop rotation. It breaks pest and diseases cycle of crops, enhances soil fertility and fixes biological nitrogen (Mutyasira et al., 2018). However, legumes that are mainly used in crop rotation present a less attractive economic benefit. Therefore, farmers only intercrop one small site of their field, and these crops are mostly for domestic use. Alternatively, legumes do not compensate for the labour that is used because the crops face market challenges, especially in a context where the market structures are

imperfect. The available results of the outcomes of CA remain inconsistent. To gain further insight, more evidence evaluating the impacts of CA is needed in different contexts in SSA.

In SSA, smallholder farmers first get poor yields because they do not use agro-inputs. Labour is also a problem as they use hand hoes for cultivation (Pittelkow et al., 2015; Vanlauwe et al., 2014). Meanwhile, this environment differs from the places where CA originally emerged. Vanlauwe et al. (2014) and Pittelkow et al. (2015) have observed that CA has been driven and emerged not only from enabling environments such as the availability of fertiliser and herbicides but also from a well-organised market structure. Fertilisers combined with minimum soil disturbance allowed farmers to produce enough biomass to cover the soil more than 30% and the yield were high with guaranteed markets to consume (Vanlauwe et al., 2014). Second, manure is not available and affordable for everyone because not all farmers possess livestock to generate it. To aggravate the situation, green fertilisers have prohibitive prices for resource-poor farmers. Third, competition of crop residues between livestock and other users is common in the region of SSA (Bourne et al., 2021). Fourth, CA usually takes time for full benefit realisation (Brown et al., 2018; Montt and Luu, 2020). Like an entrepreneur, farmers look for immediate profit maximisation in their farming enterprise. CA, on the other hand, cannot offer immediate results. This may not favour smallholder farmers who, from time to time, depend on the outcome of their activities to survive. Experiments with alley cropping systems, integrated herbaceous legumes and improved legume tree fallows were introduced sometimes back in SSA. With farmers, the results were disappointing because of the lack of immediate benefits and management beyond the farmers' labour (Vanlauwe et al., 2014). Despite the concerns of CA for smallholder farmers in SSA, conservation agriculture can still generate the optimal benefits if proper management is put in place. A better approach is to start adapting CA to farmers' conditions transitionally.

In Mozambique, experiments with CA have proven to work in different agro-ecological zones but use standardised approaches to evaluate. However, the socio-economic impact evaluations remain inconsistent, indicating the lack of contextualised approaches specifically focusing on the existing farmers' capacity and objective to practice CA. The proponents of CA proposed three key principles to develop sustainable agriculture. The concern of working technology, which does not function in some contexts, perhaps call the agriculture innovators to take different steps and approaches to adapt the CA system to farmers' conditions, needs, capacity and regions. The study was conducted in the Angonia district (Mozambique) to assess (1) factors influencing CA adoption and dis-adoption, (2) the yield effect of CA and (3) redefine CA in the rain-fed

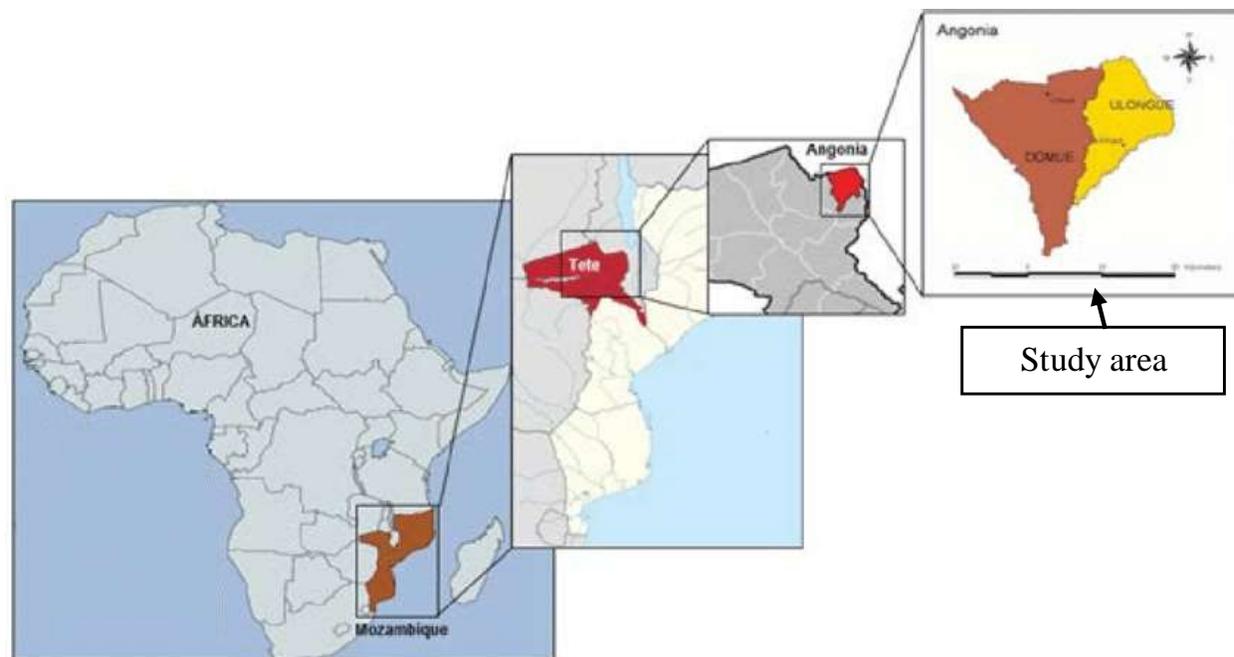


Figure 1. Map showing the location of Angonia district in Tete province, Mozambique.

Table 1. Sample size and study locations in Angonia, Mozambique.

Angonia (Mozambique) village	Frequency
Dziwanga 30 km	32
Gua 7 km	17
Makwanguala 25 km	65
Silawila 45 km	17
Zioa 37 km	61
Total	192

agriculture zones of Angonia (Mozambique).

## METHODOLOGY

### Study area description

The data for this study derived from a recent farm household survey conducted in the Angonia district of Mozambique between December 2020 and January 2021, as shown in Figure 1. Angonia (latitude 14° 43' 1.2" S, longitude 34° 22' 1.20" East) is a district located in the northern part of Tete province in the central region of Mozambique. The district's administrative posts are Ulongue and Domue with relatively high total annual rainfall (900-1,200 mm) in the rain season and it rains from late November to early April, with the rest of the year being dry. The climate is cold in the winter and warm in the summer (Ministério da Agricultura, 2016).

### Sample size and sampling procedures

A multistage sampling procedure was conducted to arrive at the

final respondent for the study. First, geographic regions were selected based on the ease of access to farmers and clusters were randomly chosen. Second, groups of associations in the targeted regions were selected according to the kinds of crops farmers grow in their fields. The groups were also randomly selected. Third, the selection was done during the administration of a close-ended questionnaire using simple random sampling (Ntshangase et al., 2018). This process ensured representation of the sample, making it unbiased and reliable (Ntshangase et al., 2018). In this regard, a total sample size of 192 smallholder farmers' households was surveyed across different localities around Angonia (Table 1).

### Data collection

The study took a quantitative approach, based on a set of structured questionnaire survey with face-to-face close ended interviews and on-farm observations to validate what was reported during the interviews. The questionnaire investigated the three principles of CA technology, field management before and after harvesting, benefits and challenges of CA, crop system, reduced tillage equipment, soil quality experience and crop yield

**Table 2.** Nature of variables used in analysis.

Dependent variable	Variables description	Description/Unity
Minimum soil disturbance	Categorical	0=does not use; 1=use
Soil cover	Categorical	0=does not use; 1=use
Crop rotation	Categorical	0=does not use; 1=use
<b>Predictor variable</b>		
Farming experience	Continuous	Years
Assistance period	Categorical	0=no assistance;1=twice a month; 2=once a month;3=trimestral; 4=irregular
Gain knowledge	Categorical	0=no; 1=yes
Cost saving	Categorical	0=no; 1= yes
Labour requirement	Categorical	0=no; 1= yes
Equipment cost	Categorical	0=no; 1=yes
Lack credit	Categorical	0=no; 1=yes
Lack information	Categorical	0=no; 1=yes
Input cost	Categorical	0=no; 1=yes

assessment in the period of the 2019/2020 season. On-farm observations included an evaluation of management practices related to planting systems, land preparation, weed control and the use of reduced tillage and its associated equipment. The study also collected data on field size for both CA and non-CA systems in order to assess crop yield. This was done to compare crop yields from CA and conventional system.

#### Data source

The data for the current study came from smallholder farmers and on-farm observations. Conservation agriculture is being promoted by public and private extension services in response to Ministry of Agriculture guidance to produce cereals and legumes with smallholder farmers. Farmers have been grouped into associations since the introduction of CA, where they receive training and other necessary inputs for field demonstration management only.

#### Data analysis

The data collected were coded and entered into the Statistical Package for Social Science (SPSS 20) and Excel for statistical analysis in order to generate descriptive and inferential statistics. Specifically, the study used the test of Tukey HSD all pairwise to compare all crop groups and the test of Welch to determine whether there were significant differences between the groups in the crop yields. This enabled the examination of possible relationships between variables and the computation of statistical tests of significance at level of 0.05.

A Multinomial logistic regression model (MLRM) was employed to identify predictor variables associated with the adoption of CA: minimum soil disturbance, soil cover and crop rotation (Table 2). The MLRM then generated coefficients (its standard errors and significance levels), which were used to predict a logit transformation of the probability of the adoption of CA. Using the variables in Table 2, a linear model was first run to check the multicollinearity and fitness of the model. The fitness of the model was determined using the chi-square of Pearson and Deviance that the SPSS package generates after the command. The model was

then tested with a  $p$  value of 0.399 Pearson and a Deviance of 0.745 for constraints of CA adoption and a Pearson of 0.245 and a Deviance of 0.606 for positive factors of CA adoption, indicating that the model fitted the data well. Equation 1 also represents the model and shows how the predictors were computed in the model.

$$p_{mi} = \left( \frac{e^{(Z_{mi})}}{\sum_{m=0}^{M-1} e^{(Z_{mi})}} \right); m = 0 \dots M - 1 \quad (1)$$

where  $i$ =each case of a sample size  $n$ ;  $M$ = total quantity of categories of the polytomous dependent variable;  $m$ = number of categories coded from 0 to  $M-1$ ;  $Y_i$ = polytomous dependent variable ( $Y_i = 0; 1; 2; \dots$ );  $Z_{0i}$ = logit of category 0 (reference category);  $Z_{mi}$ = Logit;  $p_{mi}$ = probability of occurrence of uptake of CA;  $B_0$ = constant of the equation;  $B_{mk}$ = regression coefficients;  $X_{ik}$ = independent variable  $k$  (Predictor  $k$ ) metric or dichotomous.

## RESULTS AND DISCUSSION

### Factors influencing conservation agriculture adoption in Angonia, Mozambique

Small-scale farmers engage in farming for immediate economic gain, namely to secure food for their families (Montt and Luu, 2020). Farmers were asked to explain why they use the CA system. Increased crop yield (21%), soil fertility (21%) and improved soil moisture (17%) are the main reasons why farmers use CA in Angonia, shown in Table 3. In regard to soil fertility, farmers specifically reported some positive and differences associated with the changes in soil texture experienced on their farms. Similar studies have found that when CA is properly practiced, including agronomic practice management, it leads to increased income reliability and food security as a result of soil improvement (Ngoma et al., 2021). However, Ndah et al. (2018) observed that the available

**Table 3.** Factors influencing CA adoption in Angonia, Mozambique.

Parameter	Percent (n=192)
Increased crop yield	21
Soil fertility	21
Improved soil moisture	17
Enhanced tech. skills	14
Reduced soil erosion	14
Increased livelihood	8
Less biotic stress	5
Total	100

evidence of CA leading to higher returns was limited to small groups of adopters in South Africa, Ghana and Zambia. This suggests that yield increases are not universal. Nonetheless, a lack of evidence can also be attributed to a failure to assess the outcomes of technology in various parts of SSA. The current study adds to the ongoing CA evaluation in SSA by improving understanding of the CA's issues and status today.

In Angonia, the study observed that farmers generally practice rain-fed agriculture. During the dry season (May-November), farmers sometimes exploit small portions of valley bottoms under an irrigation system. With this system, farmers primarily use soil cover for horticulture and cereals, but only in small quantities. Farmers reported having experienced immediate benefits in relation to improved soil moisture (17%) (Table 3). They also reported that soil cover reduced their weekly irrigation frequency. Additionally, farmers described the situation as freeing them up time for other business activities. This entails that the situation reduces the pressure to use water, and it is now being shared by many farmers. Previous studies have also found that soil cover conserves water and leads to the adoption of CA (Giller et al., 2015) and improved agronomic uses (Mango et al., 2017). This further indicates that water is being used efficiently as the soil is shielded from evaporation resulting from the soil cover. The study implies that farmers use the system, insofar as it provides them with tangible and immediate benefits.

A regression analysis was performed to evaluate the causal relationship between variables. The model of regression compared each category group against the reference category (minimum soil disturbance). The first and second subsets of coefficients in Table 4, "farming experience" (1 to 5 years), was found to be a negative significant predictor for soil cover ( $b=-2.17$  SE=1.123,  $p=0.048$ ) and crop rotation ( $b=-2.901$ , SE=1.117,  $p=0.009$ ) in the model. The result indicates that farmers with farming experience ranging from 1 to 5 years of CA system were less likely to use soil cover and crop rotation principles, but would more likely use minimum soil disturbance. The odds ratios of 0.109 and 0.055 suggest that for every unit of farming experience in the CA

system, the odds of farmers using the soil cover and crop rotation principles would change by a factor of 0.109 and 0.055, respectively. This implies that the more farmers have experience of at least 1 to 5 years of CA, the longer the time to use soil cover and crop rotation principles over the minimum soil disturbance alone will decrease by a factor of 0.109 and 0.055 times. The third set of coefficients, "cost saving" was found to be a negative significant predictor for all three CA principles ( $b=-2.134$ , SE=0.691,  $p=0.002$ ) in the model. The result shows that most farmers who use the CA system are less likely to follow the three CA principles, but would more likely practice minimum soil disturbance alone. The odds ratio of 0.118 suggests the degree of decrease that may happen with farmers that use all three principles at the same time over minimum soil disturbance alone.

The regression analysis reveals that the causal relationship is entirely negative in connection to all statistically significant predictors of the supplied variables, pointing to the practice of minimum soil disturbance in general. Although the findings support the use of this technology, policymakers must be aware of some limitations on the minimum soil disturbance that may affect smallholder farmers in particular. These include a lack of suitable seeders, the availability of herbicides for weed control, the slash and burn tradition, and the availability of skilled, scientific, and manpower to promote the technology. Without the proper reduced tillage equipment and relying solely on hand hoes to practice minimum soil disturbance may not yield desirable results. Abouziena and Haggag (2016) have also observed that a lack of weed control leads to crop yield losses. Therefore, decision-makers are advised to solve them in order for the technology to be successfully implemented. Moreover, the study observed that Angonia is prone to frequent erosion caused by heavy rains between January and February. This issue can also be mitigated by using minimum soil disturbance. The use of minimum soil disturbance may also reduce the amount of labour involved in heaping up the soil for planting, allowing farmers to save time and enhance their crop yield. Ofstehage and Nehring (2021) and Rust et al. (2020) have observed that these aspects of social

**Table 4.** Factors impacting farmers' conservation agriculture adoption in Angonia, Mozambique.

CA adopted vs. predictors variables		B	Std. Error	Wald	df	Exp (B)
Soil cover/stubble retention	Farming experience	-2.217	1.123	3.898*	1	0.109
	Gain knowledge	-0.247	0.644	0.147	1	0.781
	Cost saving	-0.780	0.681	1.315	1	0.458
Crop rotation or intercropping	Farming experience	-2.901	1.117	6.745*	1	0.055
	Gain knowledge	0.904	0.640	1.991	1	2.468
	Cost saving	-1.090	0.692	2.479	1	0.336
All 3 principles	Farming experience	-1.836	1.175	2.441	1	0.159
	Gain knowledge	-0.425	0.694	0.375	1	0.654
	Cost saving	-2.134	0.691	9.530*	1	0.118

The reference category is: minimum soil disturbance;  $p \leq 0.05$ .

profitability determine the uptake of CA.

### Immediate impact of conservation agriculture on crop yield

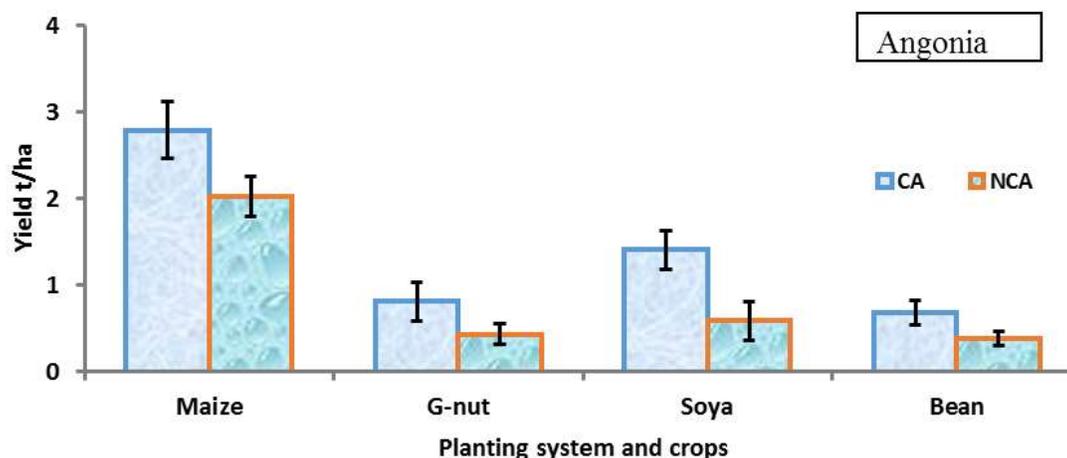
The study assessed whether CA (the three principles) that have been claimed to be successful in the developed world could produce similar results for smallholder farmers in Angonia (Mozambique). To investigate this, farmers were asked to provide information on the production quantity of each crop measured in kilograms per hectare in the previous season for two production systems, namely CA and non-conservation agriculture (NCA) fields. To that end, the study used the Tukey HSD all-pairwise comparison test to compare all crop groups and the Welch test to determine significance levels.

Figure 2 shows the levels of production of maize, groundnut, soya and common bean in both CA and non-CA systems. The results reveal a significant difference for all crops grown under the CA system (maize, groundnut, soya bean and common bean). It is then clear that CA has the potential to increase crop yields for farmers. Maize is a very important crop in Angonia because it is used for daily needs and consumption. This is justified by its high mean average in comparison to other crops. CA's significant levels could also be attributed to the simultaneous application of three principles by some farmers, appropriate agronomic practices, farmer capacity building, and the use of improved seed varieties. Similarly, previous findings in SSA showed an increase in yield, as seen in Zambia (Ngoma et al., 2021), Malawi (Bouwman et al., 2021) and Tanzania (Kimaro et al., 2016). Moreover, Ndah et al. (2018) have observed that the practice of the three combined principles of CA enhances outcomes remarkably. By saying this, it should not be assumed that all farmers benefit from increased yields as a result of CA practice. There are also some farmers that disregard CA because it does not produce

the desired results.

### Constraints hindering CA adoption in Angonia, Mozambique

Assessment of the challenges of CA should be considered as part of the process of tailoring the technology to the local conditions. Farmers were asked to describe any constraints they have encountered while implementing CA. Table 5 depicts the challenges farmers face during the implementation of CA in Angonia. Farmers cited a lack of herbicides (25%), a lack of reduced tillage equipment (25%), high cost inputs (17%) and the effectiveness of CA (17%) as the major barriers to CA implementation. Farmers' resources are typically limited and they are unable to purchase necessary inputs such as herbicides and appropriate equipment to fully implement CA. The term "resources" refers to the ability to purchase inputs. It is for this reason that farmers perceive inputs to be expensive. It has also been observed that the government only supports information on technology and inputs for experimental fields. When farmers implement CA on their own farms, the dilemma becomes a reality. The effectiveness of CA is another depressing factor. Farmers are discouraged because CA takes so long to make a difference in their lives. Because of this, appropriate measures must be implemented if CA is to produce the desired results. This can include the appropriate use of fertilisers to generate immediate outcomes. In Angonia, a lack of these inputs is real, forcing farmers to confine CA to a small plot of land. Similarly, Mango et al. (2017), Mulimbe et al. (2019) and Ntshangase et al. (2018) demonstrated how input availability influenced CA outcomes and adoption in South Africa, Lesotho and Malawi. In this regards, the study concludes that the manner in which CA is practiced may lead to dis-adoption at any point because herbicides and appropriate tillage equipment play an important role



**Figure 2.** Levels of production of conservation agriculture and conventional systems.

**Table 5.** Constraints to the use of conservation agriculture in Angonia, Mozambique.

Constraints of CA practices in Mozambique	Percent (n=192)
Herbicides	25
Equipment cost	25
High cost of inputs	17
Effectiveness of CA	17
Lack of credits	10
Labour requirement	6
Total	100

in the field management.

The existing causal relationship between the predicting constraints variables and the principles of CA was also assessed (Table 6). In general, "equipment cost" was found to be a significant predictor for soil cover ( $b = -1.349$ ,  $SE = 0.550$ ,  $p = 0.014$ ), crop rotation ( $b = -1.404$ ,  $SE = 0.695$ ,  $p = 0.043$ ), and all three principles ( $b = 1.333$ ,  $SE = 0.583$ ,  $p = 0.022$ ). The result indicates that when farmers encountered the problem of a lack of equipment and tools to implement CA, they were less likely to employ soil cover, crop rotation, or all three principles together, but more likely to apply minimum soil disturbance. The study's observation is that there is a lack of CA-specific tools in the field. Therefore, farmers likely employ common instruments (hand hoes) that are likewise used in conventional systems. Previous research has also found that the minimum soil disturbance approach is straightforward and that farmers prefer to employ it since it produces the optimal yield (Ginigaddara, 2019). The odds ratios of 0.246, 0.260 and 0.264 indicate the degree of decrease of farmers using soil cover, crop rotation and the three principles together over minimal soil disturbance. The result entails to minimise the equipment cost because it causes farmers to not fully practice soil cover, crop rotation and the three

CA principles. Among other options, one is to design locally produced equipment at low costs to facilitate the implementation of CA.

In the two subsets of coefficients, "lack of information" was also found to be a negative significant predictor for soil cover ( $b = -1.779$ ,  $SE = 0.878$ ,  $p = 0.043$ ) and crop rotation ( $b = -4.111$ ,  $SE = 0.988$ ,  $P = 0.000$ ). The result suggests that farmers who do not get enough or cannot process the right information about CA were less likely to employ soil cover and crop rotation but would more likely apply minimum soil disturbance. This also holds true for errors that occur during the diffusion process by innovators. The odds ratios of 0.169 and 0.016 indicate the level of decrease of farmers using soil cover and crop rotation over minimum soil disturbance. This conception also applies to those farmers who have the problem of utilising CA because of the input cost. The third subset of coefficients, "labour requirement" ( $b = 1.121$ ,  $SE = 0.548$ ,  $p = 0.041$ ) and "lack of credit" ( $b = 1.624$ ,  $SE = 0.581$ ,  $P = 0.005$ ) were found to be positive significant predictors for all three CA principles in the model. This suggests that the farmers were more likely to follow the three CA principles rather than rely solely on minimum soil disturbance. The odds ratios of 3.068 and 5.076, respectively, indicate the proportion of farmers who are

**Table 6.** Constraints impacting conservation agriculture use in Angonia, Mozambique.

CA adopted vs. predictors variables		B	Std. Error	Wald	df	Exp (B)
Soil cover/stubble retention	Assistance period	0.559	1.346	0.172	1	1.748
	Farming experience	1.205	1.371	0.773	1	3.338
	Equipment cost	-1.349	0.550	6.012*	1	0.260
	Labour requirement	0.643	0.517	1.545	1	1.903
	Input cost	-0.151	0.542	0.077	1	0.860
	Lack credit	0.708	0.524	1.831	1	2.031
	Lack information	-1.779	0.878	4.108*	1	0.169
Crop rotation or intercropping	Assistance period	1.557	1.706	0.833	1	4.743
	Farming experience	1.072	0.760	1.987	1	2.921
	Equipment cost	-1.404	0.695	4.088	1	0.246
	Labour requirement	0.235	0.694	0.115	1	1.265
	Input cost	1.101	0.747	2.168	1	3.006
	Lack credit	1.292	0.707	3.346*	1	3.642
	Lack information	-4.111	0.988	17.321*	1	0.016
All three principles of conservation Agriculture	Assistance period	-0.459	1.359	0.114	1	0.632
	Farming experience	1.124	0.629	3.196	1	3.078
	Equipment cost	-1.333	0.583	5.221*	1	0.264
	Labour requirement	1.121	0.548	4.190*	1	3.068
	Input cost	-1.183	0.571	4.297*	1	0.306
	Lack credit	1.624	0.581	7.810*	1	5.076
	Lack information	-1.194	0.944	1.601	1	0.303

The reference category is: minimum soil disturbance;  $p \leq 0.05$ .

more likely to use the three CA principles rather than minimal soil disturbance alone. Despite controversies, Ndah et al. (2018) and Vanlauwe et al. (2014) have observed that the effects of combining three principles are easily realised. CA promotion should then match farmers' expectations and realities, specifically by recognizing farmers' economic needs, culture, and agro-ecological zones in a flexible manner. According to the findings, recognition should also include how information is disseminated. The study found that innovators use farmer field schools in the process of dissemination of CA technology. The study then concludes that the farmer field school approach is ineffective because farmers do not receive adequate information about CA. In this regard, the study recommends innovators to use farmer-to-farmer extension because it allows farmers to communicate using language and expressions that are appropriate for their environment for better comprehension.

### **Redefinition of conservation agriculture in dry rain fed agriculture zone of Angonia, Mozambique**

The process of designing the implementation of CA, understanding how economic variables impact the

adoption of CA informs projects and policies to adapt to the new challenges and solutions towards food security (Ngoma et al., 2021). CA dissemination in Mozambique has focused on the agronomic key factors in its implementation. Corrective measures focusing on agronomic factors have failed to produce appropriate solutions to the ultimate goal of increasing food security for all CA farmers. Using the economic factors chosen for this study, the model of regression analysis of both factors influencing and impeding farmers' use of CA generally shows that farmers would likely use minimum soil disturbance over other principles. In the fields for demonstrations, minimum soil disturbance is generally achieved through the use of appropriate fertiliser. This enables experimental fields to produce expected yield productivity. Farmers deceivably attempt to use reduced tillage without fertilisers and herbicides; when they do use them, it is only for small plots of land due to economic constraints. This study concludes that CA can only be used by farmers with enough economic resources to buy inputs in Angonia. In order to avoid this, inputs in the form of credits (herbicides, fertilisers and reduced tillage equipment) are required to increase yields and reduce the demand for food security among participants' farmers. As regard to reduced tillage equipment, there is a need to locally adapt based on farmers' economic resources.

Again, advising farmers to use the reduced tillage materials in the form of rentals can alleviate the problem of financial constraints in acquiring them. Labour saving is one reason for using reduced tillage, but it also increases weed pressure. As a result, the study suggests incentivising farmers to use herbicides appropriately.

There has been much debate in the literature about whether or not CA should include the use of fertiliser and herbicides. The enabling environment in South America and Australia, where CA produced good results, included the use and availability of fertilisers and herbicides (Anghinoni et al., 2021; Vanlauwe et al., 2014). While conscious of the risks associated with the inappropriate use of fertilisers and herbicides, the study contends that excluding these elements is an omission of the main elements of CA to generate desired results in rain-fed zones, specifically in Angonia. Furthermore, the conflict over organic residues between livestock and other users is apparent in rain fed agriculture, particularly in Angonia. Anghinoni et al. (2021) and Vanlauwe et al., (2014) have argued that minimal soil disturbance without organic residues depresses yields because mulch improves soil moisture conservation and physical soil conditions, to name a few benefits. In the environment of rain-fed agriculture and tropical wet and dry climates, the use of appropriate fertilisers and herbicides would aid in the implementation of CA and produce planned outcomes, including (1) enough vegetative cover to meet demand; (2) herbicides and appropriate tillage equipment to reduce the labour caused by weeds in reduced tillage, (3) immediate results expected by farmers and (4) overcoming the problem of farm financial demand. To avoid the misuse of herbicides and fertilisers, research assessing the appropriateness of their use in CA technology will be finely combined with economic factors to reflect the Angonia environment and soil responses. The term "appropriate" refers to the use of the proper fertilisers and herbicides at the appropriate rate, time, and place (Anghinoni et al., 2021). The suggestion will only be effective if the agricultural department in Angonia, in collaboration with the ministry of agriculture, addresses the issue of market imperfections, such as access to agricultural inputs, equipment and information sharing.

## CONCLUSION AND RECOMMENDATIONS

The study advocates greater flexibility in the use of CA, taking into account the positive and negative factors that influence the use of CA in rain-fed agriculture, specifically in Angonia. The main reason why farmers use CA in Angonia is that they immediately see benefits, namely increased crop yields, owing to the soil cover and other related factors. Using economic factors, the study indicates the possibility of farmers using minimum soil disturbance over other approaches. Successful implementation of CA demands the use of inputs such as appropriate use of fertilisers and herbicides to address

the issue of CA's lack of immediate results, generate enough residues for soil cover, and control weeds. Further research into the appropriate response of fertilisers and herbicides to soil conditions is recommended. Furthermore, the study suggests that reduced tillage equipment be designed with farmers' needs and economic resources in mind. This can only be accomplished with the farmers' collaboration. Market imperfections, such as the establishment of facilities for access to agricultural inputs, should also be considered.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The authors thank the European Union under Intra-African Mobility (MOUNAF) project (2016-2989) for kindly supporting the study at the University of Kisangani, the CA farmers for responding to the questionnaires analysed in the study, and Professor Gratien Mokonzi for administrative support. Gratitude goes to Mr. Edson Cachepa and the research assistants for their technical support during data collection.

## REFERENCES

- Abouziena H, Haggag WM (2016). Métodos alternativos de controle não químicos de plantas daninhas: Uma revisão. *Planta Daninha* 34(2):377-392.
- Anghinoni G, Anghinoni FBG, Tormena CA, Braccini AL, de Carvalho Mendes I, Zancanaro L, Lal R (2021). Conservation agriculture strengthen sustainability of Brazilian grain production and food security. *Land Use Policy* P 108. <https://doi.org/10.1016/j.landusepol.2021.105591>
- Bourne M, de Bruyn LL, Prior J (2021). Participatory versus traditional agricultural advisory models for training farmers in conservation agriculture: a comparative analysis from Kenya. *Journal of Agricultural Education and Extension* 27(2):153-174.
- Bouwman TI, Andersson JA, Giller KE (2021). Adapting yet not adopting? Conservation agriculture in Central Malawi. *Agriculture, Ecosystems and Environment* P 307. <https://doi.org/10.1016/j.agee.2020.107224>
- Brown B, Nuberg I, Llewellyn R (2018). Constraints to the utilisation of conservation agriculture in Africa as perceived by agricultural extension service providers. *Land Use Policy* 73:331-340. <https://doi.org/10.1016/j.landusepol.2018.02.009>
- Giller KE, Andersson JA, Corbeels M, Kirkegaard J, Mortensen D, Erenstein O, Vanlauwe B (2015). Beyond conservation agriculture. *Frontiers in Plant Science* P 6. <https://doi.org/10.3389/fpls.2015.00870>
- Ginigaddara GAS (2019). Zero Tillage/ Minimum Tillage pp. 1-32. Available at: [http://www.rjt.ac.lk/agri/agri\\_onlinematerials/agricultural\\_systems/Zero%20tillage%20GAS%20Ginigaddara.pdf](http://www.rjt.ac.lk/agri/agri_onlinematerials/agricultural_systems/Zero%20tillage%20GAS%20Ginigaddara.pdf)
- Kimaro AA, Mpanda M, Rioux J, Aynekulu E, Shaba S, Thiong'o M, Mutuo P, Abwanda S, Shepherd K, Neufeldt H, Rosenstock TS (2016). Is conservation agriculture 'climate-smart' for maize farmers in the highlands of Tanzania? *Nutrient Cycling in Agroecosystems* 105(3):217-228. <https://doi.org/10.1007/s10705-015-9711-8>.
- Mango N, Siziba S, Makate C (2017). The impact of adoption of conservation agriculture on smallholder farmers' food security in

- semi-arid zones of southern Africa. *Agriculture and Food Security* 6(1):1-8. <https://doi.org/10.1186/s40066-017-0109-5>
- Ministério da agricultura (2016). Anuário de Estatísticas Agrárias 2015. 66. Available at: [https://www.masa.gov.mz/wp-content/uploads/2017/12/Anuario\\_Estatistico2016.pdf](https://www.masa.gov.mz/wp-content/uploads/2017/12/Anuario_Estatistico2016.pdf)
- Montt G, Luu T (2020). Does Conservation Agriculture Change Labour Requirements? Evidence of Sustainable Intensification in Sub-Saharan Africa. *Journal of Agricultural Economics* 71(2):556-580.
- Mulimbe W, Nalley L, Dixon B, Snell H, Huang Q (2019). Factors Influencing Adoption of Conservation Agriculture in the Democratic Republic of the Congo. *Journal of Agricultural and Applied Economics* 51(4):622-645. <https://doi.org/10.1017/aae.2019.25>
- Mutyasira V, Hoag D, Pendell D (2018). The adoption of sustainable agricultural practices by smallholder farmers in Ethiopian highlands: An integrative approach. *Cogent Food and Agriculture* 4(1):1-17. <https://doi.org/10.1080/23311932.2018.1552439>
- Ndah HT, Schuler J, Diehl K, Bateki C, Sieber S, Knierim A (2018). From dogmatic views on conservation agriculture adoption in Zambia towards adapting to context. *International Journal of Agricultural Sustainability* 16(2):228-242.
- Ng'ombe JN, Kalinda TH, Tembo G, Johnson SAJ, Rodenburg J, Büchi L, Haggard J, Asseng S, Zhu Y, Basso B, Wilson T, Cammarano D, Delaroché M, Mudemba R, Taruvinga A, Zhou L, Mudemba R, Britto D, Filho F, Russell T (2020). Adoption by adaptation: moving from Conservation Agriculture to conservation practices. *Why Did Ancient Civilizations Fail?*, 0(0):79-99. <https://doi.org/10.4324/9781315512891-13>
- Ngoma H, Angelsen A, Jayne TS, Chapoto A (2021). Understanding Adoption and Impacts of Conservation Agriculture in Eastern and Southern Africa: A Review. *Frontiers in Agronomy*, 3(June). <https://doi.org/10.3389/fagro.2021.671690>
- Ntshangase NL, Muroyiwa B, Sibanda M (2018). Farmers' perceptions and factors influencing the adoption of no-till conservation agriculture by small-scale farmers in Zashuke, KwaZulu-Natal province. *Sustainability (Switzerland)* 10(2):555. <https://doi.org/10.3390/su10020555>
- Ofstehage A, Nehring R (2021). No-till agriculture and the deception of sustainability in Brazil. *International Journal of Agricultural Sustainability* 19(3-4):335-348.
- Pittelkow CM, Liang X, Linquist BA, Van Groenigen LJ, Lee J, Lundy ME, Van Gestel N, Six J, Venterea RT, Van Kessel C (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature* 517(7534):365-368.
- Powlson DS, Stirling CM, Thierfelder C, White RP, Jat ML (2016). Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agriculture, Ecosystems and Environment* 220:164-174.
- Rust NA, Ptak EN, Graversgaard M, Iversen S, Reed MS, de Vries JR, Ingram J, Mills J, Neumann RK, Kjeldsen C, Muro M, Dalgaard T (2020). Social capital factors affecting uptake of sustainable soil management practices: a literature review. *Emerald Open Research*, 2(8). <https://doi.org/10.35241/emeraldopenres.13412.1>
- Scheba A (2017). Conservation agriculture and sustainable development in Africa: insights from Tanzania. *Natural Resources Forum* 41(4):209-219. <https://doi.org/10.1111/1477-8947.12123>
- Vanlauwe B, Wendt J, Giller KE, Corbeels M, Gerard B, Nolte C (2014). A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research* 155:10-13.