Environment for Development

Discussion Paper Series December 2020 ■ EfD DP 20-38

Smallholder Farmers' Response to Climate Change in Zambia

What are the Drivers and Hindrances?

Obrian Ndhlovu and Edwin Muchapondwa

Central America
Research Program in Economics and Environment for Development in Central America Tropical Agricultural Research and Higher Education Center (CATIE)

Chile
Research Nucleus on Environmental and Natural Resource Economics (NENRE)
Universidad de Concepción

China
Environmental Economics Program in China (EEPC)
Peking University

Colombia
The Research Group on Environmental, Natural Resource and Applied Economics Studies (REES-CEDE), Universidad de los Andes, Colombia

Ethiopia
Environment and Climate Research Center (ECRC), Policy Studies Institute, Addis Ababa, Ethiopia

Ghana
The Environment and Natural Resource Research Unit, Institute of Statistical, Social and Economic Research, University of Ghana, Accra

India
Centre for Research on the Economics of Climate, Food, Energy, and Environment, (CECFEE), at Indian Statistical Institute, New Delhi, India

Kenya
School of Economics
University of Nairobi

Nigeria
Resource and Environmental Policy Research Centre, University of Nigeria, Nsukka

South Africa
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town

Sweden
Environmental Economics Unit
University of Gothenburg

Tanzania
Environment for Development Tanzania
University of Dar es Salaam

Uganda
EfD-Mak, School of Economics and Department of Agribusiness and Natural Resource Economics, Makerere University, Kampala

USA (Washington, DC)
Resources for the Future (RFF)

Vietnam
University of Economics
Ho Chi Minh City, Vietnam

Smallholder Farmers' Response to Climate Change in Zambia: What are the Drivers and Hindrances?

Obrian Ndhlovu and Edwin Muchapondwa*

Abstract

The paper employs a mixed methods approach to document and evaluate drivers of climate change adaptation among smallholder farmers in Zambia. We combine rich household survey data, satellite rainfall and in-depth interviews to model adoption based on the choice of adaptation strategy and the intensity of adoption. We document a changed agricultural environment, with declining rainfall amount and duration. While government and partners have been promoting climate smart practices such as conservation farming and irrigation, the level of adoption remains low. We show that farmers respond to rainfall shocks by adopting minimum tillage and crop rotation. Extension services also have proven effective in promoting minimum tillage and crop rotation. On the other hand, soil cover adoption (plant residue retention and planting soil cover) is driven more by farming cultures, while irrigation adoption is driven by availability of surface water. Another notable finding is the low level of crop diversification, which has a direct bearing on the adoption of crop rotation and, to some extent, minimum tillage. Our analysis shows that mono-cropping stems from a cultural perspective and lack of certified inputs and structured markets for alternative crops. The prevalent practice of off-season free grazing also hinders the adoption of soil cover, irrigation and minimum tillage, while irrigation is limited to surface water along seasonal streams or reservoirs.

Keywords: climate change, adaptation, adoption, conservation farming, Zambia

JEL Codes: O13, Q12, Q54

---

* Obrian Ndhlovu (corresponding author: obriandhlovu@yahoo.com) and Edwin Muchapondwa, School of Economics, University of Cape Town, South Africa. The authors are grateful to the Indaba Agricultural Policy Research Institute (IAPRI) for the Rural Agricultural Livelihoods Surveys (RALS) data.

1. Introduction

Smallholder dryland farmers continue to dominate the agriculture sectors of many developing countries and remain highly dependent on rain-fed agriculture. With more erratic rains and frequent occurrence of precipitation extremes such as droughts, dry spells and excess rains, the smallholder farmers are highly exposed to the effects of climate change. In addition, smallholder farmers lack the resources necessary to cope with the effects of climate change and therefore remain vulnerable (Smit and Pilifosova, 2001).

A changing climate threatens the viability of the agriculture sector, especially in tropical zones of developing countries (Altieri and Koohafkan, 2008). For instance, the Intergovernmental Panel on Climate Change (IPCC) (Hewitson et al., 2014; Olsson et al., 2014) warns that the risk from droughts and precipitation deficits is projected to be higher and likely to exacerbate the challenges facing rain-dependent smallholder farmers.

In Zambia, the UNDP (McSweeney et al., 2012) reported that the mean annual temperature has increased by 1.3◦C since the 1960s, while the annual rainfall has decreased both in duration and quantity. For instance, the mean annual rainfall over Zambia has decreased by an average of 1.9mm per month per decade since 1960 (McSweeney et al., 2012). The declining rains pose a danger to the viability of the agricultural sector, especially in the southern regions of the country, where the changes have been more pronounced (AFAI, 2015).

In response, the Zambian government and partners have been promoting a number of initiatives aimed at creating climate resilience (MoA and MFL, 2016). These include the promotion of climate smart agriculture (CSA) technologies including conservation farming (CF) and irrigation, microclimate suited crop varieties, crop insurance schemes, etc. (CFU, 2012). The Ministry for Agriculture (MoA),[1] adopted CF as an official government policy aimed at promoting climate resilience among farmers (MoA, 2001). A number of institutions have been helping smallholder farmers adopt CF (CFU, 2012; Kuntashula and Nhlane, 2018). Other initiatives include the Irrigation Development and Support Project, 2011-2020 (WB, 2011), a mandatory weather index insurance program operating alongside the Farmer Input Support Program (FISP) (MoA, 2018).

Despite all the above efforts, the adoption of CF and other CSA practices among smallholder farmers remains low in Zambia. For instance, the adoption of minimum tillage (MT) is around 15% while CR and soil cover (SC) are below 50% and 60% respectively (Arslan et al., 2014; Zulu-Mbata et al., 2016). Despite a high irrigation potential in the dry season, the country is irrigating only about 6% of irrigable land (Akayombokwa et al., 2015; MoA, 2013) while smallholder farmers irrigate only about 3% of land they cultivate (Akayombokwa et al., 2015; Ngoma et al., 2017).

[1] Although the Ministry for Agriculture has undergone a number of changes to the name, this paper uses the Ministry of Agriculture nomenclature throughout.

This paper seeks to examine factors inhibiting adoption of climate adaptation strategies and explore ways to encourage their adoption. The paper particularly examines the role of extension/farmer training services and exposure to adverse weather in driving climate change (CC) adaptation.

The overall objective is to determine factors that drive the adoption of different CC adaptation strategies among smallholder farmers. The paper is guided by the following specific objectives: to document strategies that smallholder farmers are employing to mitigate the impact of CC; to investigate determinants of the decision to adapt to CC; and to investigate determinants of choice of different adaptation strategies by smallholder farmers.

Factors driving adoption, non-adoption and dis-adoption of CC adaptation strategies have not been conclusively evaluated, but strong indications point to levels of education, availability of CF supportive services such as specialised implements and herbicides, and landholding system (Grabowski et al., 2014; Zulu-Mbata et al., 2016). Studies from other regions are of limited application in understanding decision-making driven by local/regional biophysical and cultural factors (Baudron et al., 2007; Lee, 2005). The findings are important to help map the different strategies for climate change adaptation and hindrances to adoption.

The paper also brings in some methodological innovations. First, not many studies on the topic have incorporated the effect of an objectively measured exposure to climate shock (Michler etal., 2019), or applied multivariate choice models that account for complementarities among strategies (Arslan et al., 2014; Kassie et al., 2013, 2015; Mulwa et al., 2017; Teklewold et al., 2013). This paper proposes models that capture the role of exposure to objectively measured climate extremes in driving adaptation, and employs methods that are robust to interrelationships among adaptation strategies.

Second, the paper benefits from a rare combination of rich quantitative data, primary qualitative data from Agriculture Extension Officers, and high-resolution satellite rainfall data. Third, the paper proposes new measures of gender and level of education in the household which take into account all members of the household. This is in contrast to the tradition of considering the gender and education of the head only. There is overwhelming evidence on the importance of other members in a household, whose gender and education also matters (Anderson et al., 2017; Zepeda and Castillo, 1997).

The paper is organized as follows: Section 2 reviews the literature while 3 discusses the methodology. Descriptive analysis is in section 4, results and findings in section 5, and conclusions in section 6.

2. Review of Literature

A number of studies have been conducted to understand factors affecting climate change adaptation among smallholder farmers. Some have investigated the broader topic of adaptation (Komba and Muchapondwa, 2018; Nyanga et al., 2011), relying on multinomial and multivariate models, while others have looked at adoption of specific strategies such as CF (Arslan et al., 2014; Baudron et al., 2007; Chompolola and Kaonga, 2016; Habanyati et al., 2018; Zulu-Mbata et al., 2016), irrigation (Ngoma et al., 2017), etc. Results on level and drivers of adoption are mixed and remain inconclusive. This section provides a systematic review of literature, highlighting notable aspects of literature in order to identify gaps. The paper highlights three broad areas of literature: conceptual econometric approaches, in section 2.1; variables used, in section 2.2; and data issues, in section 2.3.

2.1 Econometric Approach

Econometric approaches in climate change adaptation can be put into two broad categories. The first category comprises models used to analyse dichotomous decisions to adopt a given strategy. The second category comprises models used to assess the depth of adoption.

Studies evaluating the choice of farmers to adopt CSA practices often rely on binary choice models. For instance, Arslan et al. (2014) and Zulu-Mbata et al. (2016) have employed probit models in the analysis of adoption of CF in Zambia, while Chompolola and Kaonga (2016), Habanyati et al. (2018) and Komba and Muchapondwa (2018) have used a logit model. The models implicitly assume that farmers decide on the adoption of each strategy independently. More often, adaptation strategies tend to be complementary (Kassie et al., 2013; Mulwa et al., 2017) – that is, the utility derived from one is affected by the utilization of another strategy (Kassie et al., 2015). This is reflected in the promotion of CF, which emphasizes the cumulative adoption of different principles or strategies (CFU, 2012). In the presence of such correlations, binary choice models are inefficient because they ignore the correlations in the error terms (Kassie et al., 2015; Mulwa et al., 2017).

Multinomial logit or probit models have been applied in the analysis of choice of adaptation strategy among many alternatives. Zulu-Mbata et al. (2016) applied a multinomial logit in the analysis of factors affecting full and partial adoption of CF in Zambia, while Komba and Muchapondwa (2018) applied a multinomial logit in the choice of climate adaptation strategies in Tanzania. The model is superior to the binary models discussed earlier because it allows for many alternatives. However, it has the general weakness of assuming independence of irrelevant alternatives (IIA) in the choice of strategies (Wooldridge, 2010, p. 501).

A multivariate probit, based on Zellner's (1962) seemingly unrelated regressions (SUR), comes as a solution to the failure of multinomial models to deal with interrelations in the adoption of different strategies. Kassie et al. (2013, 2015) and Mulwa et al. (2017) have used SUR-based probit to analyse the adoption of related farming practices in a number of countries. The model has the advantage of recognizing the correlation in the error terms and estimating the adoption of multiple strategies as a system.

Studies looking at the intensity of adoption rely on ordered probit (see Wooldridge (2010, sec. 16.3)), using the number of strategies adopted. The number of strategies adopted is an important indicator of the degree of adaptation to CC. For instance, in the adoption of CF, farmers adopt CF principles cumulatively and progressively from minimum tillage (MT) through conservation tillage (CT) and ultimately, CF (CFU, 2012). A number of studies (Pedzisa et al., 2015; Sharma et al., 2010; Teklewold et al., 2013), have used the number of principles or practices employed as a measure of intensity of adaptation. An ordered probit is, however, blind to the composition of each package of adaptation strategies. For instance, it takes the adoption of any combination of strategies to rank solely on the number of strategies involved.

Other studies have employed the tobit model to analyse the intensity of adoption of each strategy, often using the proportion of land on which the strategy is applied. For instance, Arslan et al. (2014) used a random effects tobit to model the share of land allocated to an adopted farming practice among smallholders in Zambia. Grabowski et al. (2014) also used the tobit model to analyse determinants of the percentage of land on which minimum tillage is applied. An advantage of tobit models is their ability to measure the intensity of adoption of strategies individually.

In this paper, we employ both the individual and SUR probit to model adoption. This combination is important to highlight the effect of correlation in the adoption of difference strategies. We model the intensity of adoption using the tobit model.

2.2 Variables Used

The types of variables and how they are measured have the potential to affect research findings. In this section, we examine how literature has treated key variables in the study of climate adaptation.

2.2.1 Measure of Rainfall

The effectiveness of new farming technologies and hence their attractiveness to farmers in rainfed agriculture is influenced by rainfall (Andersson and D'Souza, 2014; Grabowski et al., 2014; Kassie et al., 2013). However, a number of studies that sought to look at adoption of climate related agriculture practices failed to incorporate measures of rainfall. Others failed to obtain objectively measured local rainfall. For instance, Kassie et al. (2013) used individual farmers' perceptions of the timeliness, adequacy and distribution of rainfall as a measure of rainfall shock in Tanzania. Similarly, Komba and Muchapondwa (2018) used farmers' own observations of rainfall and temperature. The major drawback of this approach is that perceptions are likely to be influenced by the level of sensitivity, resilience or preparedness of each farmer.

Arslan et al. (2014, 2015) obtained objectively measured rainfall data. However, due to lack of geo-references in the main data, rainfall data is aggregated at district level. This has the potential to mask within-district variations in rainfall that have an impact on farmer behaviour. Michler et al. (2019) aggregated similar high-resolution satellite rainfall data at the ward level in Zimbabwe. They compute a measure of rainfall shock based on normalized seasonal deviation of rains from the long-term average.

$$R_{it} = \frac{r_{it} - \overline{r_i}}{\sigma_{r_i}} \tag{1}$$

where r_{it} is the amount of rainfall in a season and $\overline{r_i}$ is the long-term rainfall average. We cite two shortcomings of Michler's (2019) approach. First, aggregating rainfall data at ward level means they failed to estimate the rainfall closest to the farmer. Second, the formula does not capture within-season maldistribution of rainfall, which might be equally important in shaping farmer response (Lalani et al., 2017).

2.2.2 Human Capital

Household demographic characteristics have the potential to affect decisions on which farming assets to own and farming practices to adopt (Chompolola and Kaonga, 2016; Mulwa et al., 2017). For instance, households with higher levels of education are more likely to access and comprehend information on new technologies. Many studies use the level of education and gender of the household head, implicitly assuming that the head is the sole decision maker (Carney and Carney, 2018; Kassie et al., 2013; Meijer et al., 2015; Pender and Gebremedhin, 2008). However, Anderson et al. (2017) and Zepeda and Castillo (1997) have shown the importance of other members of the household such as the spouse in decision-making. In addition, the absence of functional factor markets in rural settings limits labour inputs to household labour (Gollin, 2014; Pedzisa et al., 2015). Therefore, household size is important as an indicator of labour availability in a farming household. In order to exclude minors, studies use number of adults a household (Arslan et al., 2014; Pedzisa et al., 2015; Xu et al., 2009).

2.2.3 Physical Capital

Ownership of farming implements/equipment has the potential to aid adoption of better, climate suited farming practices. Studies traditionally include measures of ownership of physical capital such as draft animals (Chompolola and Kaonga, 2016; Kassie et al., 2013; Mulwa et al., 2017), farming equipment (Kassie et al., 2015; Teklewold et al., 2013) and land (Arslan et al., 2014; Feliciano, 2019; Maggio et al., 2018; Zulu-Mbata et al., 2016). Some studies look at land from a tenure or security perspective, arguing that farmers with security to land have higher chances of adopting sustainable farming practices such as CF (Feliciano, 2019; Kassam et al., 2019; Kassie et al., 2015). These define tenure using a dummy variable, often separating more secure landholding systems from less secure systems.

2.2.4 Crop Diversification

Household level diversity of cultivated crops provides a basis for the adoption of new farming practices such as CF (Kassie et al., 2013; Liebman and Dyck, 1993). Studies often measure the level of crop diversity using the Simpson index of diversification (SID) (Jones et al., 2014; Kankwamba et al., 2018) based on Simpson (1949). However, no study has attempted to include the level of crop diversity as an explanatory factor in the adoption of other CSA practices.

2.3 Data Issues

There are two broad categories of data in the literature. There is a group of literature that relied on district case studies. Examples include Chompolola and Kaonga (2016) and Habanyati et al. (2018) on one district each in Zambia and Kassie et al. (2013) and Komba and Muchapondwa (2018) on selected districts of Tanzania. Studies of this nature are highly informative on study districts but less informative beyond those districts. Farmers' behaviour is influenced by local factors such as microclimate, farming culture and systems (Baudron et al., 2007; Lee, 2005; Zulu-Mbata et al., 2016) which will vary from district to district. Therefore, findings from a set of districts may not always be applicable to other contexts.

The other category has used nationally representative surveys of farmers. Arslan et al. (2014, 2015) used a nationally representative survey of small-scale farmers in Zambia, while Ngoma et al. (2017) and Zulu-Mbata et al. (2016) used the same data as this paper. Similar surveys were used by Mulwa et al. (2017) for Malawi, Michler et al. (2019) for Zimbabwe and Kassie et al. (2015) in a four-country study involving Ethiopia, Kenya, Malawi and Tanzania. Grabowski et al. (2014) used two waves of census of cotton input distributors in 2002 and 2011 to study the adoption of MT among smallholder cotton farmers in Zambia.

This paper benefits from a rich combination of datasets, which allows the computation of all the important variables discussed above. In addition, the paper proposes some modifications to variables. For instance, we propose a better measure of rainfall shock, deviate from the tradition of considering the gender of the head only, and measure household size by the number of labour-providing members.

3. Methodology

This paper incorporates both quantitative and qualitative approaches. As noted by Trotter (2012), mixed methods approaches incorporate the strengths of both approaches while simultaneously reducing the limitations of each.

3.1 Model Specifications

Our econometric approach tackles adaptation in two stages: (1) adaption strategy choice by farmers, and (2) intensity of adoption. Model specifications are discussed in detail below.

3.1.1 Choice to Adopt

This paper uses a multivariate probit model based on Zellner's (1962) SUR models to analyse adoption of different climate change adaptation strategies. In the adoption of multiple adaptation strategies, there are common factors that are likely to explain adoption, potentially creating contemporaneous correlation in the error terms. SUR models are appropriate because they estimate the adoption of different strategies simultaneously, allowing the random errors to be related across adaptation strategies.

In deciding to adopt each strategy, a farmer is assumed to perform a cost-benefit analysis, based on available resources, including information. The expected net benefit y_{ijt}^* to the ith farmer adopting strategy j at time t is unobserved, but is assumed to be a linear combination of household characteristics, training received, rainfall, and unobserved characteristics. Household characteristics such as size, level of education, gender and age composition affect the appropriateness and effectiveness with which the household will implement a given strategy and hence the net benefit. The latent variable for the ith farmer deciding to adopt strategy j at time t is given by

$$y_{ijt}^* = X_{ijt}'\beta_j + \delta_j R_{it} + \gamma_j E_i + u_{ijt}, \tag{2}$$

where X is a vector of explanatory variables, β is a vector of corresponding parameters and u_{ijt} is the error term. E_i is a binary measure of having received extension or training services and R_{it} is a measure of rainfall shock as defined later in equation 7. The dichotomous decision on each strategy or practice is observed as

$$y_{ijt} = \begin{cases} 1, \text{ if } y_{ijt}^* > 0 \\ 0, \text{ if } y_{ijt}^* \leq 0 \end{cases}. \tag{3}$$

The model in equation 2 can be expressed in a more compact form as follows.

$$Y_i^* = Z_{ij}'B + \varepsilon_i, \tag{4}$$

where Y is a vector of dichotomous response variables, and Z is a $J \times K$ matrix containing X, R and E. The error vector ε is assumed to be jointly normally distributed with conditional mean zero and covariance matrix standardized to a matrix of correlation coefficients Σ (Chib and Greenberg, 1998).

3.1.2 Intensity of Adoption

The paper estimates a tobit regression based on Greene (2012, Sec.19.3.2). A farmer chooses to adopt a strategy and decides on the proportion of land P^* on which to apply the strategy. The decision on the proportion is informed by farmer characteristics X, training E and rainfall outcomes R and other unobservable factors as shown in equation 5 below.

$$P_{ijt}^* = X_{ijt}'\beta_j + \delta_j R_{it} + \gamma_j E_i + \varepsilon_{ijt} \tag{5}$$

The desired proportion is censored on both ends and only observable within 0 and 1. The observed values of the proportion P will be

$$P_{ijt} = \begin{cases} 1, & P_{ijt}^* \geq 1 \\ P_{ijt}^*, & 0 < P_{ijt}^* < 0. \\ 0, & P_{ijt}^* \leq 0 \end{cases} \tag{6}$$

The tobit regression corrects the results for the high number of legitimate corner observations.

3.2 Data

This paper combines quantitative data comprising a rich survey of farmers and high-resolution satellite rainfall data and qualitative data from key informant interviews.

3.2.1 Quantitative Data

Our main data comes from Rural Agricultural Livelihood Surveys (RALS), a two-wave panel of geo-coded nationally representative rural households (IAPRI, 2016). The 2012 round enumerated 8,839 households. The 2015 round followed the same households with 680 additional households in Eastern, Lusaka and Muchinga provinces giving a total of 7,934 households, with 7,254 having been enumerated in the 2012 round.

The paper used high-resolution, daily satellite data from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS). CHIRPS uses the tropical rainfall measuring mission multi-satellite precipitation analysis to calibrate cold cloud duration rainfall estimates (Funk et al., 2015). The data is available at $0.25° \times 0.25°$ (approximately $27.75km \times 27.75km$) spatial resolution. The data is merged with RALS data and each farmer is linked to the nearest satellite rainfall observation point using a Stata command, *geonear* (Picard, 2012). This results in the longest distance between the farmer and the satellite point of 19.3km with a mean of 10.4km.

3.2.2 Qualitative Data

Primary in-depth interviews were conducted with Agriculture Extension Officers (AEOs) also referred to as Camp Extension Officers. The role of AEOs is to provide extension services in order to facilitate dissemination of information and technologies for improved agriculture at camp level, a subdivision of a district (MoA, 2019). The interviews solicited detailed information on the available supportive framework for climate change adaptation, as well as challenges and opportunities that each adaptation strategy presents. A multi-stage sampling approach was utilized. First, two farming districts were purposely selected, mainly to represent the two farming regions of the country: Monze in the low-rainfall southern region and Chisamba in the medium-rainfall central region.

At the time of the interviews, Chisamba had 16 AEOs while Monze had 39. However, only 10 were available in Chisamba and were all interviewed. In Monze, a systematic sampling method was used to select 11 from among AEOs who had clocked 5 years in their positions. In addition, one officer was interviewed from the District Agriculture Office in each of the two districts. Figure A.1 in the appendix shows the geographical locations of the key informants. The numbers are sufficient to attain both saturation and redundancy as defined in Cleary et al. (2014) and Trotter (2012). In the citation of key informants, MO denotes Monze and CH denotes Chisamba, while M and F denote male and female respondents, respectively.

3.3 Operational Definitions of Variables

This sub-section provides operational definitions of adoption of various adaptation strategies and selected independent variables.

3.3.1 Dependent Variables

The paper considers the use of planting basins, zero tillage or ripping as constituting minimum tillage (MT) and all other methods as conventional. Crop rotation (CR) refers changing crop on a plot in two consecutive seasons, while soil cover (SC) refers to either leaving crop residues or cutting and spreading them in the field, then ploughing/incorporating into the field. A farmer is considered to have adopted irrigation (IR) if they reported irrigating at least one crop field.

3.3.2 Rainfall Shock

We measure rainfall shock based on standardized monthly deviations from the long-term monthly averages and summed over twelve seasonal months as shown in equation 7a.

$$R_{it} = \sum_{m=1}^{12} \frac{(r_{itm} - \bar{r}_{im})^2}{\sigma_r^2} \tag{7a}$$

$$R_{it}^{-} = \sum_{m=1}^{12} \frac{(r_{itm} - \bar{r}_{im})^2}{\sigma_r^2}, \text{ if } r_{itm} < \bar{r}_{im} \tag{7b}$$

where $\bar{r}_{im}$ is the long-term average rainfall for month m at the location of farmer i. This captures *within-season* maldistribution of rainfall such as droughts, short dry spells, or excessive rains.

3.3.3 Human Capital

This paper measures household size as the number of members who are above 15 years and gender using the proportion of males among members above age 15. Male-dominated is defined as a household with a greater proportion of males relative to females. Male-dominated households are expected to have a higher probability of adopting new technologies. Education is measured as the highest level of education in the household, irrespective of whether it is attained by the head or another member, while age is the age of the head of the household. Training is treated as a binary indicator of receipt of advice or information on any agriculture aspect.

3.3.4 Social Capital

We measure social network as a binary variable indicating membership of a farmer cooperative, group or association by any member of the household. Remoteness is measured by the distance to a tarred road; we expect farmers closer to markets or motorways to have higher chances of adopting new technologies, compared to remote farmers.

3.3.5 Physical Capital

Farmer categories are 1 if cultivating less than 2ha; 2 if cultivating 2-5ha and 3 if cultivating more than 5ha. Ownership of enabling or specialised farming assets changes the cost of adopting new farming technologies. For instance, a ripper is designed for MT and owning one is hypothesised to increase the likelihood of a farmer adopting MT. Ownership of physical capital is measured by binary indicators of ownership of various farming assets including mouldboard plough, ripper, knapsack sprayer or other assets, as of the 1st of May preceding the farming season under observation. In Zambia, farming seasons arguably run from October through September (Mason et al., 2013). Measuring ownership of farming assets prior to the season helps avoid a potential endogeneity problem in which asset ownership is influenced by decisions on which farming technologies to adopt. In addition, we measure ownership of cattle by the number of cattle owned. We measure both the total land owned and total land cultivated and compute the ratio of land owned to land cultivated as a measure of land availability or adequacy (LA)

$$LA = \frac{L_O}{L_C},$$

where L_O is the area of land owned and L_C is the area of land cultivated.

3.3.6 Crop Diversification

The paper measures crop diversification at household level using the Simpson index of diversification (SID), based on the *Herfindahl-Hirschman Index* (HHI), as follows

$$SID = 1 - \sum_{j=1}^{k} P_j^2 \,,\ where\ P_j = \frac{A_j}{\sum_{j=1}^{k} A_j}, \quad (8)$$

where A_j is the total area under each crop. The index will range between zero for a mono-cropping farmer and close to one for a perfectly diversified farmer.

3.3.7 Plot Characteristics

The paper incorporates distance of the field from the homestead in km. *Dambo* is a binary measure of whether the field is located in a wetland/dambo area. “Floods” takes a value of one if the field is prone to flooding and zero otherwise. Zambia has a dual land tenure system: the leasehold system (mainly on state land) and the customary systems. According to the Ministry of Lands and Natural Resources (MLNR, 2017), the leasehold system provides documented state guaranteed rights of ownership and security of tenure, while the customary system lacks formal land documentation and the security of tenure is based on traditional institutions. The leasehold system is recognised for its advantages, including better security of tenure and use for collateral (Tagliarino, 2014). This paper defines tenure of land as one if under leasehold tenure and zero otherwise.

4. Descriptive Analysis

This section provides descriptive analysis as follows: demographic information in section 4.1, ownership of farming assets in section 4.2, adoption in section 4.3 and rainfall performance in section

4.1 Demographic Information

Selected demographic information about the respondent farmers is presented in table 1.

Table 1: Demographic Information of RALS Farmers

Variable	Obs.	Mean	Std. Dev.	Min	Max
Gender (% of males)	7,931	49.2	19.2	0	100
Age	7,931	48.66	14.8	16	105
Highest education	7,931	8.15	3.2	0	18
No. of adults	7,931	4.25	2.22	1	21
Distance to tarred road	7,930	27.57	35.98	0	300

The majority of household heads are males (79%) with an average age of 49 years. The highest level of education in a household is 8 years, corresponding to the first year of secondary education.[2] The average distance of the homestead from a tarred road is 27km with standard deviation of 36km. This is a highly skewed distribution, with extreme cases on the right pushing up both the mean and the standard deviation. A detailed examination shows the 95th and 99th percentiles are 100km and 175km respectively.

4.2 Ownership of Farming Assets

Table 2 shows the ownership of various farming assets and social networks among farmers.

Table 2: Descriptive Statistics of Selected Regressors

Variable	Obs.	Mean	Std. Dev.	Min	Max
Owns plough	7,930	.247	.431	0	1
Owns ripper	7,930	.032	.177	0	1
Owns sprayer	7,930	.218	.413	0	1
Owns oxen	7,930	.238	.426	0	1
o/w Number of oxen	1,876	3.60	2.9	1	54
Land owned	7,798	4.82	4.6	0	281
Land cultivated	7,798	2.32	2.38	0	45.5
Land tenure (leasehold=1) of fields	29,574	.044	.206	0	1
Any training	7,931	.709	.454	0	1
Cooperative membership	7,931	.506	.500	0	1
Women group membership	7,931	.215	.411	0	1
LSLS membership	7,931	.060	.238	0	1

[2] Zambia's education system has 7 years of primary and 5 years of secondary education.

Ownership of different farming assets are at 24.7% for a plough, 3.2% for a ripper, 21.8% for a sprayer and 23.7% for at least one pair of trained oxen. These are oxen trained for draft use and are part of the overall owned cattle. For comparison, 34% of households owned cattle, at an average of 11 cattle among households that owned cattle.

The size of land owned averaged 4.8ha with 95th and 99th percentiles of 14.1ha and 38ha respectively. The amount of land cultivated averaged 2.3ha with 95th and 99th percentiles of 6.5ha and 11.8ha respectively. The land availability shows that, on average, the size of land owned is about threefold of land cultivated. The land tenure variable shows that only a very small proportion (4.4%) of fields were under leasehold, with the remaining 95.6% categorised as customary.

About 71% of households have members who have undergone some training or advice on at least one of the practices. Social networks show that half of households have members belonging to farmer cooperatives, and 21% had membership in women's groups, while only 6% belonged to local saving and loans groups.

4.3 Adoption of Various Farming Practices

Table 3 shows the implementation of various strategies. Column (1) shows the percentage of farmers who implemented a strategy in the 2013/2014 season and the period since first implemented, shown in column (2). Of the adopters in column 2013/2014, column (3) shows the percentage that implemented in the 2014/2015 season. Finally, households that reported "No use" were asked if they had ever employed the practice in the past; responses are presented in column (4) of the table.

Table 3: Proportion of Farmers Practising each Strategy

Practices	(1) Implemented last season	(2) Started (yrs)	(3) Continued in current season	(4) Ever practiced in the past
Zero tillage	15.0	7.4	88.4	4.8
Minimum tillage (planting basins)	14.2	6.5	83.9	4.6
Ripping with animal draft power	12.5	8.2	92.1	2.1
Ripping with mechanical power	1.7	6.1	81.9	0.4
Crop rotation of cereals/legumes	49.3	8.9	96.5	9.5
Intercropping of cereals/legumes	12.3	8.0	90.7	5.8
Leaving crop residues in field	58.4	8.9	97.6	6.9
Using crop residues as mulch	16.0	7.7	96.4	1.6
Agroforestry	5.8	6.2	81.0	1.1
Irrigation	18.2[a]		16.6[b]	
Sample size	7,933			

[a] Proportion irrigating at least one field in 2012.
[b] Proportion irrigating at least one field in 2015

Between 12% and 15% of respondents employed the three types of MT. Crop rotation was also quite popular, practised by about half the respondent households, while intercropping was at 12%. The table shows that most households left crop residues in the field, a practice noted by Baudron et al. (2007). The average time from the year the household first practised the principle is between 6 and 9 years for all the practices.

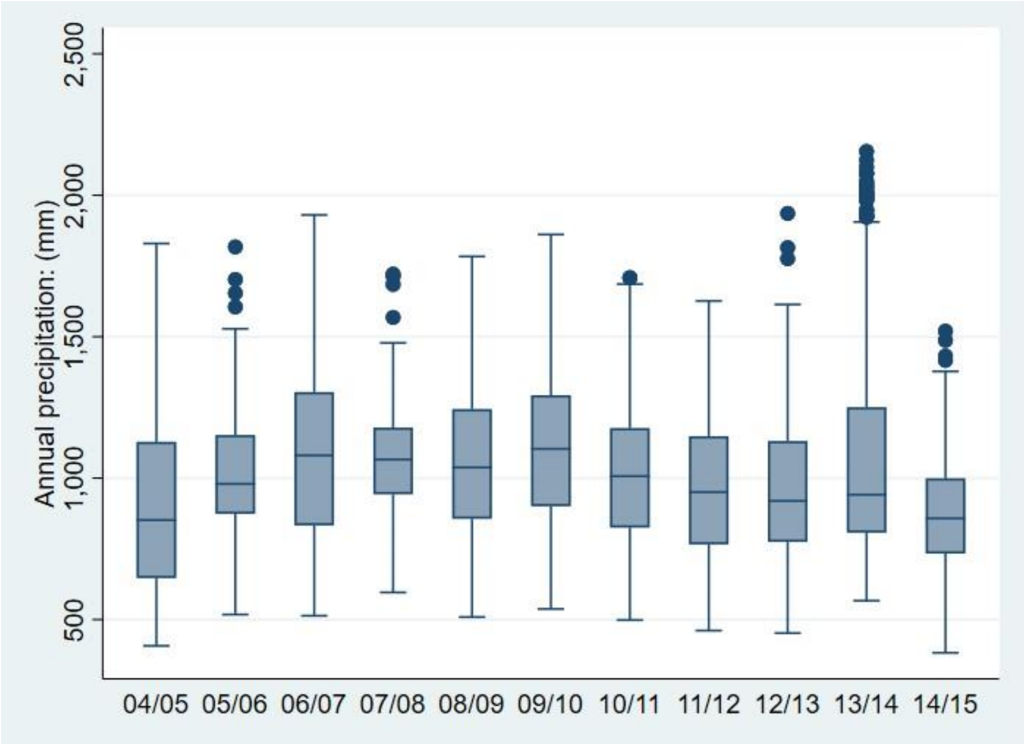
MT suffered from high rates of dis-adoption. For instance, of the farmers who implemented zero tillage in the 2013/2014 farming season, only 88.4% continued to use the practice in the 2014/2015 season. The most cited reason for abandoning MT was, *"too risky/uncertain due to land tenure insecurity"*. Among farmers who left crop residues in the field, almost all of them (97.6%) continued with the practice in the 2014/2015 season. As noted by Baudron et al. (2007), crop residue management is mostly a cultural issue. Farmers leave the residue in the field and allow free grazing.

Adoption of irrigation also remains low and seemingly is declining. The proportion of farmers reporting irrigating at least one field actually fell from 18.2% in the 2012 survey to 16.6% in 2015. These results were also reported by Ngoma et al. (2017). Overall, the adoption of various practices is comfortably higher than was recorded by Arslan et al. (2015) from the 2004 and 2008 surveys of similar representation.

4.4 Rainfall Performance

The performance of rains between the 2004/2005 agricultural season and 2014/2015 season, based on the satellite data, is shown in figure 1 using the box plot.

Figure 1: Annual Precipitation at each Satellite Point



The figure shows that rainfall has been fluctuating between 2004 and 2010. The median was lowest in the 2004/05 season, rose to a high in the 2006/07 season, then dropped in the next two seasons. It rose to the all-time high in the 2009/2010 season. From the 2009/10 season, it has been declining in each agriculture year. These observations were also echoed by a number of key informants:

"The change of climate has been there, because even the rainfall pattern has changed. The rains are coming very late instead of the right time when it's supposed to be there." (CH,F)

"it was fine and above 800mm. Recently, especially for last year, it was less than 500mm. The rains have decreased compared to some years." (CH,F)

"Since I came in 2013, rains have been very erratic. ..., our rains season was starting mid-December, that is when we can experience serious rains, except this year when it started in November. But even though it started in November, there have been gaps, it rains maybe weekly." (CH,M)

"There are so many changes or variations in rainfall patterns. ... The climate was okay though with occasional dry spells. But the past two farming seasons, they have been dry spell at times, causing a reduction in output." (MO,F)

"For the past 10 years, the first five years it was better but now it is getting worse. It is getting hotter and the rain is erratic. The temperatures are rising, even if it is raining, the temperature is rising." (MO,F)

"Data for the past 12 years and we can see that things are not the same. ... Most of the rains we receive is below 800 and we have a few years when we had close to 800 and a year or so when we had above 800mm. ... The amount of rains that we receive is varying. Like last year, we received about 398mm. Actually, it reached 398 because at the end of the season when the crop was already damaged, we received a good amount of rainfall. Otherwise, the whole rain season was about 273mm. ....So we can see that the distribution of rainfall has changed, which is telling us that climate change is real. The temperatures are increasing, compared to previous seasons. The amount of rainfall received is reducing as we go on and they are also varying and the distribution has changed." (MO,F)

"There has been a change in the weather pattern. In the past years, it used to rain a lot and rains used to start somewhere in November and ending in April. But this time around, rains start late. Starting from somewhere in 2015, there was late onset of rain season and it has been ending fast. The rain season has been shortened" (MO,F)

The verbatim quotes above attest to the local awareness or perception of the changing climate which has resulted in decreased and erratic rainfall activities. Although this is coming out of both districts, the number of comments seems more pronounced from Monze. Of notable concern also is the changed distribution of rains, particularly the shortening duration. The rains not only start late, but also end early, resulting in reduced volume and duration, both of which are critical for crop performance (Guan et al., 2015).

5. Results and Discussion

The preceding subsection provided a preliminary analysis of the data. This subsection analyses the data and discusses the findings. The sections tackle adaptation from four angles as follows: Section 5.1 explores the policy and support available for climate change adaptation among smallholder farmers. The next two sections discuss different measures of adaptation: choice of adaptation strategy in 5.2 and intensity of adoption in section 5.3. The sections blend quantitative and qualitative data.

5.1 Adaptation Policy and Options

This section documents strategies that farmers are employing to adapt to climate change, and the policies and support available, mostly based on key informant interviews and review of policy documents.

There are a number of climate smart agriculture practices currently being promoted and practised in Zambia. These include CF, crop diversification, better seed varieties with emphasis on early maturing varieties, irrigation, and crop insurance (Arslan et al., 2014; Baudron et al., 2007). To help document camp level strategies, key informants were asked the question, "What policy and strategies are being implemented to support smallholder farmers in adapting to climate change?" Respondents described all the strategies they were promoting in their catchment areas. The responses are then classified into the major CSA practices and the frequencies of respondents subscribing to each strategy shown in table 4.

Table 4: Climate Smart Practices Being Promoted

Practice	Mentioned by	
	Number	Percent
Conservation farming (CF)	17	73.9
Crop diversification	5	21.7
Improved varieties	6	26.1
Irrigation	4	17.4
Small livestock	4	17.4

The responses show that most respondents (74%) were engaged in promoting the adoption of CF as a response to climate change. CF is considered the major policy response to climate change and efforts have been intensified to promote its adoption as described in the cited phrases.

"there are a set of climate smart agriculture technologies that we are promoting and one of them is CF" (MO,F)

"The whole of this season, there has been a program on radio and television on the issue of smart agriculture, encouraging farmers to take up CF for them to have good yield."(CH,M)

"for me as a Camp Officer, I have been preaching about the very CF" (MO,F)

"We are also encouraging our farmers in the efficient use of water in irrigation, promoting drip irrigation, growing of vegetable as a coping mechanism." (MO,F)

Other practices were mentioned by few respondents. For instance, just over a quarter were promoting the use of improved or suitable seed varieties, often early maturing varieties,[3] while 21.7% mentioned crop diversification, which is lauded for spreading the risk of crop failure.

"facilitating so that they start diversifying. When they grow maize, they grow cow-peas, sweet potatoes. If maize fails, at least maybe groundnuts can do better and they can survive." (CH,F)

"we have intensified on crop diversification so that there is something that can tolerate this weather or climate difference"(CH,F)

"We are also encouraging our farmers in the efficient use of water in irrigation, promoting drip irrigation, growing of vegetable as a coping mechanism." (MO,F)

Crop diversification is often promoted alongside CF because it provides an enabling environment for the adoption of CR. However, there are still major challenges on smallholder farmers diversifying from the traditional maize growing culture. Key informants raised two major barriers to crop diversification, affecting mostly smallholder farmers. The first relates to availability of certified

[3] This is a yield-safety trade-off. While early maturing varieties offer better yields under water stress, late maturing varieties offer better yields when well watered (Katengeza et al., 2018; Waldman et al., 2017)

seed for alternative crops. Most seed producers, and hence dealers, concentrate on maize seed, neglecting other crops. The following key informant quotes attest to this problem:

"there is the issue to do with the availability of legume seeds. I can't walk into an agro-shop and buy either beans or groundnut. Usually they are in short supply. They are not readily available. So what the farmer has to rely on is recycled seed."(CH,M)

"cow peas in most cases farmers use recycled seed. It's not that it is their wish. Even when you go on the market, there is a shortage of certified seed for legumes. Even just soybeans, it's not there. ... You find that these seed companies, their concentration is maize, maize, maize." (MO,F)

In growing other crops, farmers are forced to rely on recycled seed, for which there is overwhelming evidence of suboptimal yield (Wineman et al., 2020). This has contributed to *maize-centric* agriculture, with secondary repercussions on adoption of CR and food security.

The second barrier to crop diversification pertains to availability of output markets. Farmers grow alternative crops for the monetary value on the market. However, evidence points to the absence of structured markets in most rural areas for crops besides maize as a major barrier.

"Then the farmer will not grow things for the sake of growing, they will also look at [the market] .... The cereal already has a structured market, but for the legumes it's different. I may grow beans and I may not have a ready market to sell the beans, I may grow groundnuts, I will not have a ready market for that. So why should I grow it at a large scale despite being told the benefits?"(CH,M)

"... they always talk about available markets for other crops. They know that maize, they can sell to FRA [Food Reserve Agency] or briefcase buyers. But if one wants to maybe grow four (4) hectares of groundnuts, where would they find the market for groundnuts? Those are the issues coming out from the field."(MO,M)

"we saw a lot of farmers still going back to maize .... Of course you can't really blame them, the issues of market. Farmers ... can grow anything as long as they have an assured market. Because of issues of markets, you find them involuntarily going back to maize production."(MO,F)

The government food reserve program is mostly restricted to maize and there are no reliable private buyers of other crops, save for a few crops like tobacco, cotton and soybeans which have dedicated buyers. Most other legumes such as groundnuts and common beans rely on private small-scale traders for their market (Mofya-Mukuka and Shipekesa, 2013).

Although irrigation is considered critical in the response to climate change, its adoption and support are hampered by more frequent water shortages. Precipitation deficits do not only cause crop failure, but have also led to non-availability of water for irrigation. There are also cases where irrigation is banned in preference to conserving the limited water for livestock, as is evident from the comment below.

"the level [water] was very low, some of them were even told to stop [irrigation] so as to reserve water for the animals. ... A lot of people are discouraged because the fear is that water may run dry midway of irrigation and forced to stop midway."(CH,M)

The evidence implies that irrigation is not always a feasible option, especially for smallholder farmers, the majority of whom rely on surface water (Akayombokwa et al., 2015). In extreme cases, droughts have also led to dried up water reservoirs and streams. This may explain the low importance that key informants attached to irrigation.

Although this section has highlighted a number of climate adaptation strategies, the rest of the paper will focus on the adoption of irrigation (IR) and CF principles, namely minimum tillage (MT), crop rotation (CR) and soil cover (SC). The available data does not allow for a conclusive analysis of the adoption of improved seed varieties and livestock.

5.2 Choice of Adaptation Strategy

This section analyses a farmer's choice to adopt or not to adopt a particular practice. A farmer makes an adoption choice on each practice in a seemingly independent manner. However, because different practices tend to complement or substitute each other, a farmer's choice on one may not be completely independent of the adoption status of other practices (Kassie et al., 2013; Mulwa et al., 2017). A post-estimation correlation matrix table (table 6) shows significant correlations among error terms, necessitating the choice of SUR over standard probits. Therefore, a multivariate or SUR probit, based on Zellner's (1962) SUR model, is preferred to standard probit models. The SUR model has the advantage of dealing with potentially correlated disturbance terms and is also efficient compared to the standard probit (Wooldridge, 2010, p.595).

We replicate the SUR probit model from equation 4 below

$$Y_i^* = Z_i'B + \varepsilon_i \tag{9}$$

Where, again, Y is a vector of binary adoption variables, and X is a matrix of plot and household level explanatory variables, while B is the vector of parameters. The ε is assumed to be jointly normally distributed as $\varepsilon \sim N(0, \Sigma)$, where Σ is a covariance-variance matrix standardized to a matrix of correlation coefficients based on Chib and Greenberg (1998).

The estimation is performed at two levels: household and plot levels. Household level estimation highlights the role of household attributes in driving adoption, while plot level estimation provides an additional examination of plot or field characteristics in the decision to adopt various adaptation strategies.

The SUR probit regression results are shown in table 5. Columns (1-4) show household level estimation while columns (5-8) are plot level results, with additional plot level explanatory variables. The post-estimation table of the correlation coefficients matrix Σ for both household and plot level regressions is given in table 6.

Table 5: Adoption of Farming Practices

VARIABLES	(1) MT	(2) CR	(3) SC	(4) IR	(5) MT	(6) CR	(7) SC	(8) IR
Gender (male=1)	-0.0973	0.1031	0.0545	-0.2611	-0.0425	0.1010***	0.0290	-0.1573
	(0.1208)	(0.0653)	(0.0642)	(0.2694)	(0.0691)	(0.0376)	(0.0374)	(0.1554)
age	0.0095	-0.0053	-0.0011	-0.0196	0.0111*	-0.0022	-0.0019	-0.0078
	(0.0105)	(0.0055)	(0.0053)	(0.0214)	(0.0060)	(0.0032)	(0.0031)	(0.0128)
educ_highest	0.0052	-0.0212***	0.0152***	0.0177	-0.0017	-0.0166***	0.0148***	0.0057
	(0.0083)	(0.0046)	(0.0045)	(0.0182)	(0.0049)	(0.0027)	(0.0026)	(0.0105)
adult_number	-0.0002	0.0106	-0.0059	0.0168	-0.0149**	0.0039	0.0012	-0.0034
	(0.0122)	(0.0070)	(0.0069)	(0.0234)	(0.0070)	(0.0039)	(0.0039)	(0.0140)
distance_tarmac	-0.0003	-0.0019***	-0.0008**	0.0010	0.0002	-0.0020***	-0.0011***	-0.0001
	(0.0007)	(0.0004)	(0.0004)	(0.0013)	(0.0004)	(0.0002)	(0.0002)	(0.0008)
owns_plough	-0.2931***	0.0657**	-0.0484	0.2348**	-0.2560***	0.0043	0.0137	0.0899
	(0.0631)	(0.0324)	(0.0316)	(0.1185)	(0.0357)	(0.0186)	(0.0184)	(0.0703)
owns_ripper	0.9424***	0.1641**	0.0653	-0.0012	1.0337***	0.1014***	0.1147***	-0.0193
	(0.0874)	(0.0687)	(0.0677)	(0.2278)	(0.0463)	(0.0363)	(0.0357)	(0.1274)
owns_sprayer	0.2860***	0.2866***	-0.0755**	0.0292	0.2291***	0.2565***	-0.1001***	0.0680
	(0.0555)	(0.0328)	(0.0326)	(0.1218)	(0.0316)	(0.0185)	(0.0184)	(0.0698)
cattle_number	-0.0048	-0.0047***	0.0000	0.0011	-0.0062***	-0.0046***	-0.0000	0.0022
	(0.0031)	(0.0013)	(0.0011)	(0.0031)	(0.0019)	(0.0007)	(0.0006)	(0.0017)
land_avai	-0.0329***	0.0019	-0.0019	0.0043**	-0.0383***	0.0023**	-0.0022*	0.0037**
	(0.0112)	(0.0016)	(0.0017)	(0.0020)	(0.0066)	(0.0011)	(0.0013)	(0.0017)
any_trained	0.3862***	0.2061***	0.0131	-0.1472	0.3701***	0.1473***	0.0074	-0.0218
	(0.0648)	(0.0290)	(0.0283)	(0.1091)	(0.0363)	(0.0165)	(0.0164)	(0.0676)
SID	0.2752***	1.5012***	-0.0990*	0.1842	0.1754***	1.4100***	-0.0366	0.0961
	(0.1023)	(0.0556)	(0.0524)	(0.2150)	(0.0668)	(0.0366)	(0.0350)	(0.1438)
_Icategory_2	-0.1218**	0.0273	0.0320	-0.1290	-0.0784**	-0.0045	-0.0043	-0.1058
	(0.0556)	(0.0296)	(0.0293)	(0.1248)	(0.0320)	(0.0171)	(0.0171)	(0.0744)
_Icategory_3	-0.0585	0.0614*	0.0043	0.0252	0.0443	0.0397**	-0.0058	0.1696**

	(0.0621)	(0.0342)	(0.0338)	(0.1281)	(0.0362)	(0.0202)	(0.0202)	(0.0768)
soc_net_coop	-0.0782	0.0872***	0.0491*	0.0416	-0.0653**	0.0807***	0.0321**	0.0749
	(0.0486)	(0.0261)	(0.0258)	(0.1043)	(0.0276)	(0.0149)	(0.0149)	(0.0609)
soc_net_lsls	0.0980	0.0136	0.0973*	0.1787	0.2038***	-0.0293	0.1587***	0.1312
	(0.0890)	(0.0560)	(0.0552)	(0.1804)	(0.0461)	(0.0305)	(0.0303)	(0.1044)
R_minus	0.0072	-0.0112	-0.0668***	0.0197	0.0242**	-0.0129***	-0.0482***	-0.0165
	(0.0185)	(0.0085)	(0.0083)	(0.0368)	(0.0096)	(0.0044)	(0.0044)	(0.0200)
R_minus_1	-0.0102	0.0355***	0.0555***	-0.0282	0.0087	0.0386***	0.0648***	-0.0230
	(0.0223)	(0.0105)	(0.0102)	(0.0447)	(0.0118)	(0.0059)	(0.0058)	(0.0256)
_Iyear_2015	0.6036***	-0.0436	-0.5074***	0.2676**	0.6482***	-0.0220	-0.4352***	0.1350*
	(0.0744)	(0.0339)	(0.0331)	(0.1363)	(0.0401)	(0.0189)	(0.0186)	(0.0760)
hect					-0.0254**	0.0471***	-0.0062	-0.0464*
					(0.0103)	(0.0053)	(0.0053)	(0.0243)
dist_field					-0.0029	-0.0062***	-0.0050**	0.0081
					(0.0040)	(0.0020)	(0.0020)	(0.0075)
dambo					0.1068***	-0.1631***	-0.0961***	0.3376***
					(0.0390)	(0.0227)	(0.0227)	(0.0691)
floods					-0.0341	-0.2123***	0.0336**	-0.1813***
					(0.0283)	(0.0160)	(0.0159)	(0.0590)
tenure					-0.1720***	0.0641**	0.0790***	-0.0793
					(0.0640)	(0.0290)	(0.0286)	(0.1270)
Constant	-2.1772***	-0.8942***	0.0967	-2.485***	-2.6424***	-0.4198***	-0.1648*	-2.2062***
	(0.2956)	(0.1503)	(0.1463)	(0.5929)	(0.1757)	(0.0901)	(0.0889)	(0.3641)
Observations	11,599	11,599	11,599	11,599	35,799	35,799	35,799	35,799

Standard errors in parentheses : *** p<0.01, ** p<0.05, * p<0.1

There is a marginal influence of gender on the adoption of CR at, with male domination in the household (as defined in Section 3.3.3) positively affecting plot level adoption of CR. The probability of adopting MT on a given plot increases with the age of the head of household, albeit at a decreasing rate, with a turning point at about age 60 years. This finding is consistent with Chompolola and Kaonga (2016), who noted that age increases exposure to technologies and environments and accumulation of physical and social capital, which increase adoption. But beyond a certain level, age is associated with lost energy, increased aversion to risk, and short planning horizons, which do not favour adoption of new technologies, as observed by a number of studies (Kassie et al., 2013; Teklewold et al., 2013).

The highest level of education in the household has a negative impact on adoption of CR but a positive impact on SC. Household size increases the adoption of CR, but is insignificant on other practices. Larger households are more likely to commit more land to cash crops, allowing the practice of crop rotation with the staple crop.

The degree of remoteness, measured by the distance to a tarred road, has a negative impact on the adoption of CR and SC at both household and plot level. Remoteness may be associated with limited access to information and other support services which may be cardinal to the adoption of better farming practices. This is consistent with *a priori* assumptions.

Ownership of specialized implements, particularly rippers, has significant impact on MT and CR. This is not surprising given the ripper is designed for MT. The ownership of a sprayer also has a positive impact on MT and CR but a negative impact on adoption of SC at household level. MT is associated with the use of herbicides (Brown et al., 2018; Grabowski et al., 2014), which require the use of sprayers. Ownership of a sprayer also encourages the cultivation of crops such as cow-peas or cotton (CFU, 2007, p.33) which are suitable for rotation with cereals but susceptible to pests and diseases.

Households that own more cattle are less likely to adopt MT and CR. With more animal draft power, the household is more inclined to conventional tillage and mono-cropping the staple crop, which has the effect of suppressing the adoption of CR. Training or farmer orientation shows consistently significant impact across all farming practices. This finding is important as it highlights the importance of agriculture extension services in the adoption of better farming technologies. The results are consistent with findings from other studies (Habanyati et al., 2018; Lalani et al., 2017; Pedzisa et al., 2015).

Both category 2 and 3 farmers (large in size) are more likely to adopt CR. This is evident at both household and plot levels. Larger farmers tend to grow large portions of cash crops such as soybeans and cotton, which permit rotation with cereals. In addition, crop diversification, as measured by the Simpsons index of diversification (SID) in equation 8, is positively associated with the adoption of all practices at household level and MT, CR and SC at plot level, with a visibly high coefficient on CR. Crop diversification allows the cultivation of crops that may require different levels of tillage, hence departing from the traditional intensive tillage associated with maize. More importantly, crop diversification has a remarkable influence on the adoption of CR. As noted earlier, crop diversification is the basis upon which crop rotation thrives (Kassie et al., 2013; Pedzisa et al., 2015). In addition, the culture of mono-cropping was heavily cited as a hindrance to adoption of CR by most key informants.

Membership in farmer groups such as cooperatives and loans and savings groups generally increase the chances of adopting CF-based principles but not irrigation. Similar results were found by Teklewold et al. (2013) in Ethiopia and Zulu-Mbata et al. (2016) in Zambia. Farmer groups provide a platform for receipt of extension and support services and for sharing of knowledge and vital community resources among farmers. These have the effect of encouraging adoption of new farming technologies.

The field size or hectarage has a marginally significant positive impact on adoption of CR but is negative on the adoption of irrigation. Irrigation levels still remain low and often restricted to very small portions of land (Akayombokwa et al., 2015; Ngoma et al., 2017). Therefore, farmers are less likely to irrigate large fields.

Farmers are also less likely to implement any of the CF principles on fields that are far from the homestead. In Kassie et al. (2013) and Zulu-Mbata et al. (2016), distance to plot was found to have a negative effect on adoption of CF related practices such as CR and SC. Teklewold et al. (2013) found similar results and concluded that distant fields tended to receive less attention and farmers tended to apply new and beneficial technologies on nearby fields.

The location of a field near in a wetland/dambo area has a negative impact on the adoption of CR and SC but a positive impact on the adoption of irrigation. Not many crops are tolerant to dambo or wetland conditions, therefore limiting the practice of CR. Irrigation is driven by the location of a field in a dambo area. It was mentioned in Akayombokwa et al. (2015) that irrigation in Zambia is mainly practised in low-lying wetlands or dambo areas. This was also highlighted by a number of key informants, that irrigation is still restricted to surface water, either along streams or in dambo areas.

Fields that are prone to flooding are less likely to be crop rotated. Nonetheless, there is evidence of adoption of SC. SC has been noted for its role in minimizing soil erosion, which is often exacerbated by floods. This result may be pointing to farmers taking proactive steps to minimize soil erosion through the adoption of SC in flood-prone fields.

The impact of rainfall extremes depends on how the rainfall shock is defined and measured. When defined as standardized deviations based on equation 7a, we find no significant contribution. However, when the shock is defined by negative deviations, that is, measuring standardized precipitation deficits using equation 7b, there is a positive contemporaneous effect on MT and CR. This indicates that farmers respond to exposure to rainfall deficits by adopting MT. This was also found by Kassie et al. (2013) and Zulu-Mbata et al. (2016) and a number of key informants were also of the view that farmers are quick to adopt MT when they experience the effects of droughts or dry spells.

At the plot level, exposure to rainfall deficits reduces the probability of adopting CR and SC. It was noted earlier that farmers respond to threats of droughts by concentrating on maize, at the expense of CR. One key informant stated that, "They just concentrated on maize immediately they received early rains. Most of them planted maize than other crops." Further, droughts also lead to less pasture, which increases the pressure of livestock on crop residue (Arslan et al., 2015). A few KI sentiments are worth citing:

"I think it can be easy for them to adopt because they can see the effects of climate change now unlike in the past whereby we were telling them to do CF." (CH,M)

"Some farmers have started adopting [MT], after seeing the weather pattern." (CH,F)

These results show that exposure to climate extremes, especially dry spells and droughts, are significant contributors to adaptation decisions. There is inertia among farmers to adapt until they experience the effects of climate change, as evidenced from the following excerpts from key informants:

"it is very difficult to appreciate CF when there is abundant rains and it's all good because they are harvesting", (CH,F)

"Challenges to adoption include the behavioural aspect. Farmers take agriculture as a tradition and can't adopt new methods." (CH,M)

"Because when you tell the farmer, 'can you change from this to this', they say, No, I have been doing this for a long time. What can you tell me, I know everything" (CH,F)

"Others will say, this is what our forefathers have been doing and they have been harvesting." (MO,M)

These sentiments give an indication of farmers' inertia in adopting new technologies and underscore the importance of information sharing through extension services.

The post-estimation table of correlation coefficients matrix Σ from the SUR probit regressions in table 5 are given in table 6. This table is important to show the presence or absence of correlation in the disturbance terms, which guides the choice between the SUR model and standard probit models.

Table 6: Correlation Matrix Based on SUR Probit Regressions in Table 5

	Household level			Plot level		
	MT	CR	SC	MT	CR	SC
CR	.220157			-.0132961		
SC	-.0103371	-.0464641***		-.004571	-.008759	
IR	-.0746298	.0215177	.0922238**	.0067574	-.007110	.0664267**
LR test	$\chi^2(6) = 18.3729, p = 0.0054$			$\chi^2(6) = 6.79495, p = 0.3402$		

The table shows a strong pairwise correlation only between CR & SC and SC & irrigation at household level adoption. There is a negative correlation between the adoption of CR and SC and a positive correlation between SC and irrigation. This might reflect the common practice of mulching in garden nurseries, a common feature of gardening and irrigation, or that farmers are more conscious with conserving water on irrigated crops than rain-fed crops. The likelihood ratio test for the significance of the pairwise correlation coefficients rejects the null of zero correlations with a chi-square value of $X^2(6) = 18.4$. This validates the use of the SUR model over the standard probit models, as farmer decisions are interdependent.

At plot level, there is a marginally significant correlation between SC and irrigation. This means fields that are irrigated are also likely to have SC implemented. In general, however, the likelihood ratio test fails to rule against the null of zero correlations. The results point to the low tendency of implementing many practices on the same plot. While farmers may adopt many practices, this finding implies that farmers seldom implement them on the same plot, negating the potential complementary benefits of multiple practices. The results also show that irrigation is driven, not so much by farmer characteristics or abilities, but by field characteristics. The results strongly suggest that irrigation is driven by the location of the field near a source of surface water, mainly dambos or wetland.

5.3 Intensity of Adoption

The intensity of adoption is important to understand the level, depth or degree of adoption of farming practices. To help illustrate the measurement of intensity, consider the case of adoption of MT. A farmer is assumed to own k fields and the hectarage of each is known to be h_{ij}, where i denotes the household and $j = 1, \dots, k$ denotes the field. In respect of each crop field, a farmer indicates the tillage method used, which is categorized as MT or conventional based on the definition in section 3.3.1. The farmer also indicates the proportion of the field p_{ij} on which the tillage method was used. The proportion is zero if the whole field was under conventional tillage. The household level intensity of MT is then given as

$$P_i^{MT} = \frac{\sum_{j=1}^{k} p_{ij} h_{ij}}{\sum_{j=1}^{k} h_{ij}}. \qquad (10)$$

The intensity P_i^{MT} will be zero if the household did not adopt the MT and 1 if all the land was under MT. The same procedure is used on other practices to compute P_i^{CR} for crop rotation, P_i^{SC} for soil cover and P_i^{IR} for irrigation.

A random effects tobit regression in line with Papke and Wooldridge (2008) is run on each proportion on the Xs, which include farmer characteristics, receipt of training and exposure to rainfall shocks. The tobit regression model, when the lower and upper bounds are set to zero and one respectively, simplifies to

$$E(y|0 < I_{it} < 1) = X_{it}'\beta + \sigma \frac{\phi\big((-X_{it}'\beta)/\sigma\big) - \phi\big((1 - X_{it}'\beta)/\sigma\big)}{\Phi\big((1 - X_{it}'\beta)/\sigma\big) - \Phi\big((-X_{it}'\beta)/\sigma\big)}, \qquad (11)$$

where $\Phi(\cdot)$ and $\phi(\cdot)$ are the cdf and pdf of a normal distribution, respectively. The above model is run on the intensities of the four adaptation strategies and results provided in table 7.

Table 7: Regression Results for Intensity of Adoption

	(1)	(2)	(3)	(4)
VARIABLES	p_MT	p_CR14	p_SC13	p_IR13
gender (male=1)	0.0421	0.00542	0.022	0.0541***
	-0.0622	-0.0183	-0.0374	-0.0156
age	0.012	-0.00265	-0.00645	-0.00292
	-0.0112	-0.0031	-0.00626	-0.00251
educ_highest	0.0177**	-0.0159***	0.0265***	0.00444**
	-0.00887	-0.00254	-0.00509	-0.00215
adult_number	0.0421*	0.0151**	-0.00743	-0.0037
	-0.0221	-0.00645	-0.0138	-0.00534
_Icategory_2	-0.0896	0.0332**	-0.0241	0.000186
	-0.0568	-0.016	-0.0326	-0.0131
_Icategory_3	0.125**	0.0955***	-0.0748**	0.0235*
	-0.0635	-0.018	-0.0371	-0.014
SID	0.814***	1.257***	-0.174***	-0.028
	-0.108	-0.0323	-0.0634	-0.0248
distance_tarmac	0.000342	-0.00162***	-0.00101***	-0.000576***
	-0.000686	-0.000189	-0.000393	-0.00017
owns_plough	-0.171***	0.0116	-0.243***	0.0261**
	-0.0581	-0.0165	-0.034	-0.0126
owns_ripper	0.544***	0.0427	-0.013	0.00828
	-0.144	-0.0378	-0.0741	-0.0263
cattle_number	-0.00503*	-0.00105*	-0.000669	0.000906***
	-0.00278	-0.000593	-0.00121	-0.00035
land_owned	-0.00203	0.00163**	0.00156	0.000727*
	-0.00271	-0.000814	-0.00148	-0.00044
any_trained	0.487***	0.147***	0.0176	0.0622***
	-0.0647	-0.0156	-0.0319	-0.0136
soc_net_coop	-0.0307	0.0486***	0.0579**	0.0299***
	-0.0493	-0.0141	-0.0289	-0.0113
soc_net_lsls	0.239***	-0.0298	0.216***	0.0423*
	-0.0889	-0.0298	-0.0619	-0.0225
R_minus	0.00843	-0.0168***	-0.0599***	-0.0288***
	-0.0188	-0.0046	-0.00909	-0.00397
R_minus_1	-0.0332	0.0365***	0.0721***	-0.00303
	-0.0239	-0.00586	-0.0117	-0.00425
R_minus_2	-0.237***	0.0205***	-0.0585***	0.0151***
	-0.0249	-0.00544	-0.0108	-0.00437
_Iyear_2015	1.615***	0.0715	-0.972***	-0.0737
	-0.296	-0.074	-0.147	-0.0516

Constant	-3.538***	-0.342***	1.182***	-0.357***
	-0.414	-0.112	-0.224	-0.0852

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The results show that male dominated households tend to irrigate larger proportions of land than comparable female dominated households. The age of the head of household is insignificant across all the practices. The level of education in the household has a positive impact on the intensity of all but CR. The number of adults in a household is associated with higher intensities of MT and CR. With more family labour, a household can comfortably increase hectarage of cash crops which provide a basis for the adoption of CR.

Similarly, category 2 and 3 farmers have higher intensity of CR compared to the category 1 farmers. Larger farmers grow large portions of cash crops, some of which may be suitable for rotation with maize, such as soybeans, cotton, etc. The intensity of SC and IR declines with higher categories of farmers.

The index of crop diversification (SID) is positively related to the intensity of MT and CR. Some crops may not require as intensive tillage as maize, which explains crop diversification being positively associated with intensity of MT. The results on CR are in line with earlier expectations. Crop diversification provides a basis for the practice of crop rotation (Kassie et al., 2013; Pedzisa et al., 2015) as noted earlier in the paper. In addition, a number of key informants cited low crop diversification as the major hindrance to the intensity of crop rotation. The following key informant sentiments are worth noting:

"Then crop rotation also, monoculture is also high"(MO,F)

"Usually, legumes they plant small areas compared to cereal crops. So now to rotate a cereal crop where a legume was, it can't fit properly."(CH,M)

"They prefer planting, a big area they plant maize and a small area they plant legumes, a combination of legumes they plant it in the other side (CH,F)

"you find that the maize portion is very big and for groundnuts very small. So next year, you find it will not balance. They don't have equal portions of land to balance with maize. Farmers are concentrating much on maize" (CH,M)

"the legumes are done on a smaller piece. They don't do it on a big field"(MO,F)

"because they don't grow big fields of legumes. They would have maybe five (5) hectares of maize and maybe just 2 lima [1lima=0.25ha] of groundnuts" (MO,F)

The results therefore confirm the above sentiments, that the intensity of crop rotation is being limited by disproportionately small portions of land committed to crops other than maize. As farmers diversify or increase the proportions of other crops, the intensity of crop rotation also increases. Very remote farmers have low intensities on all but MT. Remote farmers have limited access to essential information and support services for adoption of new farming technologies. Ownership of implements such as a ripper has a positive influence on the intensity of MT, consistent with prior expectation. Farmers with more cattle tend to have low intensity on all the practices.

Training does enhance the intensity of adoption of all practices, save for an insignificant coefficient on SC. Key informant evidence shows concerted efforts to promote the adoption of CF. Our results show that farmers who attended some training tended to implement the new practices on a much larger proportion of their fields. Trainings or extension services help farmers appreciate the benefits of the new farming technologies.

Membership in farmer groups produces varying results. This may be due to varying orientations, objectives and approaches of different groups. Although these serve to promote peer learning, some do specialize in particular areas of agriculture. For instance, there are groups that will only deal with irrigation and not touch on other aspects of agriculture. The paper is unable to disaggregate this due to limited data available.

The results show that there is less CR, SC and irrigation when there is rainfall deficit. There is evidence from key informants that threats of drought cause farmers to concentrate on maize, the staple crop. This has the effect of diminishing the intensity of CR as farmers diversify less. In addition, droughts also put pressure on the use of crop residue for animal feed, reducing its alternative use as soil cover. While irrigation may be a natural response to droughts, severe droughts have actually led to drying up of surface water, the major source of irrigation water for smallholder farmers. In some cases, local/traditional authorities have had to ban irrigation in preference to conserving water for the livestock.

Our earlier expectation was that farmers exposed to climate extremes would be more likely to adopt these practices as an adaptation measure. There are plausible explanations from key informants. The intensity of MT, for instance, is said to be partly hampered by weakened animal draft power due to depleted pastures in periods before the onset of the farming season. As conservation-based MT ought to be done before the onset of rains, as opposed to the conventional tillage which is performed after the onset of rains, farmers are not able to begin MT because they depend on animals that do not have enough strength due to lack of pasture. We cite a few key informants:

> *"They have seen it's [climate change] real, they have no option but to do away with conventional farming to go to CF. The animals were weak, finished. Towards ripping time, animals were weak, such that they could not go and rip in the field because there wasn't enough grass, not enough water and unfortunately when that first rain came, most animals again died." (MO,F)*

> *"and water for livestock, grass for livestock are a problem. So you find that when rain season come, the cattle are very weak because they had no food" (MO,F)*

"we didn't have grass and water and the main draft power here is cattle. If you look at the state in which the animals are, it is pathetic. Even if today the rains come, the animals don't have the energy to till." (MO,F)

While farmers may be inclined to adopt MT in response to rainfall deficits, the deficits also create an inhibiting environment by affecting the source of draft power. When the rains finally come and animals have gained some strength, MT is no longer tenable because of weeds which would be overgrown in the fields. Use of herbicides also remains low among smallholder farmers (Mutale et al., 2017). At that point, farmers go for conventional thorough tillage, in order to also remove overgrown weeds.

Drought also affects CR adoption, as farmers respond to threats of droughts by prioritizing maize, the staple crop. When the rains are low, farmers will make all efforts to grow maize, at the expense of other crops. As a result, they are less likely to provide for other crops that can be rotated with the staple crop. The practice of SC is hampered by two drought related factors: First, cover crops are not well developed because of droughts. Second, because of lack of pastures, animals depend on the crop residues and farmers have a trade-off between retaining residues in the field and using them for stock feed (Baudron et al., 2007). A few citations from key informants will help explain the problem:

"Even if they leave those residues, you find that during the dry season, everything in eaten up" (CH,M)

"Residue retention in the field, because animals have little to eat, they also utilize the same residue" (MO,M)

"when it comes to residue retention, it is difficult because of the animals. Animals can almost clean up the whole field" (MO,M)

The above quotations highlight challenges that are faced, especially in years of rainfall deficits. While farmers may be inclined to practice residue retention, the purpose is defeated by cattle herding practices such as free grazing (Baudron et al., 2007).

6. Conclusion

This paper contributes to the literature on climate change adaptation in general and in the Zambian context in particular. The paper used a rich combination of household survey, satellite rainfall and key informant data to address questions on adaptation strategy choice and depth of adoption.

The paper notes that the rainfall patterns have changed, increasing the occurrence of droughts and shortening rainfall periods. KII data has shown CF as the main adaptation strategy that is being promoted. Despite the changed climate and promotion of adaptation strategies, the paper found the level of adoption of CSA practices still low, with pronounced levels of dis-adoption. In particular, the adoption of MT and irrigation remains low, at around 15% and 17% respectively.

Our econometric models show that farmers adopt MT and CR in response to precipitation deficits and training. However, these efforts are hampered by low adoption of complementary practices such as crop diversification and use of herbicides. Our analysis shows that the level of crop diversification is low due to absence of certified seed and structured markets for alternative crops, hence entrenching the culture of mono-cropping. In order to enhance climate adaptation and improve resilience among mostly poor farming households, there is a need to improve markets for alternative crops. This is important to promote crop diversification, which has partly been hampered by absence of structured markets for alternative crops. Other drivers of adaptation include ownership of specialized implements and membership in farmer cooperatives or associations. This calls for the scaling up of agriculture extension services that provide necessary skills and knowledge for the adoption of new farming practices, including the use of herbicides.

On the other hand, our evidence shows the adoption of SC is driven mostly by farming culture. The adoption of the practice is hampered by the free grazing practices in traditional farming communities and the need to break pest cycles by burning crop residues. We find irrigation to be driven by plot-level characteristics, mainly the field being in a dambo (wetland) area. This is because of upfront costs of investment that farmers can seldom afford. As such, there is a need to promote access to irrigation resources by smallholder farmers.

References

Adaptation Finance Accountability Initiative (AFAI). (2015). *Climate change adaptation finance in Zambia: A call to transparency and Accountability Country Report*. AFAI.

Akayombokwa, I. M., B. van Koppen, B., and Matete, M. (2015). *Trends and Outlook: Agricultural Water Management in Southern Africa Country Report Zambia*. International Water Management Institute.

Altieri, M. A., and Koohafkan, P. (2008). *Enduring Farms: Climate Change, smallholders and traditional farming communities*. Penang: Third World Network.

Anderson, C. L., Reynolds, T. W., and MGugerty, K. (2017). Husband and wife perspectives on farm household decision-making authority and evidence on intra-household accord in Rural Tanzania. *World Development, 90,* 169–183.

Andersson, J. A., and D'Souza, S. (2014). From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment, 187*, 116–132.

Arslan, A., Asfaw, S., Cavatassi, R., Lipper, L., McCarthy, N., Kokwe, M., and Phiri, G. (2018). Diversification as part of a CSA strategy: The cases of Zambia and Malawi. In: L. Lipper, N. McCarthy, D. Zilberman, S. Asfaw and G. Branca (ed). *Climate Smart Agriculture: Building Resilience to Climate Change*. Cham: Springer International Publishing, 527– 562.

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., and Cattaneo, A. (2014). Adoption and intensity of adoption of conservation farming practices in Zambia. *Agriculture, Ecosystems and Environment, 187*, 72–86.

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Catteneo, A., and Kokwe, M. (2015). *Food Security and adaptation impacts of potential climate smart agricultural practices in Zambia*. Food and Agriculture Organisation.

Baudron, F., Mwanza, H. M., Triomphe, B., and Bwalya, M. (2007). *Conversation agriculture in Zambia: a case study of Southern Province*. Nairobi: African Conservation Tillage Network, Centhre de Cooperation Internationale de Recherche Agronomique pour le Developpement and FAO.

Brown, B., Llewellyn, R., and Nuberg, I. (2018). Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa. *Global Food Security, 17*, 213–220.

Carney, C., and Carney, M. H. (2018). Impact of soil conservation adoption on intra-household allocations in Zambia. *Review of Development Economics, 22*(4), 1390–1408.

Chib, S., and Greenberg, E. (1998). Analysis of multivariate probit models. *Biometrika, 85*(2), 347–361.

Chompolola, A., and Kaonga, O. (2016). Adoption of Conservation Agriculture in Zambia - The case of Chongwe District. *Journal of Sustainable Development, 9*(3), 77–86.

Cleary, M., Horsfall, J., and Hayter, M. (2014). Data collection and sampling in qualitative research: Does size matter? *Journal of Advanced Nursing*, *70*(3), 473–475.

Conservation Farming Unit (CFU). (2007). *Conservation Farming and Conservation Agriculture Handbook for Hoe Farmers in Agro-Ecological Regions I & II - Flat Culture: 2007 Edition*. CFU.

— (2012). *The Practice of Conventional and Conservation Agriculture in East and Southern Africa*. Zambia National Farmers Union.

Feliciano, D. (2019). A review on the contribution of crop diversification to Sustainable Development Goal 1 "no poverty" in different world regions. *Sustainable Development, 27*(4), 795–808.

Funk, C., et al. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data, 2*(1).

Gollin, D. (2014). Smallholder agriculture in Africa: An overview and implications for policy. *IIED Working Paper*.

Grabowski, P. P., Haggblade, S., Kabwe, S., and Tembo, G. (2014). Minimum tillage adoption among commercial smallholder cotton farmers in Zambia, 2002 to 2011. *Agricultural Systems, 131*, 34–44.

Greene, W. H. (2012). Economic Analysis. 7th Essex: Pearson Education Ltd.

Guan, K., Sultan, B., Biasutti, M., Baron, C., and Lobell, D. B. (2015). What aspects of future rainfall changes matter for crop yields in West Africa? *Geophysical Research Letters, 42*(19), 8001–8010.

Habanyati, E. J., Nyanga, P. H., and Umar, B. B. (2018). Factors contributing to dis-adoption of conservation agriculture among smallholder farmers in Petauke, Zambia. *Kasetsart Journal of Social Sciences*, 1–6.

Hewitson, B., Janetos, A. C., Carter, T. R., Giorgi, F., Jones, R. G., Kwon, W. T., Mearns, L. O., Schipper, E. L. F., and van Aalst, M. K. (2014). Regional context. In: V. R. Barros et al. (ed). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, 1133–1197.

Indaba Agricultural Policy Research Institute (IAPRI). (2016). *Rural Agricultural Livelihoods Survey: 2015 Survey report*. Lusaka: IAPRI.

Jones, A. D., Shrinivas, A., and Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy, 46,* 1–12.

Kankwamba, H., Kadzamira, M., and Pauw, K. (2018). How diversified is cropping in Malawi? Patterns, determinants and policy implications. *Food Security*, 10(2), 323–338.

Kassam, A., Friedrich, T., and Derpsch, R. (2019). Global spread of Conservation Agriculture. *International Journal of Environmental Studies, 76*(1), 29–51.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., and Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change, 80*(3), 525–540.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., and Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy, 42*, 400–411.

Katengeza, S. P., Holden, S. T., and Lunduka, R. W. (2018). Adoption of drought tolerant maize varieties under rainfall stress in Malawi. *Journal of Agricultural Economics, 70*(1), 198–214.

Komba, C., and Muchapondwa, E. (2018). Adaptation to climate change by smallholder farmers in Tanzania. In: C. S. Berck, P. Berck and S. D. Falco (eds). *Agricultural Adaptation to Climate Change in Africa: Food Security in a Changing Environment*. Oxford: RFF Press, 129–168.

Kuntashula, E., and Nhlane, R. (2018). *Final Evaluation of the Conservation Agriculture Scaling-Up (CASU) Project funded by the European Union (GCP/ZAM/074/EC)*. FAO.

Lalani, B., Dorward, P., and Holloway, G. (2017). Farm-level economic analysis: Is conservation agriculture helping the poor? *Ecological Economics, 141*, 144–153.

Lee, D. R. (2005). Agricultural sustainability and technology adoption: Issues and policies for developing countries. *American Journal of Agricultural Economics, 87*(5), 1325–1334.

Liebman, M., and Dyck, E. (1993). Crop rotation and intercropping strategies for weed management. *Ecological Applications, 3*(1), 92–122.

Maggio, G., Sitko, N. J., Ignaciuk, A., Maggio, G., Sitko, N. J., and Ignaciuk, A. (2018). *Cropping system diversification in Eastern and Southern Africa: Identifying policy options to enhance productivity and build resilience*. FAO Agricultural Development Economics Working Paper 18-05.

Mason, N. M., Jayne, T. S., and Mofya-Mukuka, R. (2013). *A Review of Zambia's Agriculture Input Subsidy Programs: Targeting, Impacts and the way forward*. Working Paper 77. IAPRI.

McSweeney, C. F., New, M., and Lizcano, G. (2012). *UNDP Climate Change Country Profiles: Zambia*. UNDP.

Meijer, S. S., Sileshi, G. W., Kundhlande, G., Catacutan, D., and Nieuwenhuis, M. (2015). The role of gender and kinship structure in household decision-making for agriculture and tree Planting in Malawi'. *Journal of Gender, Agriculture and Food Security (Agri-Gender), 1*(1), 54–76.

Michler, J. D., Baylis, K., Arends-Kuenning, M., and Mazvimavi, K. (2019). Conservation agriculture and climate resilience. *Journal of Environmental Economics and Management, 93*, 148–169.

Min. of Agriculture (MoA). (2001). *Conservation farming and land use: 5-year programme proposal for ASIP successor programme*. Lusaka: MoA.

— (2013). *Zambia National Agriculture Investment Plan (NAIP) 2014-2018*. Lusaka: MoA.

— (2018). *Farmer Input Support Programme (FISP): 2018-2019 Agricultural season Direct Input Supply Implementation Manual*. Lusaka: MoA.

— (2019). *Agriculture Diary for Extension Officers (ADEOs)*. Lusaka: MoA.

Min. of Agriculture (MoA) and Min of Fisheries and Livestock (MFL). (2016). *Second National Agriculture Policy.* Min. of Agriculture.

Min. of Lands and Natural Resources (MLNR). (2017). *Draft National Land Policy.* MLNR.

Mofya-Mukuka, R., and Shipekesa, A. M. (2013). *Value Chain Analysis of the Groundnuts Sector in the Eastern Province of Zambia*. Indaba Agricultural Policy Research Institute (IAPRI). Working Paper No. 78.

Mulwa, C., Marenya, P., Rahut, D. B., and Kassie, M. (2017). Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate Risk Management, 16*, 208– 221.

Mutale, G., Kalinda, T., and Kuntashula, E. (2017). Factors affecting the joint adoption of herbicides and conservation tillage technologies among smallholder farmers in Zambia. *Journal of Agricultural Science, 9*(12), 205–222.

Ngoma, H., Hamududu, B., Hangoma, P., Samboko, P., Hichaambwa, M., and Kabaghe, C. (2017). *Irrigation Development for Climate Resilience in Zambia: The known knowns and known unknowns*. Working Paper 130. IAPRI.

Nyanga, P. H., Johnsen, F. H., Aune, J. B., and Kalinda, T. H. (2011). Smallholder farmers' perceptions of climate change and conservation agriculture: Evidence from Zambia'. *Journal of Sustainable Development, 4*(4), 73–85.

Olsson, L., Opondo, M., Tschakert, P., Agrawal, A., Eriksen, S. H., Ma, S., Perch, L. N., and Zakieldeen, S. A. (2014). Livelihoods and Poverty. In: V. R. Barros et al. (ed). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, 793–832.

Papke, L. E., and Wooldridge, J. M. (2008). Panel data methods for fractional response variables with an application to test pass rates. *Journal of Econometrics, 145*, 121–133.

Pedzisa, T., Rugube, L., Winter-Nelson, A., Baylis, K., and Mazvimavi, K. (2015). The intensity of adoption of conservation agriculture by smallholder farmers in Zimbabwe. *Agrekon, 54*(3), 1–22.

Pender, J., and Gebremedhin, B. (June 2008). Determinants of agricultural and land management practices and impacts on crop production and household income in the highlands of Tigray, Ethiopia. *Journal of African Economies, 17*, 395–450.

Picard, R. (2012). *GEONEAR: Stata module to find nearest neighbors using geodetic distances*. Statistical Software Components, Boston College Department of Economics. Boston College Department of Economics.

Sharma, A., Bailey, A., and Fraser, I. (2010). Technology adoption and pest control strategies among UK cereal farmers: Evidence from parametric and nonparametric count data models. *Journal of Agricultural Economics, 62*(1), 73–92.

Simpson, E. H. (1949). Measurement of diversity. *Nature, 163*(4148), 688–688.

Smit, B., and Pilifosova, O. (2001). Adaptation to climate change in the context of sustainable development and equity. In: J. J. McCarthy, O. F. C. and Neil A Leary, D. J. Dokken and K. S. White, (ed). Climate Change 2001: Impacts, Adaptation, and Vulnerability. Cambridge University Press., pp. 877–912.

Tagliarino, N. K. (2014). Zambia: Conversions of customary land to leasehold title. *Focus on Land in Africa*.

Teklewold, H., Kassie, M., and Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practices in Rural Ethiopia. *Journal of Agricultural Economics, 64*(3), 597–623.

Trotter, R. T. (2012). Qualitative research sample design and sample size: Resolving and unresolved issues and inferential imperatives. *Preventive Medicine, 55*(5), 398–400.

Waldman, K. B., Blekking, J. P., Attari, S. Z., and Evans, T. P. (2017). Maize seed choice and perceptions of climate variability among smallholder farmers. *Global Environmental Change, 47*, 51–63.

Wineman, A., Njagi, T., Anderson, C. L., Reynolds, T. W., Alia, D. Y., Wainaina, P., Njue, E., Biscaye, P., and Ayieko, M. W. (2020). A case of mistaken identity? Measuring rates of improved seed adoption in Tanzania using DNA fingerprinting. *Journal of Agricultural Economics, 71*(3), 719–741.

Wooldridge, J. M. (2010). *Econometric Analysis of Cross Section and Panel Data*. 2nd. Cambridge, MA: MIT Press.

World Bank (WB). (2011). *Irrigation Development and Support Project: Project Appraisal Report. No. 58264-ZM*. World Bank.

Xu, Z., Guan, Z., Jayne, T., and Black, R. (2009). Factors influencing the profitability of fertilizer use on maize in Zambia. *Agricultural Economics, 40*(4), 437–446.

Zellner, A. (1962). An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American Statistical Association*, *57*(298), 348– 368.

Zepeda, L., and Castillo, L. (1997). The role of husbands and wives in farm technology choice. *American Journal of Agricultural Economics*, *79*(2), 583–588.

Zulu-Mbata, O., Chapoto A., and Hichaambwa, M. (2016). *Determinants of Conservation: Agriculture Adoption among Zambian Smallholder Farmers*. Working Paper 114. IAPRI.

Appendix A

Key Informant Interviews

Key informant interviews (KIIs) were conducted with officers from DACOs offices and AEO in Chisamba and Monze districts between 17th and 24th of December, 2019. Figure A.1 shows the locations where the interviewed AEO are based. The map does not show the catchment area of each camp. These were not available at the time of the interviews. Nonetheless, the map is still informative on the spatial distribution of the interviewed informants in the two districts. It is discernible from figure A.1 that the interviewed AEOs were well spread across the two districts. This is important to ensure that, analytically, the responses do cover all possible scenarios in the districts.

Figure A.1: Geolocation of Key Informants