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Assessing the contributions of conservation agriculture to building resilience to drought

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Acronyms

AGRITEX	Department of Agricultural Technical and Extension Services
CA	Conservation Agriculture
CAFOD	Catholic Agency For Overseas Development
CFU	Conservation Farming Unit
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CSA	Climate Smart Agriculture
CRE	Correlated Random Effects
DFID	Department for International Development
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
MAL	Ministry of Agriculture and Livestock
MAMID	Ministry of Agriculture Mechanisation and Irrigation Department
NGOs	Non-governmental organisations
OVB	Omitted Variable Bias

Executive summary

Climate change and variability threaten crop productivity in smallholder farming systems in Southern Africa. The 2015–16 El Niño event generated drought across Southern Africa, putting at risk the livelihoods of more than 40 million rural people. For many of these households, this El Niño drought marked the fourth successive season of poor rains.

The effects of drought on crop production are worsened by land degradation, which is largely caused by poor management of soils leading to soil erosion and a loss of soil fertility. Conservation agriculture (CA) has been identified and promoted as a "climate smart agriculture" (CSA) technology that can ease some of the degradation challenges faced by smallholder farmers. CA is a combination of three practices: (1) reduced or minimal disturbance of soil, (2) maintenance of surface cover through retention of mulch, and (3) crop diversification through rotations and intercropping (Giller et al., 2009; FAO, 2012). CA has been proposed as an alternative to conventional agriculture because it reduces soil degradation through soil erosion, enhances soil health, and sustains long-term crop productivity (Kassam et al., 2009; Thierfelder and Wall, 2009; FAO, 2012; Nyamangara et al., 2014; FAO, 2015). In addition, experimental trials demonstrate that CA can make yields more resilient to the rising temperatures and more variable rainfall associated with climate change. Since 2004 CA has been broadly promoted in Southern Africa as a more sustainable alternative to conventional agriculture (Mafongoya et al., 2016). While a wealth of experimental plot data is available, there is a need to measure and understand the contributions of CA to building resilience to drought under the management of smallholder farmers (in non-experimental conditions). The El Niño drought of 2015–16 in Southern Africa provides an opportunity to begin to fill this information gap.

This research evaluates the contributions of CA practices,as applied by smallholder farmers, to improving crop resilience to drought. It also seeks to assess what factors differentiate full adopters of CA versus partial adopters and non-adopters in order to assess why some farmers are more likely than others to adopt these technologies. Data used in this study was drawn from a cross-sectional survey conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) with funding from the Vuna Climate Smart Agriculture Programme. The survey was implemented in August and September 2016. A total of 681 (416 CA adopters and 265 non-adopters) smallholder farmers from targeted areas of Zambia and Zimbabwe were interviewed.

The study utilises satellite data from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset (Funk et al., 2015) to measure the severity of the drought within the locations surveyed. This allows consideration of the varying impacts of low rainfall, late rainfall, and long dry spells. The analysis of the impacts of CA on improving average maize yields considers these multiple measures of meteorological and agricultural drought. A variety of econometric techniques were used to estimate the impact of CA on yields during the 2015–16 season as well as to analyse the differences between adopters and non-adopters of CA.

> “In Zimbabwe, efforts to promote CA adoption among the poor have encouraged the use of the technology by older and less educated farmers.

One of the main difficulties with this analysis lies in the definition of the CA practices being adopted. This analysis identifies the use of minimum tillage (By use of either planting basins or ripped planting lines) as a basis for defining a minimum level of CA adoption. Farmers may then apply mulch and/or crop rotation. Only 38 percent of the adopters in Zambia, and 25 percent of the adopters in Zimbabwe, applied all three CA practices (minimum tillage, mulch, and crop rotation). In effect, what farmers and non-governmental organisations identify as CA is commonly different from the technology being tested in formal agronomic trials.

The econometric results show that CA had a positive impact on yields only in Zambia. In both Zambia and Zimbabwe, CA made no meaningful contribution to building resilience to drought. CA is positively correlated with yields. However, the results suggest that this improvement largely reflects the linkage of CA use with higher rates of application of fertiliser and certified maize seed. The use of these inputs improves drought resilience. It is the choice to adopt improved inputs in combination with the choice to adopt CA—and not the choice to adopt CA as a standalone technology—that contributed to higher yields despite the low rainfall received in 2015–16.

The determinants of CA adoption differ in the two countries. In Zambia, older and better-educated farmers with access to credit are more likely to adopt the three CA practices. In Zimbabwe, efforts to promote CA adoption among the poor have encouraged the use of the technology by older and less educated farmers. Those in higher rainfall zones and with access to credit are more likely to adopt all three CA practices. In neither case is there evidence that farmers are adopting CA as a means to improve their resilience to drought.

Based on descriptive and econometric evidence, the study concludes that the promotion of CA as this technology is commonly applied by smallholder farmers will not build resilience to drought in Southern Africa. This is because even in drier farming systems, low soil fertility appears to be a more binding constraint than limited soil water. Based on these findings, agricultural development work should focus on promoting the use of fertiliser and certified seed. The analysis indicates that CA promotion appears to be a vector by which these improved farm management practices are being transmitted to farmers in low-rainfall areas. However, it may be more efficient to promote the use of at least small doses of fertiliser and the use of certified maize seed alone.

This study partially contributes to filling the existing literature gap by using observational plot-level data and actual rainfall data to assess the impact of CA in building resilience. However, the study's reliance on cross-sectional data made it difficult to control for the well known issue of omitted variable bias (OVB) in regression analysis.

Efforts to close the literature gap can be sought through the use of panel data which makes it possible to more fully control for OVB and to place farmer performance in 2015–16 within its historical context.

> “Since 2004, CA has been broadly promoted in Southern Africa as an alternative to conventional agriculture.

1 Project background

Climate change and variability threaten crop productivity in smallholder farming systems in Southern Africa. The 2015–16 El Niño generated drought across Southern Africa. The combination of El Niño events and climate change is likely to exacerbate the problem of recurrent droughts already causing crop failure under rainfed agriculture in Southern Africa(Cairns et al., 2012).The effects of drought on crop production are worsened by land degradation, which is largely caused by poor management of soils leading to soil erosion and a loss of soil fertility. A suite of“climate smart agriculture” (CSA) practices is needed to improve management of land in smallholder farming systems.

CSA technologies offer (1) adaptation to the effects of climate change to build resilience, (2) mitigation of greenhouse gas emissions and sequestration of carbon in soil organic matter, and (3) sustainable increases in crop productivity and profitability. Conservation agriculture (CA) is advocated as an archetypical example of CSA technology as it can fulfil all three of these CSA targets. CA is a combination of three practices: (1) reduced or minimal disturbance of soil, (2) maintenance of surface cover through retention of mulch or use of cover crops, and (3) crop diversification through rotations and intercropping (Giller et al., 2009; FAO, 2012).CA has been proposed as an alternative to conventional agriculture because it reduces soil degradation through soil erosion, enhances soil health, and sustains long-term crop productivity (Kassam et al., 2009; Thierfelder and Wall, 2009; FAO, 2012; Nyamangara et al., 2014; FAO, 2015). The combination of residue retention and reduced tillage can improve soil structure and water storage and regulate the fluctuations in soil moisture and temperature associated with climate change. CA contributes to the mitigation of greenhouse gas emissions by sequestering soil carbon (Gwenzi et al., 2009; Thierfelder et al., 2013). Improvements in water-use efficiency, through increased water infiltration and reduced surface runoff, contribute to resilience in the face of drought. Overall, CA improves the resilience of farming systems to the rising temperatures and more variable rainfall associated with climate change.

Since 2004, CA has been broadly promoted in Southern Africa as an alternative to conventional agriculture, or more specifically, to the use of the mouldboard plough (Mafongoya et al., 2016). Recent studies using experimental trials have shown that CA has been successful in increasing yields in some areas of Zambia and Zimbabwe (Rusinamhodzi et al., 2011; Nyamangara et al., 2014). Crop yield increases of up to 80% have been observed in some long-term field studies of CA in Southern Africa (Thierfelder et al., 2016). However, overall adoption rates of CA in Southern Africa remain low compared to adoption rates in South America (Giller et al., 2009). This may be because the benefits of CA depend, to a large extent, on the nature of the agroecosystem under consideration and how CA technologies are adapted tothe local environment (Chivenge et al., 2007; Giller et al., 2009; Mafongoya et al., 2016). The actual contribution of CA systems to increasing resilience to droughts and mid-season dry spells in Southern Africa needs to be empirically evaluated. Additionally, the reasons why some farmers continue to use CA, while their neighbours are not adopting (or adopting and then abandoning) need to be better understood.

> **“Climate change and variability threaten crop productivity in smallholder farming systems in Southern Africa.**

2 Opportunity / problem statement

The El Niño drought of 2015–16 in Southern Africa provides an opportunity to empirically examine the contributions of CA to drought resilience. For many households living in Southern Africa, this was the fourth successive season of poor rains. Climate models predict that the region will likely experience increased frequencies of extreme weather events such as droughts and floods, increased rainfall variability, and heat stress (Cairns et al., 2012). Higher average temperatures are expected to exacerbate drought stress during dry periods due to increased crop transpiration (Lobell et al., 2013).

If CA truly contributes to consistent and significant improvements in productivity in the face of drought—due to its contributions to improving water storage and moisture conservation—then broader adoption of CA should be promoted. Adoption barriers need to be better diagnosed. Greater public investment in facilitating adoption may reduce the high costs of future food aid and drought relief.

A literature review of the performance of CA conducted at the beginning of this study (Mazvimavi et al., 2016) reveals that CA contributes to better yields in drier weather conditions, or in relatively more arid agroecologies. These improvements are attributed to better water infiltration and water-holding capacity of the soil, and to improvements in soil organic matter over time. In addition, the literature shows that CA results in higher productivity gains when combined with fertiliser application. However, the majority of these findings are based on data from field experiments. As such, they do not answer the question of whether CA, as it is commonly implemented by farmers under non-experimental conditions in their own fields, contributes to drought resilience. Thus, it remains unclear if governments and development agencies should encourage the expanded adoption of CA as a means to improve resilience to drought—and, if so, which CA practices should be promoted.

3 Approach

This applied research study was conducted in two phases. First, available literature on the potential contributions of CA to improving crop productivity under drought conditions was reviewed. Second, a household survey was conducted to evaluate the levels of resilience achieved by smallholder farmers in targeted areas of Zambia and Zimbabwe where CA practices have been broadly promoted and adopted. Survey results were analysed to determine the levels of CA's contribution to drought resilience under smallholder management.

The objectives of this study were to:

1. Evaluate the contributions of CA to improving yield resilience to drought.
2. Assess what differentiates adopters of CA from neighbouring farmers who adopt these practices partially or not at all.
3. Recommend strategies for improving smallholder resilience to drought in Zambia and Zimbabwe.

4 Farm survey

Data used in this study were drawn from a CA survey conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) with funding from the Vuna Climate Smart Agriculture Programme. The survey was implemented in August and September 2016. In preparing the surveys in Zambia, consultations were done with the Conservation Farming Unit (CFU) of Zambia and local representatives of the Ministry of Agriculture and Livestock (MAL). The surveys in Zimbabwe were conducted in consultation with the Department of Agriculture and Rural Extension (AGRITEX), a branch of the Ministry of Agriculture Mechanisation and Irrigation Department (MAMID), and non governmental organisations (NGOs) promoting CA in the context of drought-relief programs such as CARE International, Catholic Relief Services, CAFOD, and World Vision.

The survey purposefully targeted areas of the two countries where adoption of CA was known to have occurred and that were thought to be drought-affected. The purposive sampling randomly selected farmers from a subpopulation of CA adopters and then selected nearby households who were non-adopters in order to construct a plausible counterfactual.

In both countries, CA farmers were identified based on their tillage technique.[1] These included farmers who practice "basin CA" and those applying mechanical ripping-based CA practices.[2]A total of 681 smallholder farmers in Zambia and Zimbabwe were interviewed. Of the interviewed farmers, 416 were CA adopters (the treatment group) and 265 were non-adopters (the control group).Table 1 presents the number of adopters and non-adopters by the amount of rainfall received in the 2015–16 season. A majority of districts in Zambia saw rainfall above 700 millimetres, while only one district in Zimbabwe experienced that level of rainfall. Conversely, only one district in Zambia experienced less than 600 millimetres of rainfall, while two districts in Zimbabwe did not reach this level. Thus, meteorological drought in Zambia was less severe than in Zimbabwe.

Table 1: Number of farmers interviewed in the survey

Country	Rainfall received in 2015–16	Districts	CA Adopters	Non Adopters	Total
Zambia	Above 700mm	Chipata	30	20	50
		Mumbwa	38	21	59
		Chibombo	31	25	56
	Between (600-700mm)	Katete	30	20	50
		Sinazongwe	35	19	54
	Below 600mm	Monze	50	22	72
		Sub total	**214**	**127**	**341**
Zimbabwe	Above 700mm	Gokwe South	33	24	57
	Between (600-700mm)	Nkayi	36	22	58
		Bindura	27	29	56
		Murehwa	36	20	56
	Below 600mm	Hwange	33	21	54
		Masvingo	37	22	59
		Sub total	**202**	**138**	**340**
		Grand total	**416**	**265**	**681**

The survey, which targeted maize fields, was implemented post-harvest and collected data on sociodemographics, plot-level information on CA, measured inputs, soil type, and other agronomic practices.

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[1] Unless otherwise noted, throughout this report a farmer is considered an "adopter of CA" if he or she applies the minimum disturbance practice on one or more plots in 2015–16.

[2] Basin CA is manual CA which uses a hand hoe to prepare planting basins as a form of reduced tillage aimed at minimum soil disturbance. Basin CA as practiced in Zambia has these dimensions of 20x30 x15 cm and is specifically prepared using Chaka hoe. Basin CA as practiced in Zimbabwe has these dimensions 15x15x15cm. Mechanised CA is the use of a ripper which can be animal drawn in the case of a Magoye ripper or the ripper can be tractor drawn.

5 Estimation strategy

In order to understand factors influencing the adoption of CA practices, we ran a binary response (probit) model at household level on farm and household characteristics. In this case, a CA adopter is classified as a farmer who practice at least minimum tillage. However, since adoption of CA practices is not binary, we also estimate a multivariate probit regression to identify factors that influence the adoption of different combinations of CA practices.

In estimating the impact of CA on yields during periods of low rainfall, this study uses a correlated random effect model to account for the possible correlation of plot and household unobserved heterogeneity with observed covariates. In any econometric estimation, including estimation of production functions, coefficient estimates may be biased if care is not taken to control for unobserved factors, such as soil micronutrient levels or household skill and ability. This is called omitted variable bias (OVB). As an example, we can examine a simple production function:

$$y_i = \alpha + X_i\beta + \rho R_j + \delta CA_i + \varphi CA_i * Rj + \epsilon_i$$

where y is yield on plot i, X_i is a vector of inputs such as fertiliser and seed, R_j is some measure of rainfall at the ward level, CA_i is an indicator of whether CA methods were used on the plot, and ϵ_i is an error term. In this report we are particularly interested in the sign and significance of φ, the coefficient on the interaction between CA and our measure of rainfall. If CA contributes to the resilience of yields to drought, this coefficient should be positive and significant. A non-significant coefficient would signal that CA performs no better than traditional practices in building resilience of yields to drought. A negative and significant coefficient would mean that farmers practicing CA receive lower yields during drought when compared to farmers practicing traditional methods of cultivation.

In developed countries where markets function efficiently, farmers can choose the optimal level of inputs to maximise yields. However, in developing countries where markets frequently fail, we cannot assume that farmers are able to choose the optimal input quantities. Thus, any unobserved agronomic or household factors that impact y and influence the farmer's choice of X_i and CA_i will create bias in the estimates of β, δ, and φ. This is because these unobserved factors are captured in the ϵ_i term and create correlation between the error term and the choice variables.[3] An example of an unobserved agronomic factor would be poor micronutrients in the soil. In this case, farmers may apply more fertiliser than a neighbour whose soil has better micronutrients but still receive lower average yields. An example of an unobserved household factor would be highly skilled farmers who correctly apply fertiliser on a timely basis and therefore achieve higher yields than unskilled farmers who apply the same amounts of fertiliser late. Similarly, if fertiliser markets are poorly functioning, farmers situated farther away from retail outlets may receive their fertiliser late.

Thus, even in the estimation of production functions, OVB should be a concern and care should be taken that coefficient estimates are unbiased. In an ideal situation, the scientist would observe all relevant agronomic and household factors. Absent that ideal, a variety of approaches have been developed to control for unobserved factors. Most common is a fixed-effects model, which controls any correlation between time-invariant unobserved factors captured in the error term and the choice variables. The use of fixed effects estimates requires multiple observations over time. Since this study utilises cross-sectional data, the correlated random coefficient model is an alternative. The correlated random coefficient model assumes that the correlation between unobserved factors, be they agronomic or household, are correlated with observed factors (Mundlak, 1978; Di Falco and Bulte, 2013). By including the means of the observed factors we can (imperfectly) control for the unobserved factors.

In all models we include the log levels of yield and measured inputs (basal and top fertiliser and seed). The log transformation of these variables allows us to estimate the Cobb-Douglas production function by linearizing the function. In addition to measured inputs we include measures of management practices such as tillage technique and weeding frequency. We also include a set of household characteristics in order to control for unobserved household factors that may be correlated with the choice variables (see Appendix A for complete list of variable definitions). These household characteristics include the gender, age, education level in years,and farm experience in years of household head. These variables are proxies for unobserved farmer ability. As a further precaution against OVB, we include distance to input market and use of credit to obtain inputs. These variables are proxies for a farmer's ability to purchase the measured inputs in sufficient quantity. If input markets in Zimbabwe and Zambia functioned perfectly, households would be able to purchase exactly the amount of inputs that would maximise their yields and there would be no need for these additional

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[3] Note that because households do not choose the amount of rainfall, it will not be correlated with the error term and thus estimates of ρ will be unbiased.

control variables. However, in the presence of market failures, where farmers may be unable to purchase the optimal amount of seed or fertiliser, it is important to control for a household’s ability to purchase inputs. Failure to control for this would result in bias estimates of the yield response to fertiliser and seeds. Finally, we include agroecological region as a proxy for climate,and household size as a proxy for labour input.

> “
> **If input markets in Zimbabwe and Zambia functioned perfectly, households would be able to purchase exactly the amount of inputs that would maximise their yields and there would be no need for these additional control variables.**

6 Descriptive evidence

Table 2 presents descriptive statistics of household-level variables for the adopters and non-adopters of CA in both countries. Recall that a farmer is considered an adopter of CA if he or she practiced the principle of minimum disturbance on one or more plots in 2015–16. In both Zambia and Zimbabwe, CA adopters were significantly older than non-CA adopters. Most households were male-headed across the two countries and there was no significant difference in gender of household head between CA and non-CA farmers. In Zambia, there was no difference in the level of education between adopters and non-adopters. However, in Zimbabwe, non-CA farmers were more educated than CA farmers. This could be due to NGO targeting of farmers for promotion of CA in Zimbabwe. In most instances in Zimbabwe, CA adoption resulted from specialised development programs, implemented by NGOs, that targeted poorly resourced farmers, who may be lacking in terms of education as a human capital resource.[4] CA farmers had more years of farming experience compared to non-CA farmers across the two countries. CA farmers had about three and six more years of farming experience in Zambia and Zimbabwe, respectively.

Table 2: Descriptive statistics of household-level variables

Description	Zambia			Zimbabwe		
	Adopters	Non-adopters	Differences	Adopters	Non-adopters	Differences
Age of household head	50.8	46.6	4.28***	57.9	53.3	4.67***
Gender of head (1=male)	0.76	0.77	0.01	0.65	0.68	-0.03
Secondary education (1=yes)	0.48	0.41	0.07	0.48	0.62	-0.15***
Farming experience (years)	23.8	20.9	2.93**	26.9	21.1	5.80***
Household size (number)	8.32	7.29	1.03**	6.46	6.16	0.30
Distance to market (km)	11.4	12.4	-1.04	25.7	29.3	-3.61
Use of credit facilities (1=yes)	0.21	0.10	0.12***	0.15	0.09	0.07*
Number of observations	**341**			**340**		

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

The distance to the nearest market was used to determine the access to input markets. Given that the sampling approach targeted neighbouring adopters and non-adopters,the average distance to input market was similar for the two groups in both countries. The similarity between the two groups of farmers is also observed for the availability of credit. Although the adopters and non-adopters had equal access to formal and informal credit, a significantly higher proportion of CA farmers in both countries used credit facilities during the cropping season compared to non-CA farmers. This may be because CA farmers have an extra investment requirement in terms of purchasing CA equipment, herbicides, and other inputs.

6.1 Drought indicators

6.1.1 Drought and perceptions

During the survey, farmers were asked to compare rainfall conditions in the 2015–16 seasons with previous seasons. Regardless of country and CA adoption status, a majority of interviewed farmers indicated that they experienced abnormally dry and warm weather during the 2015–16 cropping seasons (Table 3). Farmers perceived that there was a delayed onset of the rainy season and that once the rains came they delivered below normal volumes. Fewer than 50% of the total of farmers interviewed indicated that they had produced sufficient grain for their own consumption to last them until the next season. The main exception to this general indication was in Zambia, where 53% of farmers practising CA perceived that they had produced sufficient grain. Zimbabwe had the lowest proportion of farmers (32%

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[4] This purposive targeting of CA promotion further highlights the need to control for unobserved household factors in the estimation of CA on yields.

for non-adopters) that produced sufficient grain to meet their food requirements. This suggests acute food shortages and justifies the need to identify farming techniques that build farmer's resilience to adverse conditions like drought.

Table 3: Perceptions of variations in climate by adoption status and country

Farmer perceptions	Full sample	Zambia		Zimbabwe	
		Adopters	Non-adopters	Adopters	Non-adopters
Perceived delayed onset in 2015–16	0.73	0.86	0.84	0.60	0.62
Perception of mid-season dry spells	0.99	0.99	0.98	1.0	1.0
Perceived rainfall was below normal	0.85	0.90	0.87	0.76	0.87
Perceived increase in temperature	0.71	0.52	0.48	0.93	0.91
Production of sufficient grain	0.42	0.53	0.45	0.35	0.32
Number of observations	**681**	**214**	**127**	**202**	**138**

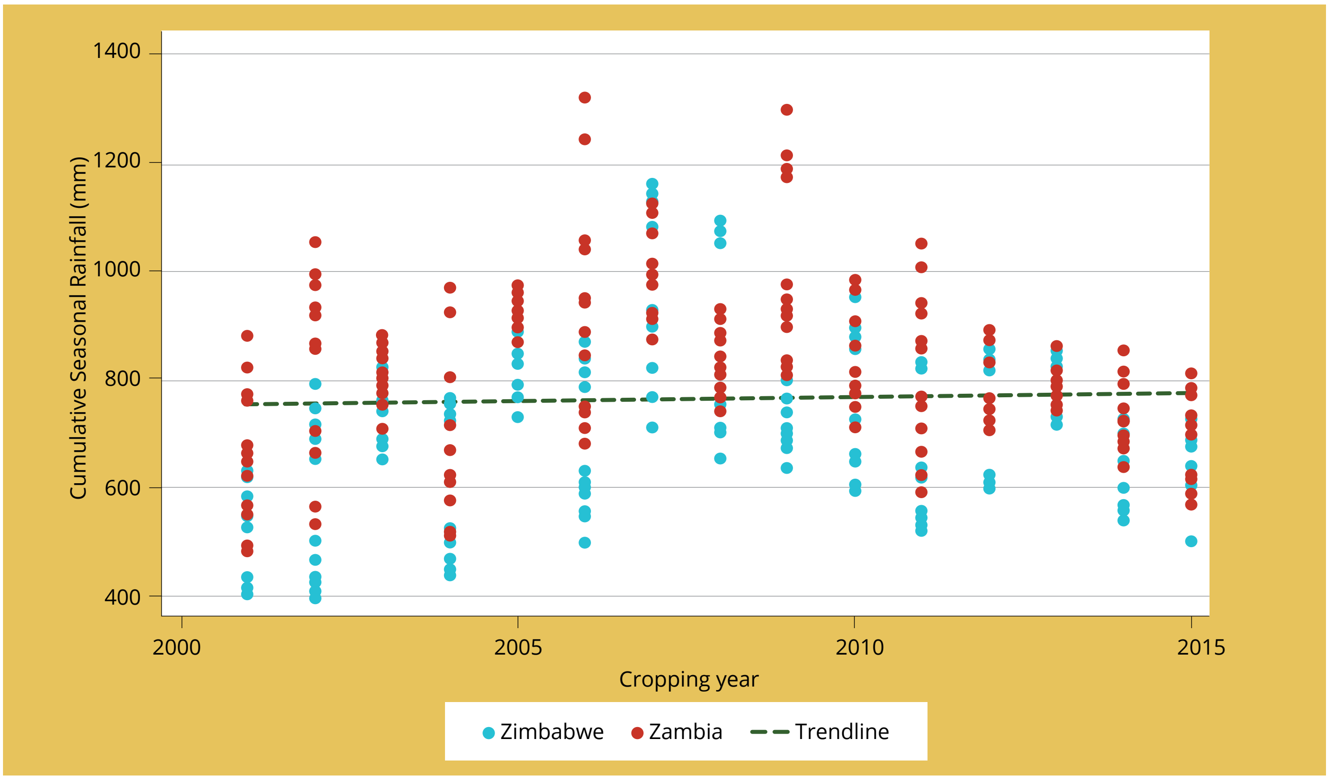


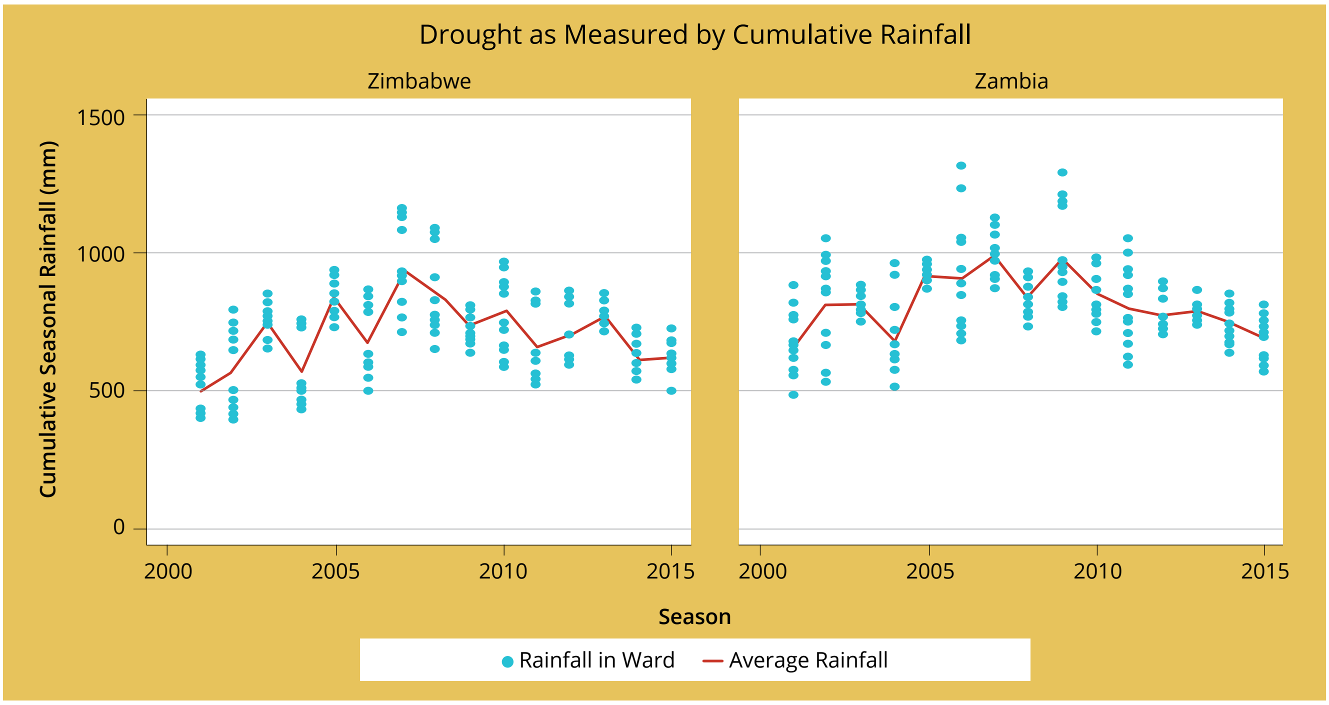
Figure 1: Seasonal rainfall in Zambia and Zimbabwe from 2001-2015

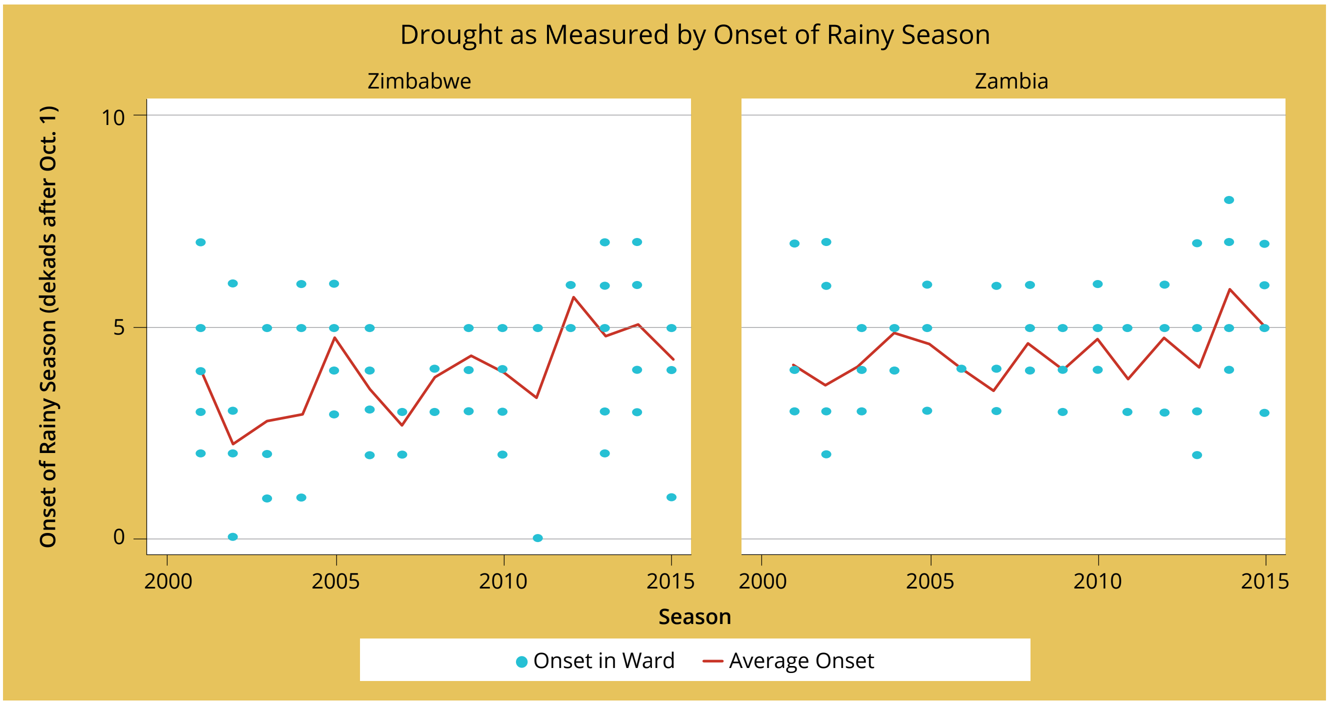
6.1.2 Meteorological drought indicators

To calculate the severity of the 2015–16 drought, we use satellite imagery from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data. CHIRPS is a quasi-global rainfall dataset that spans 50ºS–50ºN, with all longitudes. CHIRPS incorporates 0.05º resolution satellite imagery with in-situ station data to create a gridded rainfall time series (Funk et al.,2015). The dataset provides daily rainfall measurements from 1981 up to the current year. We overlay boundaries for sampled wards on the 0.05º grid cells and take the average rainfall for the day within the ward. Figure 1 presents cumulative rainfall for surveyed wards in Zambia and Zimbabwe over the last 15 years. Note that the last four years (2012–13 to 2015–16) have all experienced less rainfall than was typical for the previous ten years.

For this project we developed four different methods to measure meteorological drought in the region. First, we consider cumulative seasonal rainfall in millimetres. This is a standard measure of seasonal droughts, but due to a changing climate it may no longer be the best measure. Second, we consider the total number of days without rain during the rainy season. The logic behind this measure is that if the intensity of rain is increasing, the same amount of rain may fall in a season despite a high number of rainless days. Thus, cumulative rainfall may miss out on droughts caused by a few high-intensity rainy days followed by many rainless days. Third, the analysis considers the late onset of the rains as measured by the number of dekads (10 day periods) after October 1 it took before cumulative rainfall was greater than 20 millimetres. The logic behind this measure is that not only the amount but the timing matters in considering droughts. Thus, the cumulative rainfall and/or the number of rainy days may stay the same, but the rains may come too late to be useful to farmers. The final measure counts the number of days in the longest mid-season dry spell. As with the third measure, the logic here is that the timing of rains matters. Rains may have come on time and the total amount of rain may be the same, but there could be a prolonged dry period mid-season that damages crops.

As shown in Figure 1, 2014-15 and 2015-16 (labelled as 2014 and 2015) had less rain than was typical for the previous seven years but similar to rainfall patterns 7-15 years ago. This suggests that while rainfall in 2015-16 was less than rainfall in the recent past (2008-13), it would not have been considered an abnormally dry year if it had occurred during the period 2000-07. The number of dry days during the 2014-15 and 2015-16 rainy season was about the same as in any year, even though less than average rainfall fell in the 2014-15 and 2015-16 seasons. The onset of the rainy season has been getting later over the last 15 years, but onset in 2015-16 was about the same as it was in the previous three years. Thus, the commonly assumed advantage of early planting may in fact be a liability if the rains consistently arrive well after the beginning of October. The length of dry spells has increased over the last ten years but is only now returning to the length of mid-season dry spells experienced 10-15 years ago.


Drought as Measured by Cumulative Rainfall


Drought as Measured by Onset of Rainy Season

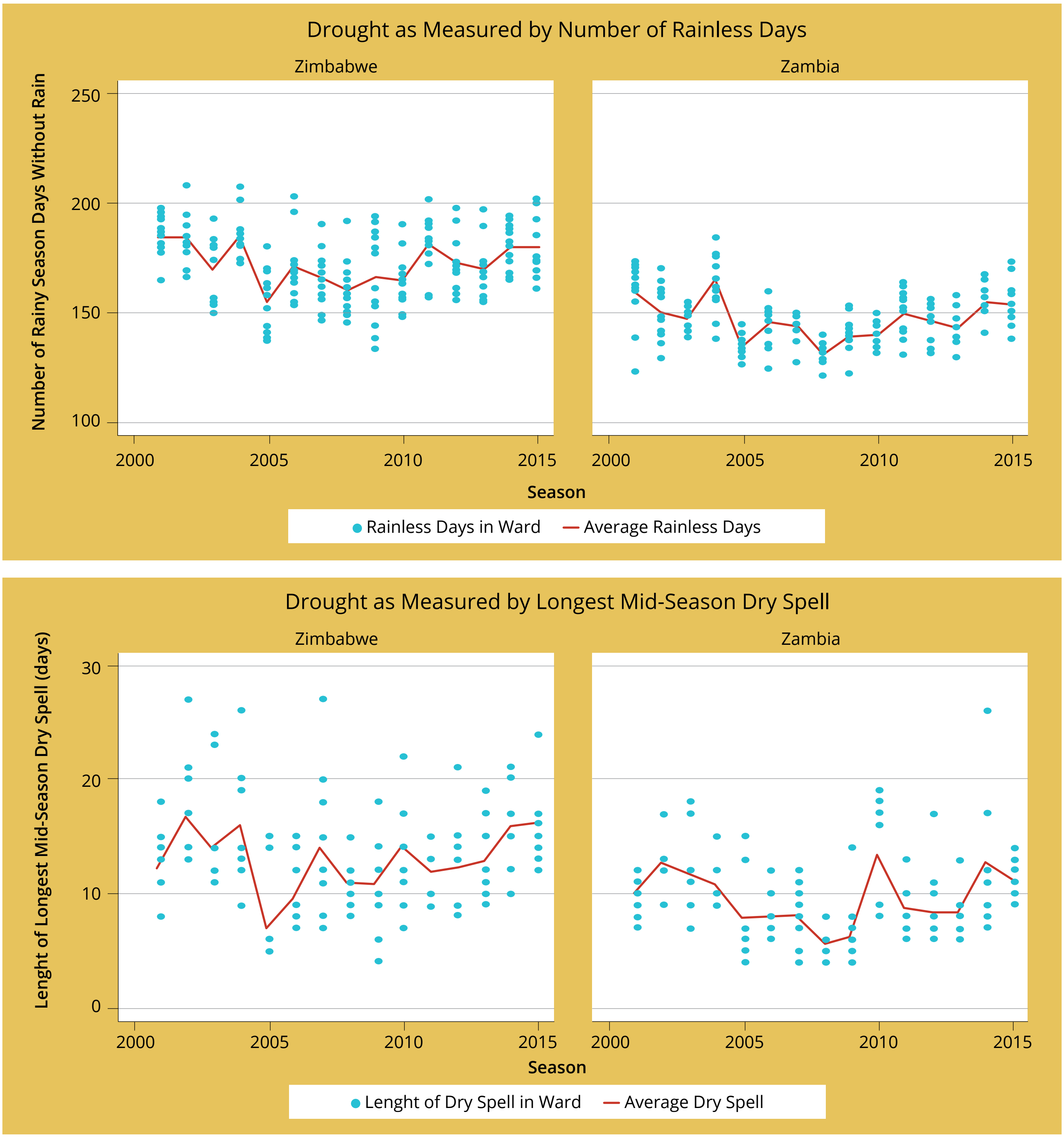


Figure 2: Drought indicators over the past 15 years

Table 4: Average rainfall in study area

Country	Districts	15 yr rainfall average	Rainfall received in 2015–16	Difference
Zambia	Chipata	921.2	789.5	-131.7**
	Mumbwa	849.3	781.6	-67.73***
	Chibombo	840.6	721.8	-118.8***
	Katete	867.4	695.0	-172.4***
	Sinazongwe	716.8	606.9	-109.9**
	Monze	748.5	583.6	-164.9***
	Mean	**818.2**	**697.7**	**-130.5*** **

Country	Districts	15 yr rainfall average	Rainfall received in 2015–16	Difference
Zimbabwe	Gokwe South	651.5	705.0	53.49
	Nkayi	620.3	674.7	54.38
	Bindura	832.7	656.7	-176.0***
	Murehwa	816.9	615.1	-201.8***
	Hwange	631.5	590.4	-41.05**
	Masvingo	693.7	500.1	-193.6***
	Mean	**707.8**	**623.7**	**-84.10*** **

The 15-year satellite rainfall data shows that most of the study area received less rainfall, which corresponds to farmer perceptions. The rainfall was below average in most of the districts except the Gokwe South and Nkayi districts of Zimbabwe. As shown in Table 4 and 5, 2015–16 had less rainfall, an above-average number of dry days, longer dry spells, and a later start to the season. Note, however, that both Gokwe South and Nkayi received above-average rainfall in 2015–16, suggesting that these districts did not experience a drought.

Table 5: Occurrence of drought indicators across study wards

Country	Districts	Ward	Rainfall below 15yr average	Dry days above 15yr average	Late onset (deviating from 15yr average)	Above normal dry spells	Abnormal dry spells soon after onset
Zambia	Chipata	Mapala 1	√	√	X	√	√
		Mapala 2	√	√	√	√	√
	Mumbwa	Kabwanga	√	√	√	√	√
		Shimbizhi	√	√	√	√	√
	Chibombo	Chankumba	√	√	√	√	√
		Mwachisompola	√	√	√	√	√
	Katete	Mwanamphangwe	√	√	X	√	√
		Chingombe	√	√	X	X	√
	Sinazongwe	Mwananjoke	√	√	√	X	X
		Sinazeze	√	√	√	X	X
	Monze	Kawumba	√	√	√	√	X
		Malende	√	√	√	√	X
		Nteme	√	√	√	√	X
Zimbabwe	Gokwe South	13	X	√	X	√	√
		26	X	√	√	√	X
	Nkayi	14	X	X	√	√	X
		22	X	√	√	√	√
	Bindura	8	√	√	√	√	√
		10	√	√	√	√	√
	Murehwa	14	√	√	X	√	√
		28	√	√	X	√	√
	Hwange	4	√	√	√	√	X
		7	√	√	√	√	X
	Masvingo	12	√	√	√	√	√
		14	√	√	√	√	√

6.1.3 Agricultural drought indicators

Meteorological drought indicators measure overall seasonal characteristics compared to past experience. A priori, there is no reason to assume that these seasonal indicators are poor proxies for agricultural drought. However, it may be the case that unexpected or unexplained weather phenomena occurred that made overall seasonal measures of rainfall systematically different from rainfall during the first 65 days after planting (which is the critical period for plant growth). To address the potential for low correlation between our measures of meteorological drought and agricultural drought, we calculate two new drought proxies.

Our first measure of agricultural drought calculates the cumulative rainfall during the first 65 days after planting. The survey collected planting dates for each plot measured as the dekad after October 1 in which planting took place. Using the CHIRPS daily rainfall data, we then calculate how much rain fell in that ward in the 65 days after the start of the dekads. If a plot was planted between October 1 and 10, then we measure the rainfall that accumulated from October 1 until December 5. If a plot was planted in the second dekad (October 11-20), then we measure rainfall from October 11 until December 15. Given that each plot had a unique planting date, the rainfall received and the occurrence of dry days within the first 65 days may be different across neighbouring fields. Our second measure of agricultural drought calculates the total number of days without rain during the first 65 days after planting. The logic behind considering dry days is that farmers may have experienced a few heavy downpours interspersed with long periods of rainless days.

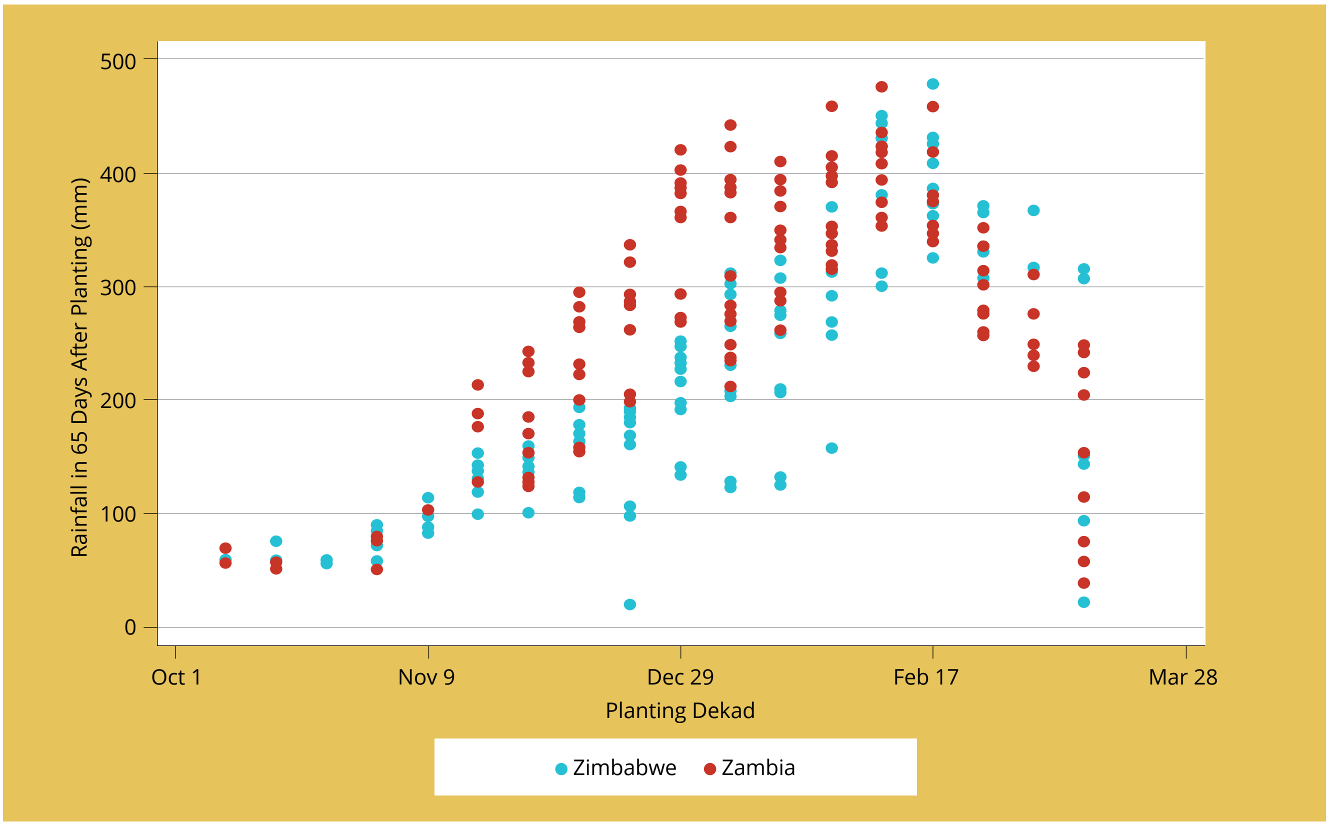


Figure 3: Pattern of rainfall in the 65 days after planting

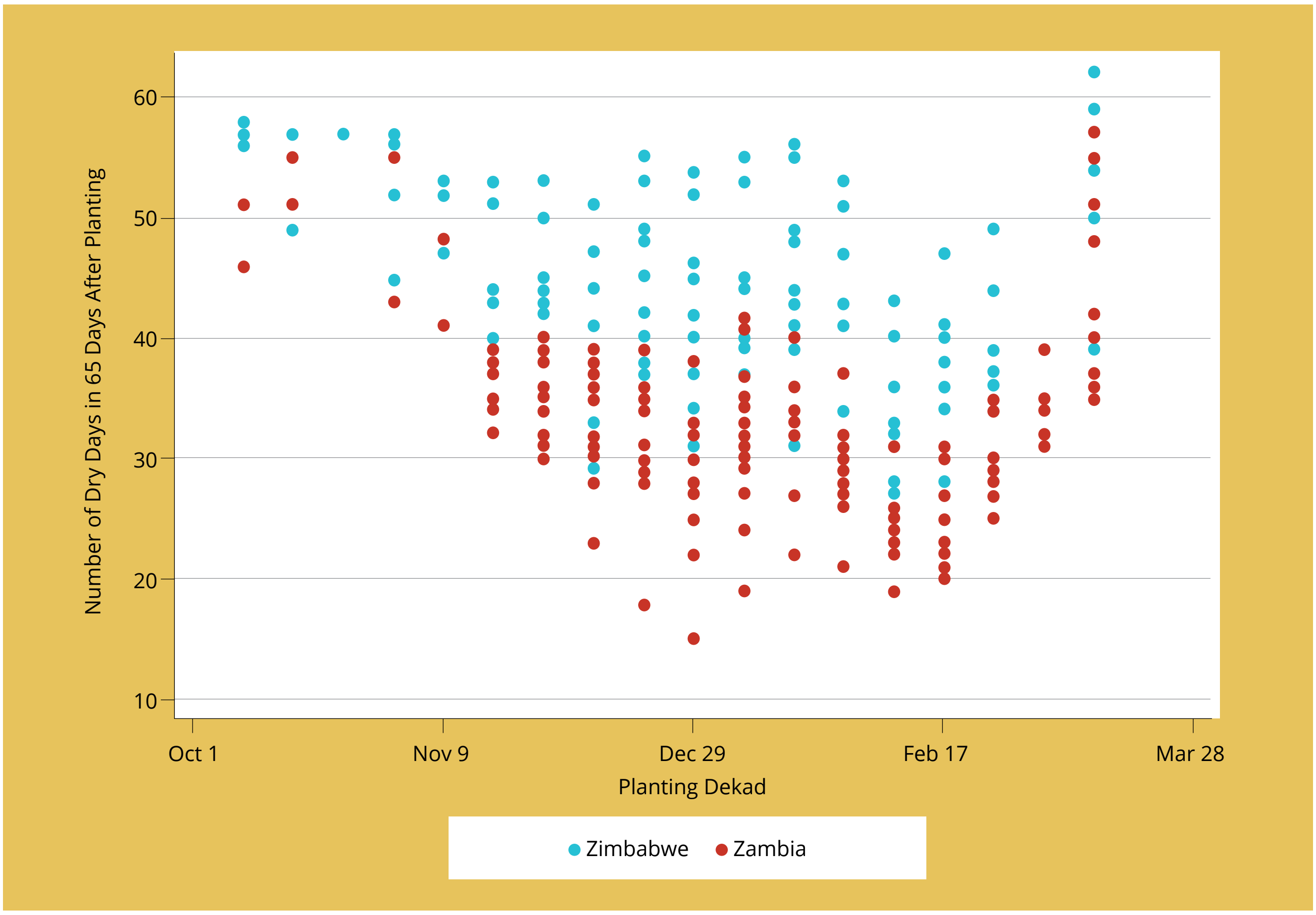


Figure 4: Pattern of dry days in the 65 days after planting

Figures 3 and 4 chart, respectively, the cumulative rainfall and the number of dry days in the 65 days after planting. In Figure 3 we see that plots planted in the first 5 dekads after October 1 received very little rain in the first 65 days (less than 100 millimetres), regardless of country. Plots planted in the 5 to 15 dekads after October 1 saw significantly more rain, with later planting dates being associated with more rain during this vital plant growth stage. Plots planted more than 15 dekads after October 1 received more rain than plots planted in the dekads 1–10 but less than those planted in the dekads 10–15, with extreme variability in rainfall level for those who planted in dekad 18. In general, plots in Zambia received more rain than those in Zimbabwe. A similar pattern is present when we use the total number of dry days that occur in the first 65 days after planting.

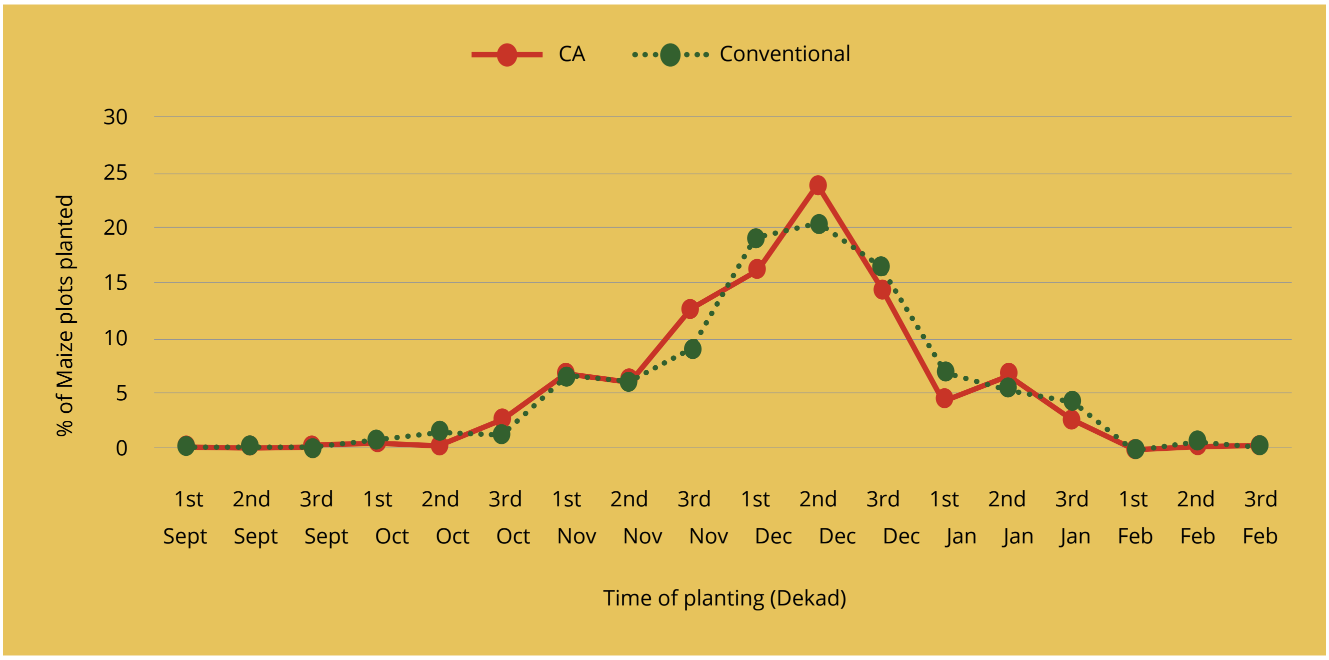


Figure 5: Proportion of maize planted by time for Zambia

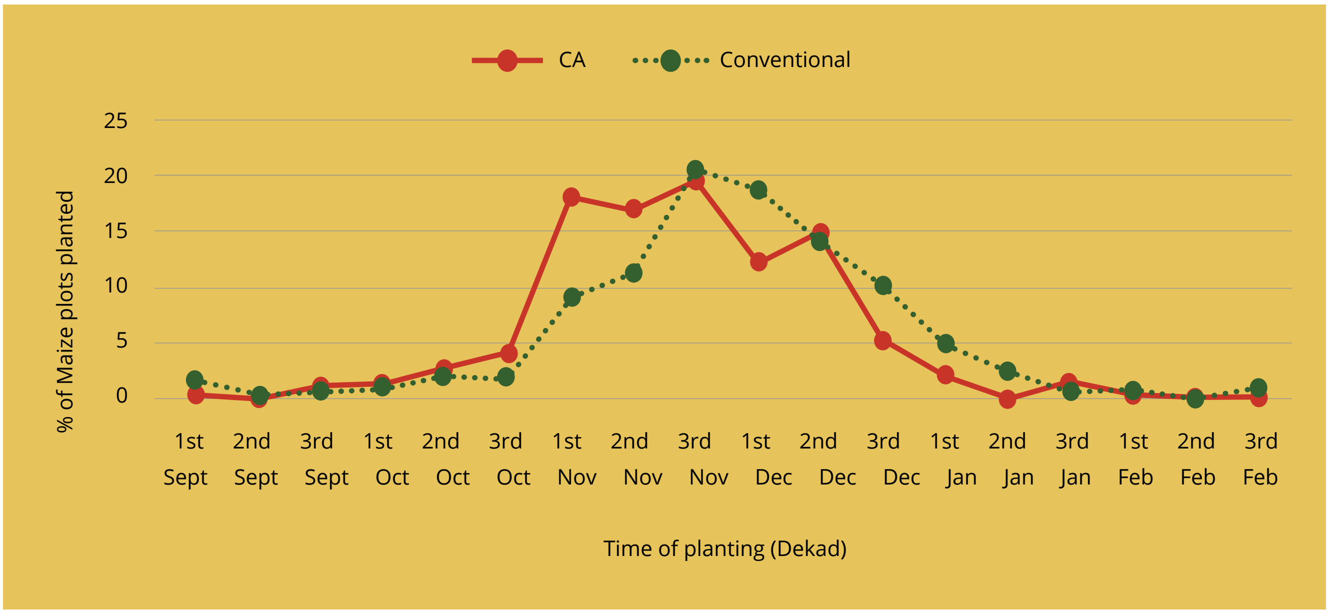


Figure 6. Proportion of maize planted by time for Zimbabwe

The spread in planting dates for CA and conventional plots is show in Figures5 and 6. Figure 5 shows maize planting dates for smallholders in Zambia. Most of the maize was planted during the second week of December for both CA and conventional tillage. Similarities in planting dates for CA and conventional agriculture in Zambia may be explained by higher adoption levels for mechanised CA, implying that land preparation is carried out at similar times. Figure 6 shows maize planting dates for smallholders in Zimbabwe. CA plots were planted earlier compared to conventional plots and thus received less rain during the first 65 days. The peak of planting was in the third week of November for both CA and conventional tillage. It is argued that early planting made possible by manual CA is preferable and has a positive impact on yields as it enables better use of limited rains(Mazvimavi, 2011; Andersson and D'Souza, 2014). However, in the event of late onset of rains, as was the case in 2015–16, this assumption proves false. In the case of CA in Zimbabwe, early planting actually was worse.

We can compare these measures of agricultural drought to our measures of meteorological drought to assess how closely correlated are the two proxies. Table 6 reports correlation coefficients between our two measures by country. Cumulative seasonal rainfall and rainfall in the 65 days after planting are moderately correlated in both Zambia and Zimbabwe. Total number of dry days in the season and dry days in the 65 days after planting are strongly correlated. This suggests that our measures of meteorological drought are good proxies for agricultural drought but that, in the case of cumulative rainfall, there may be gains to using the agricultural drought measure.

Table 6: Correlation between meteorological and agricultural measure of drought

	Zambia	Zimbabwe
Cumulative rainfall	0.39	0.45
Number of dry days	0.67	0.93

One caveat to the use of our measures for agricultural drought is that we are unable to determine if the rainfall or number of dry days in 2015–16 was different than in previous seasons. This is because we do not observe planting date for years other than 2015–16.

Table 6 shows differences between occurrence of dry days and rainfall received in the first 65 days after planting for maize in both CA and conventional plots. In Zambia, the differences in rainfall received during the crop growth stage (first 65 days) was significant only in Katete, where conventional plots received more rains that CA plots. Overall, however, the difference between rainfall in CA and conventional plots was not significant. This can be attributed to similarities in planting dates for maize in both CA and conventional plots, as shown in Figure 5. Similarly, there were no significant difference in number of dry days within the first 65 days for both CA and conventional plots.

In Zimbabwe, differences in the amount of rainfall received over the period of 65 days after planting was observed in Gokwe South and Nkayi. Overall, CA plots received less rains and more dry days when compared to conventional plots within a period of 65 days after planting. This suggests that more stable rains were received later during the season, given that CA plots where planted earlier than conventional plots, as shown in figure 6. Though early planting is recommended in most of the years, it may be less helpful if the season has an erratic start, as was the case for 2015–16.

Table 7: Average dry days and rainfall received within 65 days after planting

Country	Districts	Ward	Average rainfall within the first 65 days after planting (mm)			Average number of dry days within the first 65 days after planting		
			CA	Conven-tional	Diff.	CA	Conven-tional	Diff.
Zambia	Chipata	Mapala 1	329	335	-6.8	28.9	28.9	0.0
		Mapala 2	341	358	-17	24.0	23.1	0.9
	Mumbwa	Kabwanga	284	287	-3.5	29.9	28.6	1.3
		Shimbizhi	368	322	35	30.7	31.5	-0.8
	Chibombo	Chankumba	323	368	-45	35.7	34.3	1.5
		Mwach.	335	339	-3.5	27.3	28.4	-1.0
	Katete	Mwan.	292	332	-40**	38.4	37.4	0.9
		Chingombe	327	297	29	38.1	39.5	-1.4
	Sinazongwe	Mwananjoke	279	286	-6.7	31.8	31.5	0.3
		Sinazeze	277	294	-15	30.9	29.7	1.1
	Monze	Kawumba	311	307	4.1	30.7	31.2	-0.5
		Malende	266	261	4.3	28.8	29.8	-1.0
		Nteme	281	280	1.1	27.3	28.5	-1.2
Mean			**307**	**315**	**-8.1**	**30.7**	**31.3**	**-0.6**
Zimbabwe	Gokwe South	13	162	258	-95***	41.9	37.5	4.4***
		26	140	172	-31	37.2	37.4	-0.2
	Nkayi	14	200	223	-30**	35.1	34.9	0.2
		22	210	263	-52***	39.8	39.8	0.0
	Bindura	8	261	274	-12	40.2	39.9	0.3
		10	248	238	9.8	42.1	42.5	-0.5
	Murehwa	14	175	182	-6.0	48.2	48.4	-0.2
		28	177	189	-12	47.4	46.7	-0.8
	Hwange	4	239	195	43	30.0	31.4	-1.4
		7	190	212	-22	31.9	31.8	0.2
	Masvingo	12	110	108	1.8	53.4	54.1	-0.8**
		14	100	106	-6.4	53.2	52.9	0.4
Mean			**177**	**199.**	**-22****	**44.2**	**42.3**	**1.9*****

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

6.2 CA use among smallholder farmers

6.3 Application of CA practices

While CA comprises a package of three practices, the survey results show that most CA adopters do not apply all three. Using data from 303 CA maize plots in Zambia and 295 in Zimbabwe, we can distinguish four levels of CA adoption. The first level is when smallholder farmers use minimum tillage only. The second level is when minimum tillage is combined with crop-residue mulching. In the third level, minimum tillage is combined with crop rotation. These three levels can be classified as partial CA adoption. The fourth level is when all three practices are applied on the plot; this is considered full CA adoption. In Zambia 38% of the plots received full CA adoption, while in Zimbabwe that figure was 25% (Figure 7). These results show that the majority of the plots in each country received partial CA adoption. There are very few farmers who practice minimum tillage plus mulch in both countries. This could be because of the difficulties associated with crop residue mulching, especially under crop-livestock systems (Valbuena et al., 2012).

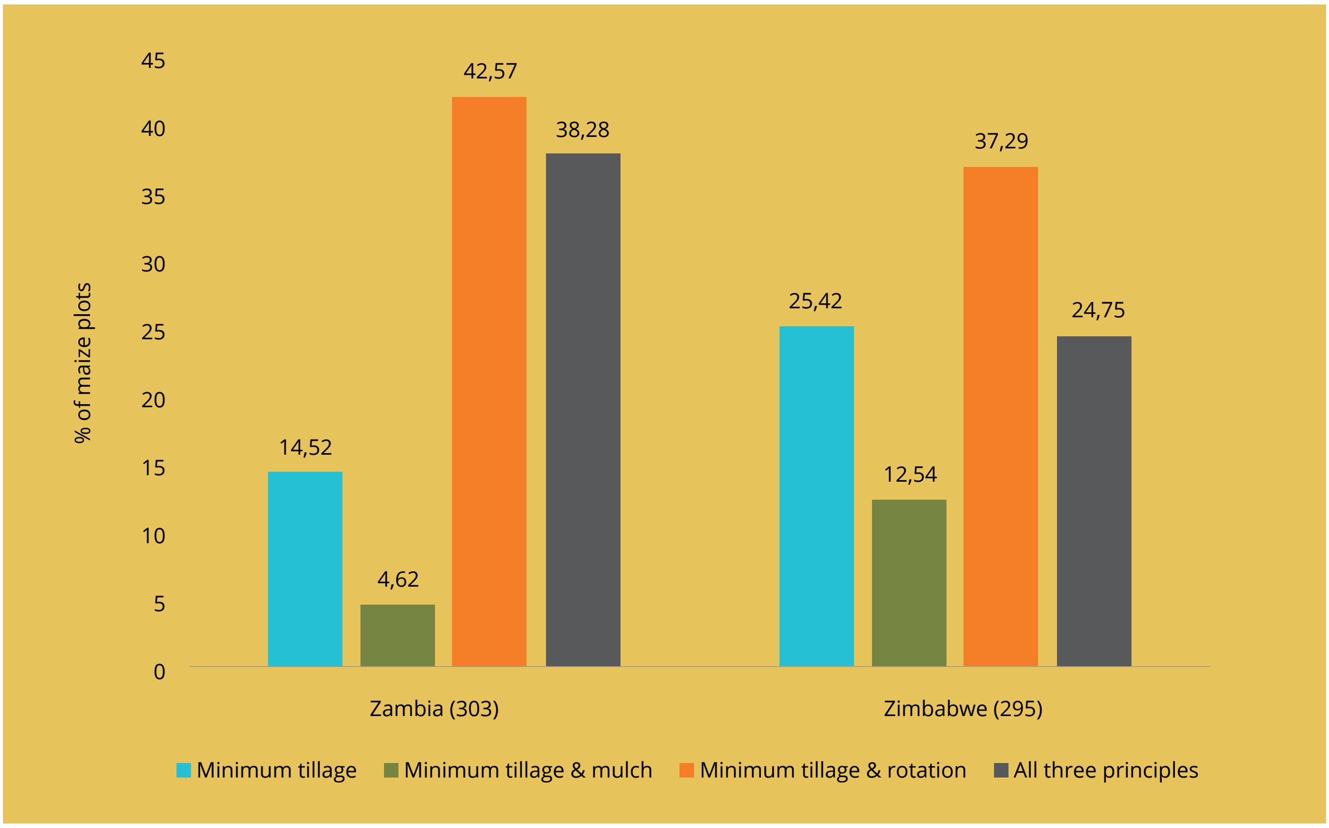


Figure 7: Proportion of maize plots with different CA practices

Even though a majority of farmers indicated that they applied more than one component of CA, it is important to note that the way farmers actually implement these practices may be very different from recommendations. This was evident in two ways. First, at the time of the study, farmers indicated that they would store their crop residues where they cannot be consumed by livestock, and then use them as mulch during the cropping season. This is different from the ideal practice used in monitored agronomic trials, where mulching material is left in the field throughout the year. As a result, the benefits of mulching may be limited in practice. Second, when farmers implement the crop rotation component, they sometimes deviate from minimum disturbance principle owing to differences in spacing, particularly where manual planting basins are used. This challenge of spacing is less binding when mechanised CA is used. Furthermore, in years in which farmers decide to rotate crops, they do not allocate the entire plot to legumes because they give preference to producing cereal crops, particularly maize. Given the way in which CA components are actually applied by farmers, there may be variations in the quality of mulching and rotation. Owing to this, the term CA in this study refers to minimum tillage, unless otherwise stated.

6.3.1 Total area planted by tillage type

Table 8 shows the total area planted to maize under CA and conventional agriculture systems. In Katete and Mumbwa, area allocated to CA is significantly larger than area allocated to conventional agriculture. In Murehwa, Gokwe South and Nkayi, total area under CA is significantly smaller than area under conventional agriculture. Overall, in Zimbabwe, area under CA is smaller compared to conventional agriculture. The digging of planting basins requires high labour input in terms of time and effort, and this may explain the smaller areas allocated to CA in Zimbabwe. The largest area under CA in Zambia, averaging 2.40 hectares, was found in Chibombo, while in Zimbabwe, Bindura had the largest area, at 0.97 hectares. Bigger CA plots in Zambia could be attributed to the fact that landholdings there are generally larger than they are in Zimbabwe, as well as to the use of mechanised rippers, which greatly reduce the labour demands of CA.

Table 8: Total maize area under CA and conventional tillage at household level by district

Country	Rainfall received in 2015–16	District	CA		Conventional		
			Farmers	Mean (ha)	Farmers	Mean (ha)	Difference
Zambia	Above 700mm	Chipata	30	1.75	26	1.16	0.59
		Mumbwa	38	1.98	25	1.12	0.86**
		Chibombo	31	2.40	27	2.38	0.02
	Between 600-700mm	Katete	28	1.03	33	1.02	0.01*
		Sinazongwe	35	1.18	28	1.10	0.08
	Below 600mm	Monze	47	1.23	33	1.36	-0.13
	Mean		**209**	**1.58**	**172**	**1.35**	**0.23**
Zimbabwe	Above 700mm	Gokwe South	30	0.72	49	1.44	-0.73***
	Between 600-700mm	Nkayi	35	0.72	46	1.13	-0.41**
		Bindura	35	0.97	25	1.05	-0.08
		Murehwa	33	0.33	49	0.50	-0.17**
	Below 600mm	Hwange	16	0.52	29	0.68	-0.16
		Masvingo	36	0.85	39	0.76	0.09
	Mean		**185**	**0.71**	**237**	**0.94**	**-0.23*** **

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

> **Bigger CA plots in Zambia could be attributed to the fact that landholdings there are generally larger than they are in Zimbabwe.**

In addition to larger areas in Zambia, CA adopters there allocate a larger proportion of their land to CA. As shown in Table 9, in Zambia CA adopters allocated roughly 89% of their cultivated land to CA, while in Zimbabwe adopters cultivated approximately 70% of the land using CA.

Table 9: Proportion of total maize area under CA for adopters at household level

Country	Rainfall received in 2015–16 in study areas	District	Number of CA adopter	Mean total area cultivated (ha)	Std error	Proportion allocated to CA (%)	Std error
Zambia	Above 700mm	Chipata	30	1.98	0.32	0.88	0.04
		Mumbwa	38	2.01	0.27	0.97	0.02
		Chibombo	31	2.43	0.63	0.96	0.03
	Between 600-700mm	Katete	28	1.41	0.17	0.77	0.06
		Sinazongwe	35	1.54	0.20	0.86	0.05
	Below 600mm	Monze	47	1.44	0.13	0.90	0.03
	Mean		**209**	**1.78**	**0.13**	**0.89**	**0.02**
Zimbabwe	Above 700mm	Gokwe South	30	1.63	0.21	0.55	0.06
	Between 600-700mm	Nkayi	35	1.37	0.15	0.58	0.06
		Bindura	35	1.12	0.16	0.94	0.03
		Murehwa	33	0.73	0.08	0.51	0.06
	Below 600mm	Hwange	16	0.68	0.13	0.79	0.08
		Masvingo	36	1.055	0.11	0.83	0.04
	Mean		**185**	**1.13**	**0.06**	**0.70**	**0.02**

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$

6.3.2 Type of CA techniques

Both manual and mechanised CA is practiced in both countries (Table 10). Manual CA generally involves the use of a hand hoe, while mechanised CA uses rippers, which can be either ox-drawn or tractor-drawn, although for the purpose of this analysis we lump both under mechanised CA.

Table 10: Area planted to maize (hectare) by country and CA technology

Country	Rainfall received in 2015–16	Manual/Basin		Mechanised/Rippers		Difference
		Plots	Area	Plots	Area	
Zambia	Above 700mm	55	0.97	91	1.62	-0.65***
	Between 600-700mm	31	0.69	50	0.85	-0.16
	Below 600mm	13	0.73	60	0.89	-0.16
	Mean	**99**	**0.85**	**201**	**1.21**	**-0.36*** **
Zimbabwe	Above 700mm	15	0.44	4	0.65	-0.22
	Between 600-700mm	120	0.40	60	0.53	-0.13
	Below 600mm	79	0.41	11	0.56	-0.14
	Mean	**214**	**0.41**	**75**	**0.54**	**0.14***

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$.

Across the two countries, plots that were tilled using mechanised CA were larger than the manual basin plots. In Zambia, most of the farmers practiced mechanised CA, while in Zimbabwe, the majority of farmer's implemented manual planting basins. In Zambia, plots in areas that received more rains were relatively larger. Plots were smaller in areas that received less than 600 millimetres of rainfall, and the difference in size between manual planting basins and mechanised CA was not statistically significant. In Zimbabwe, the majority of CA adopters were located in areas that received less than 600 millimetres of rainfall, and the plot sizes in these areas were small. Furthermore, there are no differences between mechanised and manual basins in terms of plot sizes.

6.3.3 Comparison of maize yields

Table 11 shows maize yield differences between CA and conventional plots for each district in Zambia and Zimbabwe. For Chipata, CA plots yielded 2424 kg ha^{-1} compared to 1439 kg ha^{-1}under conventional agriculture. There was no significant difference between the yields for CA and conventional plots in other areas that received above 700 millimetres of rainfall in 2015–16. Results also show that in Sinazongwe and Monze districts, which are located in areas that received less rainfall, CA plots had higher yields than conventional plots. The CA plots had an average maize yield of about 1040 kg ha^{-1}, while the conventional tillage yielded 590 kg ha^{-1} in Sinazongwe. This suggests that CA may contribute to yield resilience in dry areas. However, to verify this it is necessary to compare the relative contribution of CA with the contribution of other farming inputs. This analysis is considered below.

In Zimbabwe, there was no significant difference between CA and non-CA yields for districts that received above 600 millimetres. The one exception was Murehwa, where CA plots performed better than conventional plots. In Masvingo district, which received less than 600 millimetres of rainfall, conventional plots had higher yields than CA. Discussions with extension officers in Masvingo revealed that farmers planted CA plots with the first rains, as the basins were prepared earlier in winter. After planting there was a long dry spell, which affected crop growth in CA plots. Owing to resource constraints, some farmers failed to replant their CA plots. Most plantings on conventional plots was done after the long dry spell, and the harvest was better than in CA plots.

Table 11: Plot-level maize yield by country, rainfall, district, and tillage technique

Country	Rainfall received in 2015–16	District	CA		Conventional		
			Plots	Yield kg/ha	Plots	Yield kg/ha	Difference
Zambia	Above 700mm	Chipata	34	2,424	29	1,438	985***
		Mumbwa	65	1,275	36	1,127	147
		Chibombo	48	1,518	36	1,646	-127
	Between 600-700mm	Katete	32	956	42	912	44.3
		Sinazongwe	51	1,039	37	590	449***
	Below 600mm	Monze	73	1,013	50	704	309*
	Mean		**303**	**1,306**	**230**	**1,030**	**276*** **
Zimbabwe	Above 700mm	Gokwe South	35	945	80	756	188
	Between 600-700mm	Nkayi	50	530	82	440	90.4
		Bindura	58	982	32	1,081	-98.8
		Murehwa	61	1,956	70	1,504	451***
	Below 600mm	Hwange	17	617	37	323	295
		Masvingo	74	298	73	493	-194**
	Mean		**295**	**910**	**374**	**760**	**149** **

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$

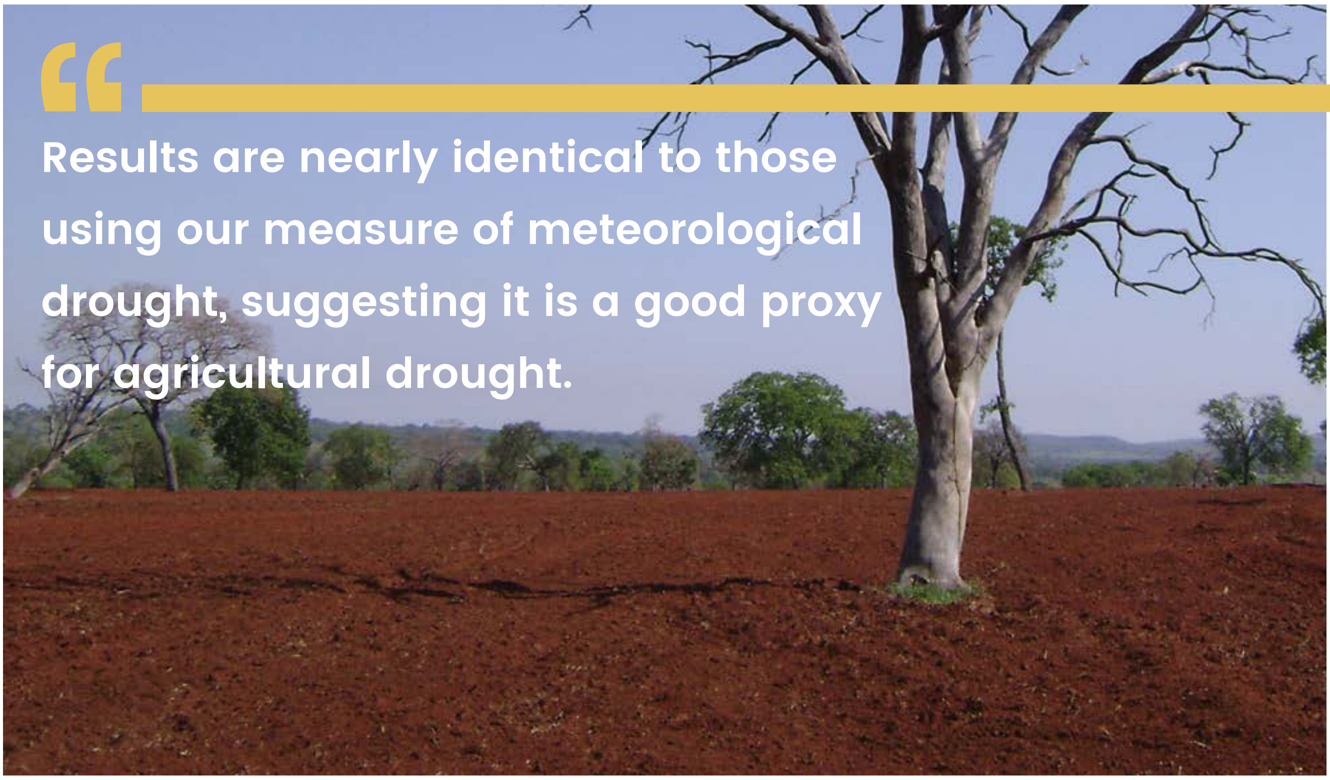
The results in Table 11 do not show a clear trend in the mean differences between yields on CA and conventional plots across districts and for different rainfall amounts received. This could be attributed to the moderate correlation between seasonal drought and agricultural drought. As a means of addressing this potential limitation, we also compare maize yield based on rainfall received within the first 65 days after planting (Table 12 and 13). Plots are categorised according to whether they received rainfall above or below the country average in the first 65 days after planting.

Results are nearly identical to those using our measure of meteorological drought, suggesting it is a good proxy for agricultural drought. No clear pattern in yield differences emerges. CA yields are higher in Chipata on plots that received above-average rainfall and are also higher in Singazongwe and Monze in plots that received below-average rainfall. In Zimbabwe, CA yields were higher in Gokwe South and Murehwa for plots that received below-average rainfall but lower in Masvingo. The results of these comparisons imply that the use of CA during periods of drought may not be the primary driver in determining maize yields.

Table 12: Zambia plot-level maize yield and actual rainfall received after planting

Country average rainfall within 65 days	District	CA		Conventional		Diff
		Plots	Yields kg/ha	Plots	Yields kg/ha	
Above country average	Chipata	24	2,638	20	1,569	1069*
	Mumbwa	38	1,382	17	1,397	-15.3
	Chibombo	30	1,367	31	1,675	-308
	Katete	15	899	26	1,009	-110
	Sinazongwe	15	889	16	646	242
	Monze	18	1,023	15	1,274	-251
	Mean	**140**	**1,443**	**125**	**1,302**	**141**
Below country average	Chipata	10	1,911	9	1,148	762
	Mumbwa	27	1,125	19	886	238
	Chibombo	18	1,771	5	1,467	304
	Katete	17	1,007	16	753	253
	Sinazongwe	36	1,102	21	546	555**
	Monze	55	1,010	35	459	550**
	Mean	**163**	**1,188**	**105**	**706**	**482*** **

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$



> **Results are nearly identical to those using our measure of meteorological drought, suggesting it is a good proxy for agricultural drought.**

Table 13: Zimbabwe plot-level maize yield and actual rainfall received after planting

Country average rainfall within 65 days	District	CA		Conventional		
		Plots	Yields	Plots	Yields	Diff
Above country average	Gokwe South	7	1260	53	878	282
	Nkayi	38	628	73	416	211
	Bindura	41	936	24	1122	-185
	Murehwa	19	2062	30	1648	413
	Hwange	10	483	24	453	30.1
	Masvingo	-	-	-	-	-
	Mean	**115**	**1001**	**205**	**801.7**	**199***
Below country average	Gokwe South	28	866	27	517	349*
	Nkayi	12	222	9	634	-412
	Bindura	17	1093	8	959	134
	Murehwa	42	1908	40	1396	511**
	Hwange	7	809	13	81.6	728
	Masvingo	74	298	72	498	-199**
	Mean	**180**	**852**	**169**	**711**	**141**

*p< 0.10, **p< 0.05, ***p< 0.01

6.3.4 Other potential drivers of yield

In order to understand the causes of variations in yields between CA and conventional plots,we consider other plot characteristics and crop management practices (Table 14). Generally, significantly more basal fertiliser was used in CA plots compared to conventional plots across the two countries. Similar trends exist for top-dressing application rates. This is due to differences in the frequency of fertiliser use across tillage practices. In Zambia, only 34% of conventional farmers apply basal fertiliser, while 46% of CA farmers do. In Zimbabwe, 25% of conventional farmers apply basal fertiliser while 53% of CA farmers do. Similarly high percentages of CA farmers apply top dressing; conventional farmers typically do not. These results suggest that adoption of CA is strongly associated with fertiliser use, and differences in mean yield between the two practices may be due to fertiliser rather than to the tillage practice itself.

While fertiliser use was higher on CA plots, seed application rates were significantly lower. However, certified seed was used on a greater proportion of CA plots. This again suggests that the primary driver of higher mean yields on CA plots compared to conventional plots might not be the tillage method but the more common use of improved inputs. These differences also highlight the need to control for OVB in estimation of the production function, since farmers may be purposively choosing to apply different levels of inputs on different plots based on unobserved characteristics.

Table 14: Maize plot management and characteristics

Description	Zambia			Zimbabwe		
	CA plots	Conventional	Difference	CA plots	Conventional	Difference
Basal fertiliser (kg ha^{-1})	104.2	84.0	20.3***	69.8	52.8	17.1***
Top dressing (kg ha^{-1})	107.3	89.6	17.7**	79.1	58.4	20.7***
Seed planted (kg ha^{-1})	20.6	21.3	-0.7*	21.7	22.4	-0.7***
Certified seed (1=yes)	0.88	0.79	0.1***	0.89	0.81	0.1***
Slope (1=flat)	0.65	0.60	0.05	0.62	0.64	-0.02
Soil type	0.58	0.56	0.02	0.64	0.67	-0.03
Weeding frequency	1.89	1.60	0.29***	2.43	1.96	0.47***
N	*303*	*230*		*295*	*374*	

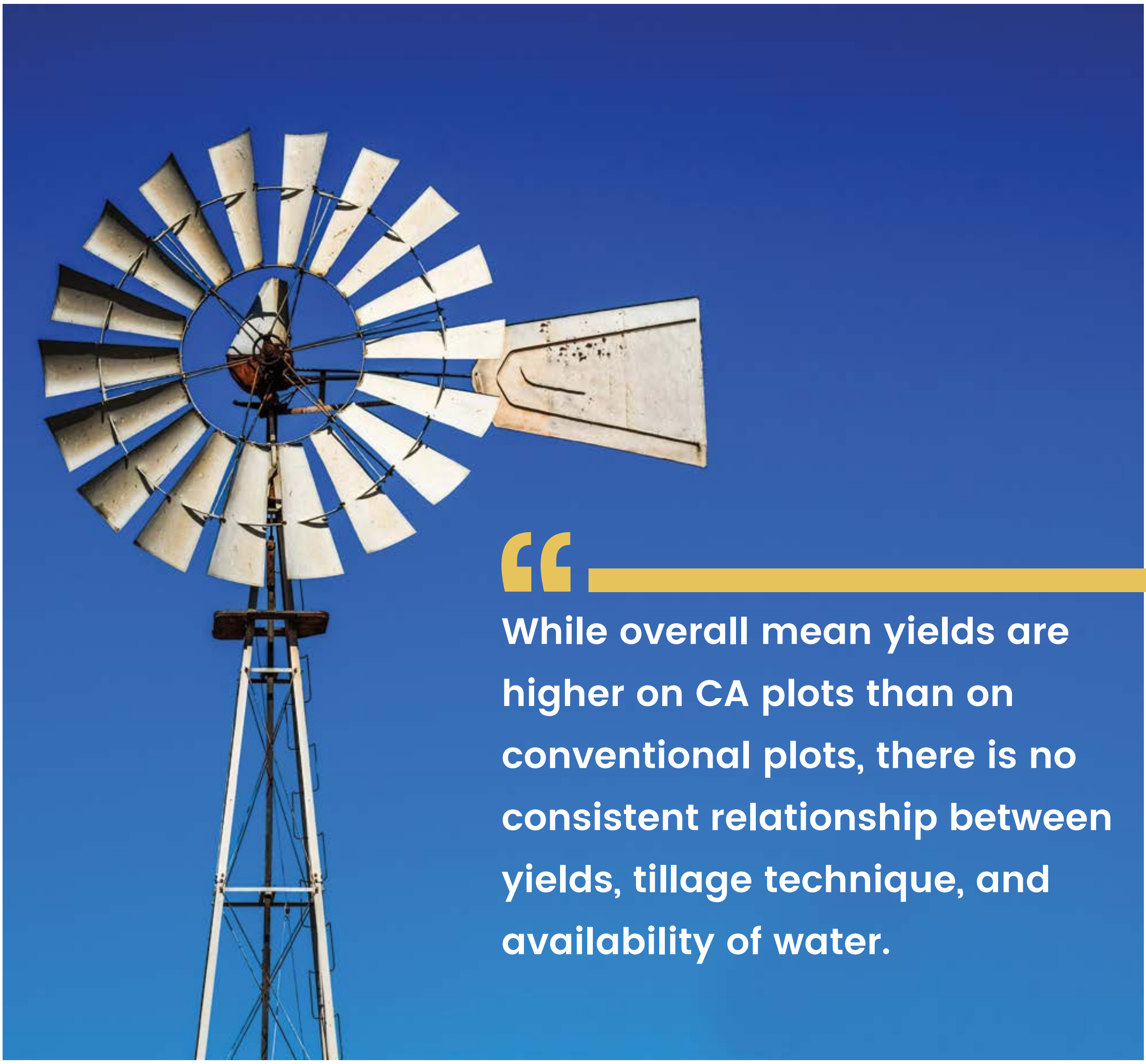
*p< 0.10, **p< 0.05, ***p< 0.01

There were no significant differences in plot characteristics (slope and soil type) for CA and non-CA plots across the two countries. In general, CA plots received more frequent weeding compared to non-CA plots. This highlights the importance of timely weed control. But it may also reflect the fact that CA plots normally have more weeds compared to non-CA plots.

6.3.5 Summary of descriptive analysis

To summarize our descriptive analysis, we fail to find clear evidence that CA contributes to building yield resilience to drought. While overall mean yields are higher on CA plots than on conventional plots, there is no consistent relationship between yields, tillage technique, and availability of water. This lack of a consistent relationship exists regardless of whether we use meteorological or agricultural measures of drought. Given that availability of water and type of tillage technique fail to sufficiently explain the yield variations,there may be other, more binding factors.

Potential additional factors that may explain differences in mean yields between CA and conventional plots are the use of improved inputs and planting date. Descriptive evidence suggests that CA farmers are more likely to use fertiliser and certified seed. It may be the use of these improved inputs associated with CA, and not the practices of CA itself, that contributed to higher yields on CA plots. Conversely, CA plots are frequently planted earlier than conventional plots, at least in Zimbabwe. In regions like Masvingo, where El Niño resulted in late onset of rains, this may have contributed to lower mean yields on CA plots. All of this suggests the need for careful multivariate analysis to ensure that assessment of CA technology is not confounded with the yield response from higher chemical fertiliser rates and use of higher quality seed.



> “While overall mean yields are higher on CA plots than on conventional plots, there is no consistent relationship between yields, tillage technique, and availability of water.

7 Econometric evidence

7.1 Factors influencing adoption of CA practices

The results from previous descriptive analysis suggest that CA is associated with better plot management (use of more fertiliser, improved seed, and increased weed management). This may be attributed to the fact that when CA was promoted, good crop-management practices were emphasised. Farmers may therefore associate CA with better use of fertiliser, purchase of certified seed, and greater attention to weeding.

The factors influencing the adoption of CA practices in Zambia and Zimbabwe are presented in Tables 15 and 16, respectively. In both tables, the first column presents results of a probit model using household-level data. Here, a CA adopter is classified as a farmer who practices at least minimum tillage. In columns 2–5, we used a multivariate probit model to understand factors influencing the adoption of different CA practices.

Results from Table 15 show that age of the household head, household size, and use of credit positively influence adoption of CA in Zambia. Since CA is labour-intensive, it makes sense that larger households, which have greater access to family labour, are more likely to adopt it. Credit facilities enable farmers to acquire inputs such as fertilisers and certified seed, which are associated with the use of CA at the plot level. Results from the multivariate probit show that older and better-educated farmers are more likely to adopt all three CA practices. Somewhat contradictory to this result is that more years of farm experience is negatively associated with the adoption of all three practices. This may suggest that experienced farmers may not find all three practices cost-effective and therefore reverted to using only the CA practices that work best for them. Finally, we find that households with access to credit and households located in climates that receive higher rainfall are more likely to adopt all three practices. By comparison, farmers in drier climates are more likely to adopt only minimum tillage or tillage in combination with rotation.

Table 15: Factors determining CA adoption in Zambia

	CA adoption	**CA practices adoption**			
		Till only	**Till & mulch**	**Till & rotate**	**All three**
	(1)	(2)	(3)	(4)	(5)
Gender (male=1)	0.050	-0.266	-0.882***	0.252	0.136
	(0.174)	(0.197)	(0.284)	(0.156)	(0.165)
Age (years)	0.015**	0.012	0.007	0.005	0.012**
	(0.007)	(0.008)	(0.012)	(0.006)	(0.006)
Education (tertiary=1)	0.180	-0.272	0.239	-0.122	0.442***
	(0.151)	(0.181)	(0.277)	(0.128)	(0.128)
Household size	0.041**	-0.008	0.032	0.008	0.017
	(0.019)	(0.023)	(0.031)	(0.015)	(0.016)
Farm experience (yrs)	0.003	0.007	-0.011	0.005	-0.012*
	(0.007)	(0.008)	(0.012)	(0.006)	(0.007)
Market distance (kms)	-0.000	-0.021	-0.063**	0.000	0.006
	(0.004)	(0.014)	(0.030)	(0.004)	(0.003)
Use of credit (yes=1)	0.555***	-0.230	0.515*	-0.068	0.561***
	(0.208)	(0.269)	(0.304)	(0.167)	(0.153)
Plot slope (flat=1)	0.021	0.214	-0.098	-0.116	0.116

	CA adoption	CA practices adoption			
		Till only	Till & mulch	Till & rotate	All three
	(0.174)	(0.201)	(0.285)	(0.135)	(0.137)
Soil type (loam =1)	-0.029	-0.099	-0.198	-0.154	0.194
	(0.164)	(0.179)	(0.270)	(0.126)	(0.129)
Climate (1=wet)	-0.048	-0.819***	-0.468	-0.374**	0.375**
	(0.166)	(0.310)	(0.392)	(0.158)	(0.151)
N	341	533			
p	0.007***	0.000***			
ll	-212.983	-695.880			

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$

Results in column 1 of Table 16 show that less-educated but more experienced farmers adopt CA in Zimbabwe. This may be due to the targeting of CA promotion to poorer farmers, i.e., those farmers who due to a lack of education have few options other than farming and thus have gained more experience at farming. Results from the multivariate probit model are shown in columns 2–5. Male-headed household are less likely to adopt all three CA practices compared to their female counterparts. This may be attributed to the fact that females usually manage legume crops, which makes it less likely that men will perform crop rotation. As in Zambia, the use of credit and living in wetter regions of the country are associated with adoption of all three CA practices.

A quick summary of our probit results leads us to conclude that farmers in both Zambia and Zimbabwe are more likely to adopt all three CA practices if they live in higher-rainfall regions and if they are able to access credit facilities. The positive association between use of credit and adoption of all three CA practices provides further evidence that adoption of CA is associated with better farm management practices, such as the effective use of fertiliser and the purchase of certified seed.

> Zambia and Zimbabwe are more likely to adopt all three CA practices if they live in higher-rainfall regions and if they are able to access credit facilities.

Table 16: Factors determining CA adoption in Zimbabwe

	CA adoption	CA practices adoption			
		Till only	Till & mulch	Till & rotate	All three
	(1)	(2)	(3)	(4)	(5)
Gender (male=1)	-0.051	0.089	0.009	0.108	-0.300**
	(0.158)	(0.152)	(0.184)	(0.138)	(0.147)
Age (years)	0.003	-0.000	-0.003	-0.000	-0.007
	(0.006)	(0.006)	(0.008)	(0.005)	(0.007)
Education (tertiary=1)	-0.252*	-0.155	-0.013	0.198	-0.216
	(0.152)	(0.145)	(0.174)	(0.130)	(0.150)
Household size	0.011	0.023	0.001	-0.041*	0.031
	(0.025)	(0.025)	(0.030)	(0.023)	(0.024)
Farm experience (yrs)	0.012*	-0.002	0.006	0.004	0.006
	(0.007)	(0.006)	(0.008)	(0.005)	(0.006)
Market distance (kms)	-0.002	-0.001	0.002	-0.002	-0.003
	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)
Use of credit (1=yes)	0.271	-0.329	-0.253	-0.269	0.455***
	(0.226)	(0.203)	(0.249)	(0.174)	(0.173)
Plot slope (flat=1)	-0.091	-0.172	-0.026	-0.206	0.113
	(0.177)	(0.141)	(0.174)	(0.129)	(0.151)
Soil type (loam =1)	-0.259	0.075	-0.098	-0.165	-0.130
	(0.170)	(0.144)	(0.173)	(0.125)	(0.145)
Climate (1=wet)	-0.073	0.029	-0.257	0.154	0.680***
	(0.163)	(0.152)	(0.201)	(0.136)	(0.145)
N	340	669			
p	0.013**	0.001***			
ll	-218.426	-840.528			

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$

7.2 CA impact on yields during meteorological drought

In order to assess whether CA contributes to building resilience to drought, we estimate several Cobb-Douglas production functions. To do this we include a binary indicator for whether the plot was planted using minimum tillage techniques, various measures of meteorological and agricultural drought, and the interaction between these two terms. The coefficient on the CA term indicates whether CA contributes to higher yields during periods of normal rainfall. Coefficients on the various rainfall measures indicate how yields respond to drought. The coefficient on the interaction term indicates if CA contributes to higher yields during periods of drought. To ensure identification of CA's impact, we control for the quantity of improved inputs used on each plot. We also control for both observable and unobservable household and farm characteristics in order to reduce OVB that could create bias in coefficients of interest.

We first estimate production functions for Zambia and Zimbabwe using our four different measures of meteorological drought.[5] Table 17 shows only the coefficients on CA, the drought indicator, and their interaction. CA builds resilience to drought if the coefficient on the interaction term is positive and significant. In columns 1 and 3 we present the results from regressions without correlated random effects for Zambia and Zimbabwe, respectively. In column 2 and

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[5] All regressions include the log of basal fertiliser, top fertiliser, and seed, as well as the frequency of weeding, the gender and age of the household head, the household head's level of education and years of experience farming, the size of the household, the distance to input markets, and the use of credit.

4 we present the results from regressions with correlated random effects for Zambia and Zimbabwe, respectively. In most cases, the variables for CA, the measure of meteorological drought, and their interaction are not statistically significant. Only in Zambia, and only when we measure drought as an above-average number of dry days, do we see CA significantly contributing to yields. But even here CA does not contribute to resilience of yields to drought when measured in this way.[6]

Table 17: Effect of meteorological drought on maize yield under different tillage techniques

	Zambia		**Zimbabwe**	
	(1)	**(2)**	**(3)**	**(4)**
Rainfall shortage				
CA status	0.461	1.261	0.056	0.265
	(0.757)	(0.876)	(0.333)	(0.393)
Rainfall shortage	0.010	0.139	0.033	0.017
	(0.557)	(0.573)	(0.231)	(0.235)
CA* rainfall shortage	-0.173	-0.387	-0.129	-0.098
	(0.712)	(0.720)	(0.325)	(0.328)
Late onset				
CA status	0.337	0.875	0.428	0.546
	(0.438)	(0.549)	(0.316)	(0.375)
Late onset	-0.017	0.013	-0.488	-0.400
	(0.274)	(0.276)	(0.348)	(0.357)
CA*lateonset	-0.042	-0.028	-0.840*	-0.776
	(0.367)	(0.372)	(0.487)	(0.496)
Dry days				
CA status	0.700**	1.207**	0.156	0.421
	(0.346)	(0.516)	(0.396)	(0.456)
Dry days	0.870***	0.847***	1.133***	1.163***
	(0.248)	(0.250)	(0.339)	(0.346)
CA*dry days	-0.400	-0.417	-0.268	-0.308
	(0.344)	(0.347)	(0.454)	(0.456)
Mid-season dry spells				
CA status	0.506	0.847	0.197	0.460
	(0.330)	(0.458)	(0.351)	(0.414)
Mid-season dry spells	-0.989***	-1.001***	-0.215	-0.273
	(0.333)	(0.341)	(0.221)	(0.227)
CA* dry spells	-0.342	-0.311	-0.300	-0.280
	(0.439)	(0.451)	(0.328)	(0.328)
CRE	No	Yes	No	Yes
Number of plots	533	533	669	669

*p< 0.10, **p< 0.05, ***p< 0.01, standard errors reported in parenthesis

The inability of CA practices to contribute to yield resilience in Zambia and Zimbabwe may be due to two factors. First, CA may in fact not build resilience to droughts. Alternatively, we are unable to accurately capture the effects of the 2015–16 drought in multiple variables for meteorological and agricultural drought. In addition, the measure of CA

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[6] In fact, this drought variable may be mis-specified since an above-average number of dry days increases yields in both Zambia and Zimbabwe.

used in this paper commonly represents only a partial application of the three components of this technology. If all three components were fully and correctly applied, CA could have contributed more to improving drought resilience. However, farmers have many reasons for not using the full practice.

7.3 CA impact on yields during agricultural drought

To address this third concern, we estimate production functions using our two improved measures of agricultural drought: rainfall in the first 65 days after planting and the number of dry days in the first 65 days after planting. As shown in Figure 6, CA plots in Zimbabwe were planted earlier than conventional plots. In both Zambia and Zimbabwe, plots planted earlier received less rain then those planted later in the season (Figures 3). Therefore, it is reasonable to assume that these measures of agricultural drought may allow us to identify resiliency aspects of CA that were not evident in the previously considered measure.

Table 18: Effect of rainfall in the first 65 days on maize yield

	Zambia		**Zimbabwe**	
	(1)	**(2)**	**(3)**	**(4)**
CA status	1.719*	2.263**	0.003	0.209
	(0.879)	(0.964)	(0.524)	(0.559)
Rainfall 65 (mm)	0.004**	0.005**	0.004***	0.005***
	(0.002)	(0.002)	(0.002)	(0.002)
CA* Rainfall 65 (mm)	-0.005*	-0.004	0.000	0.001
	(0.003)	(0.003)	(0.003)	(0.003)
Ln (Basal)	0.023	0.051	0.042	-0.049
	(0.080)	(0.105)	(0.049)	(0.072)
Ln (Top)	0.296***	0.282***	0.294***	0.300***
	(0.082)	(0.107)	(0.051)	(0.075)
Ln (Seed)	-0.518	-0.571	1.781**	1.419*
	(0.693)	(0.718)	(0.715)	(0.732)
Gender (1=male)	0.401	0.404	0.410*	0.412*
	(0.276)	(0.279)	(0.219)	(0.221)
Age (years)	-0.006	-0.004	-0.014	-0.014
	(0.011)	(0.011)	(0.009)	(0.009)
Education (1=tertiary)	0.244	0.236	0.348	0.303
	(0.233)	(0.234)	(0.212)	(0.213)
Household size	0.063**	0.067**	-0.073**	-0.054
	(0.029)	(0.029)	(0.035)	(0.036)
Farm experience (yrs)	-0.009	-0.011	0.023***	0.021**
	(0.012)	(0.012)	(0.009)	(0.009)

	Zambia		Zimbabwe	
	(1)	(2)	(3)	(4)
Market distance (kms)	0.009	0.009	-0.006*	-0.005
	(0.006)	(0.006)	(0.003)	(0.003)
Use of credit (1=yes)	0.131	0.147	0.472*	0.492*
	(0.299)	(0.300)	(0.267)	(0.278)
Weeding (days)	0.202**	0.080	0.361***	0.381**
	(0.100)	(0.131)	(0.124)	(0.183)
CRE	No	Yes	No	Yes
Number of plots	533	533	669	669

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$, standard errors reported in parenthesis

Table 18 presents results of these estimations for Zambia and Zimbabwe, with and without CREs to control for OVB, and using the cumulative rainfall in the first 65 days as our measure of agricultural drought. Unlike our previous results in Table 17, here we see that more rain in the first 65 days significantly increases maize yields. This suggests that our earlier measures of meteorological drought were specified incorrectly. However, we again find no significant contribution of CA to building resiliency in yields.

Table 19presents similar results but uses the number of dry days in the first 65 days as our measure of agricultural drought. While this measure of agricultural drought does not significantly impact yields, here again we find no significant contribution of CA to building resiliency in yields.

Table 19: Effect of dry days within the first 65 days on maize yields

	Zambia		Zimbabwe	
	(1)	(2)	(3)	(4)
CA status	-0.217	0.406	0.951	1.227
	(1.232)	(1.305)	(1.173)	(1.196)
Dry days 65	-0.032	-0.034	0.026	0.026
	(0.028)	(0.029)	(0.018)	(0.018)
CA*Dry days 65	0.016	0.013	-0.023	-0.024
	(0.039)	(0.039)	(0.026)	(0.026)
Ln (Basal)	0.028	0.046	0.036	-0.078
	(0.080)	(0.105)	(0.050)	(0.073)
Ln (Top)	0.296***	0.297***	0.285***	0.316***
	(0.082)	(0.107)	(0.052)	(0.075)
Ln (Seed)	-0.460	-0.492	1.531**	1.359*
	(0.698)	(0.723)	(0.720)	(0.738)

	Zambia		**Zimbabwe**	
	(1)	**(2)**	**(3)**	**(4)**
Gender (1=male)	0.381	0.377	0.411*	0.438*
	(0.277)	(0.280)	(0.222)	(0.224)
Age (years)	-0.006	-0.003	-0.017*	-0.019**
	(0.011)	(0.011)	(0.009)	(0.009)
Education (1=tertiary)	0.237	0.224	0.263	0.210
	(0.234)	(0.235)	(0.213)	(0.215)
Household size	0.063**	0.067**	-0.080**	-0.065*
	(0.029)	(0.029)	(0.036)	(0.036)
Farm experience (yrs)	-0.010	-0.012	0.024***	0.023**
	(0.012)	(0.012)	(0.009)	(0.009)
Market distance (kms)	0.008	0.008	-0.005	-0.005
	(0.006)	(0.006)	(0.003)	(0.003)
Use of credit (1=yes)	0.153	0.172	0.473*	0.485*
	(0.299)	(0.301)	(0.268)	(0.280)
Weeding (days)	0.208**	0.076	0.259**	0.273
	(0.100)	(0.131)	(0.124)	(0.185)
CRE	No	Yes	No	Yes
Number of plots	533	533	669	669

$^{*}p< 0.10$, $^{**}p< 0.05$, $^{***}p< 0.01$, standard errors reported in parenthesis

The lack of evidence that CA contributes to yield resilience during drought in our regression analysis is consistent regardless of how we measure drought. It is also consistent with our descriptive analysis in which we found no clear pattern of CA improving yields when rainfall was low. This suggests that other factors may be binding constraints in smallholder agricultural production in Zambia and Zimbabwe. Focusing on the results in Tables 18 and 19, we find that top-dress application of fertiliser significantly improves yields in all specifications. Additionally, increased seed application rates improve yields in Zimbabwe. This suggests that low fertility is more constraining to crop growth than water in many of these smallholder farming systems, even in drought years. While CA contributes to soil fertility, it takes several years to build up these beneficial effects. Conversely, the fertility impact of fertiliser application is immediate. In what have been traditionally low-input farming systems in Zambia and Zimbabwe, the promotion and adoption of CA tillage methods seems to have contributed to farmers adopting higher rates of input use. Thus, increased yields traditionally attributed to CA may in fact be due to the use of greater quantities of fertiliser by these farmers.

8 Information gaps

Existing analysis of CA's impact on yield primarily relies on experimental trials. Where observational data is used, studies frequently use agro-ecological zones instead of actual rainfall to measure yield resilience. The key information gap remains the lack of a solid understanding of what farmers do and why. Filling this gap requires data on farmer activity within a historical context in addition to data on measured rainfall during the periods in which it matters most to crop development. This study only partially addresses gaps in our understanding of CA's contributions to yield resilience. By using observational plot-level data and rainfall data during the first 65 days after planting, we have been able to fill some information gaps in the literature. However, we are unable to place farmer activity in the 2015–16 season in a historical context to determine how those who adopted CA fared in higher as well as lower rainfall seasons. Additionally, we are unable to fully control for OVB in our data, which may lead to biased coefficient estimates and result in erroneous conclusions and misguided policy recommendations. Our results should be interpreted with these caveats on mind.

9 Summary of findings and recommendations

This study attempts to assess whether CA contributes to building resilience to drought. Different econometric models were used to test the hypothesis using cross-sectional data. The results show that CA did not improve resiliency of yields to drought among surveyed farmers. This finding may be attributed to two factors.

First, while 2015–16 was a drought year, it was not as dry as other recent years, especially in Zambia (recall Figures 1 and 2). The implication is that farmers have adapted to historical drought by employing a low-risk maize cropping system with low application of fertiliser, less use of certified seed, and multiple planting dates. As a result of low soil fertility in particular, plants are unable to take full advantage of even the limited amounts of water available in a drought year. Therefore, fertility is more constraining than rainfall. The immediate contributions of CA to resolving this constraint are limited because these technologies contribute to improving crop fertility only in the long run.

Second, it is always difficult to demonstrate causal relationships using cross-sectional data. Therefore the results of this study—that CA has little or no apparent impact on building yield resilience—may be due to a paucity of data and may not reflect the true relationship between CA and yields. With additional years of data, it becomes possible to control for OVB at the plot and household level. Additionally, multiple observations of a household over time allow one to determine how households performed in both good and bad rainfall years. Given the data limitations in this study, the result that the use of CA does not build resilience to drought should not be taken as definitive. As a counter-example, Michler and colleagues (2016) use panel data and satellite rainfall data to demonstrate that CA does in fact build resilience for households faced with a rainfall shock.

While CA is positively correlated with yields in Zambia,it is not correlated with yields in Zimbabwe (recall Table 18). This may be due to early planting by CA farmers in Zimbabwe. While early planting is typically viewed as a beneficial element of CA adoption, in seasons like 2015–16, when rains come late, early planting may actually hinder agricultural production. As Figures 3 and 4 make clear, farmers who planted early received less rain in the crucial first 65 days after planting. As Figures 5 and 6 demonstrate, in Zimbabwe those who planted earlier were predominantly those who adopted CA. In Zambia, where CA farmers planted at similar times to conventional farmers, we find CA tends to increase yields.

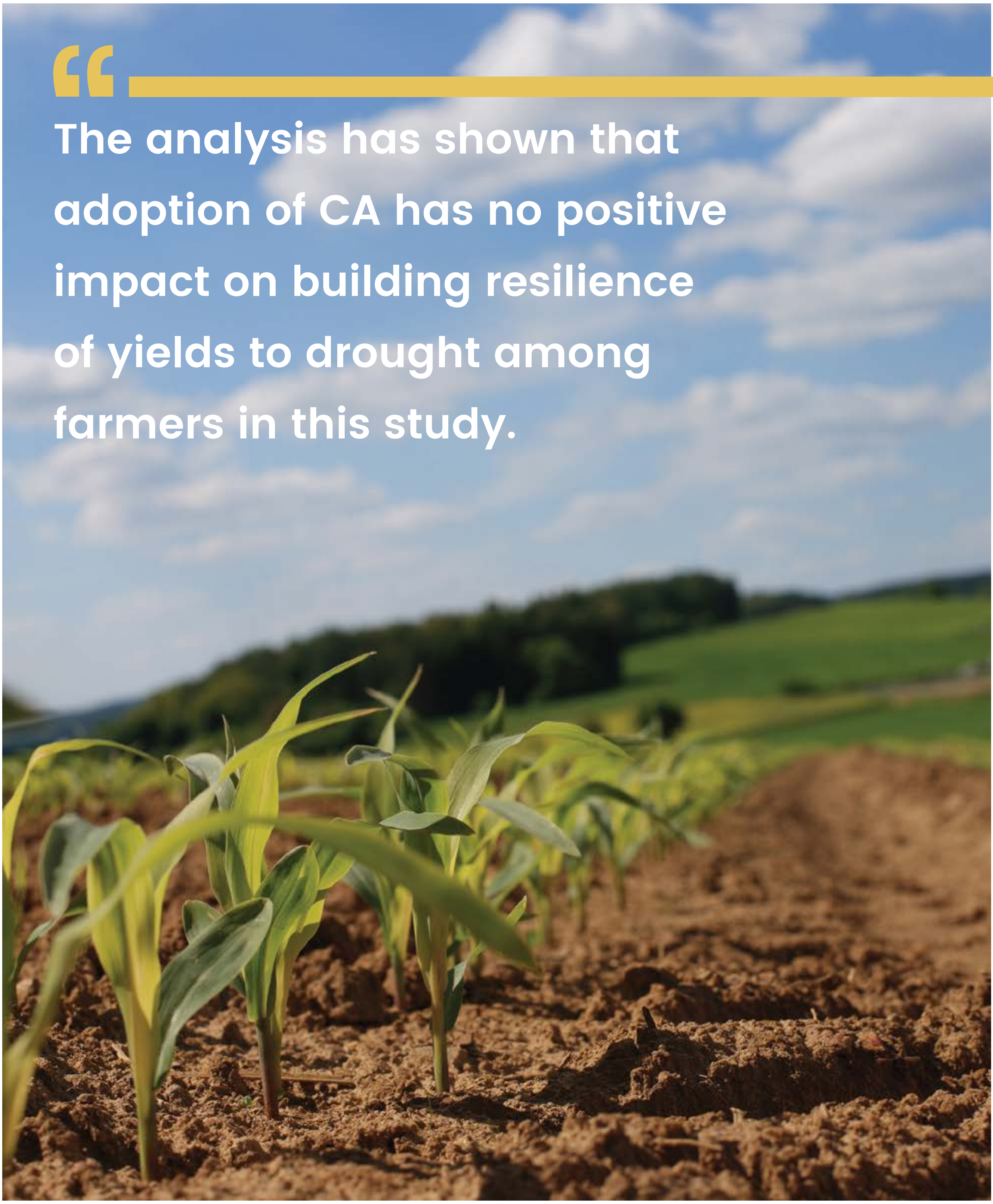
Overall the descriptive and econometric evidence leads us to believe that fertiliser use by CA households is a larger and more important factor in increasing yields, even in drought years. This coincides with ICRISAT's findings regarding microdosing in Zimbabwe(Winter-Nelson et al., 2013). It seems evident that the training of households on CA practices has encouraged greater use of chemical fertilisers. Additionally, this training has also encouraged these farmers to use more certified seed. These confounding factors may explain why in most regressions CA is not a significant determinant of yields, while fertiliser, seed use, and access to credit are significant determinants of yields.

We conclude that the promotion of CA as a technology which on its own can build resilience to drought in Southern Africa may be misguided. Rather, agricultural development work should focus on improving the fertility of farmed plots by linking it with other improved farm-management practices. CA may be a component of these improved farm practices, but the focus should be on improved water and weed management, purchase of certified fertiliser and seed, and the judicious application of both. Our analysis suggests that CA promotion appears to be a vector by which these improved farm management practices are already being transmitted to farmers in low-rainfall areas.

Additionally, we conclude that farmer adoption of all three practices of CA may not be necessary to build resilience of yields to drought. Our probit analysis demonstrates that farmers in drier regions are less likely to adopt all three practices and that this partial adoption does not appear to reduce their resiliency to drought. If the goal of development technicians and funders of agricultural development is to increase resilience, we believe a focus on increasing access to improved inputs is desirable.

10 Conclusions

The analysis has shown that adoption of CA has no positive impact on building resilience of yields to drought among farmers in this study. We have outlined several reasons why this may be the case. We do, however, find that the use of top-dressing fertiliser, purchase of certified seed, and (in the case of Zimbabwe) timely weeding contribute to higher yields, even during periods of drought. The value of these improved farming practices should be integrated into future drought relief programs.



> The analysis has shown that adoption of CA has no positive impact on building resilience of yields to drought among farmers in this study.

Appendix A: Description of variables that were used in the regression models

Variable abbreviation	Description of the variables
CA status	Application of at least minimum tillage principle (Yes =1, otherwise 0)
Rainfall shortage	Deviation from 15 year average rainfall
Late onset	Delay start on the season relative to 15 year average
Dry days	More dry days compared to 15 year average
Mid-season dry spells	Longer mid dry spells relative to 15 year average
Rainfall 65	Total amount rainfall received within the first 65 days after planting (mm)
Dry days 65	Number of dry days that occurred within the first65 days after planting
Ln (Basal)	Log transformed quantity of basal fertiliser used
Ln (Top)	Log transformed quantity of top dressing fertiliser used
Ln (Seed)	Log transformed quantity of seed used
Gender	Gender of household head (male=1)
Age	Age of household head (years)
Education	Education level of household head (tertiary=1)
Household size	Household size (members residing at homestead for more than three months)
Farm experience	General farming experience in years
Market distance	Distance to input market in kilometers
Use of credit	Use of credit facilities to obtain inputs
Weeding	Weeding frequency
Plot slope	Steepness of the plot (flat=1)
Soil type	Soil type (loam =1)

References

Andersson, J.A., 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 & Environment 187, 116–132. 10.1016/j.agee.2013.08.008.

Cairns, J.E., Sonder, K., Zaidi, P.H., Verhulst, N., Mahuku, G., Babu, R., Nair, S.K., Das, B., Govaerts, B., Vinayan, M.T., 2012. 1 Maize Production in a Changing Climate: Impacts, Adaptation, and Mitigation Strategies. Advances in agronomy 114 (1).

Chivenge, P., Murwira, H., Giller, K., Mapfumo, P., Six, J., 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. Soil and Tillage Research 94 (2), 328–337. 10.1016/j.still.2006.08.006.

Di Falco, S., Bulte, E., 2013. The Impact of Kinship Networks on the Adoption of Risk-Mitigating Strategies in Ethiopia. World Development 43, 100–110. 10.1016/j.worlddev.2012.10.011.

FAO, 2012. What is CA: Benefits of CA. Food and Agriculture Organization of the United Nations. http://www.fao.org/ag/ca/index.html.

FAO, 2015. Conservation Agriculture. The principles of conservation agriculture. Food and Agriculture Organization of the United Nations. http://www.fao.org/ag/ca/6a.html.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., Michaelsen, J., 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Scientific Data 2, 150066 EP -.

Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114 (1), 23–34. 10.1016/j.fcr.2009.06.017.

Gwenzi, W., Gotosa, J., Chakanetsa, S., Mutema, Z., 2009. Effects of tillage systems on soil organic carbon dynamics, structural stability and crop yields in irrigated wheat (Triticum aestivum L.)–cotton (Gossypium hirsutum L.) rotation in semi-arid Zimbabwe. Nutrient Cycling in Agroecosystems 83 (3), 211–221. 10.1007/s10705-008-9211-1.

Kassam, A., Friedrich, T., Shaxson, F., Pretty, J., 2009. The spread of Conservation Agriculture: Justification, sustainability and uptake. International Journal of Agricultural Sustainability 7 (4), 292–320. 10.3763/ijas.2009.0477.

Lobell, D.B., Hammer, G.L., McLean, G., Messina, C., Roberts, M.J., Schlenker, W., 2013. The critical role of extreme heat for maize production in the United States. Nature Climate Change 3 (5), 497–501.

Mafongoya, P., Rusinamhodzi, L., Siziba, S., Thierfelder, C., Mvumi, B.M., Nhau, B., Hove, L., Chivenge, P., 2016. Maize productivity and profitability in Conservation Agriculture systems across agro-ecological regions in Zimbabwe: A review of knowledge and practice. Agriculture, Ecosystems & Environment 220, 211–225.

Mazvimavi, K., 2011. Socio-Economic Analysis of Conservation Agriculture in Southern Africa. Network paper 02. FAO Regional Emergency Office for Southern Africa (REOSA), Rome, Italy.

Mazvimavi, K., Pedzisa, T., Murendo, C., Chivenge, P., 2016. Assessing the contributions of conservation agriculture to building resilience to drought. Literature Review Report 6924-EL04. VUNA, Pretoria, South Africa.

Mundlak, Y., 1978. On the Pooling of Time Series and Cross Section Data. Econometrica 46 (1), 69. 10.2307/1913646.

Nyamangara, J., Nyengerai, K., Masvaya, E.N., Tirivavi, R., Mashingaidze, N., Mupangwa, W., Dimes, J., Hove, L., Twomlow, S., 2014. Effect of conservation agriculture on maize yield in the semi-arid areas of Zimbabwe. Experimental Agriculture 50 (02), 159–177. 10.1017/S0014479713000562.

Rusinamhodzi, L., Corbeels, M., van Wijk, M.T., Rufino, M.C., Nyamangara, J., Giller, K.E., 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agronomy for Sustainable Development 31 (4), 657–673. 10.1007/s13593-011-0040-2.

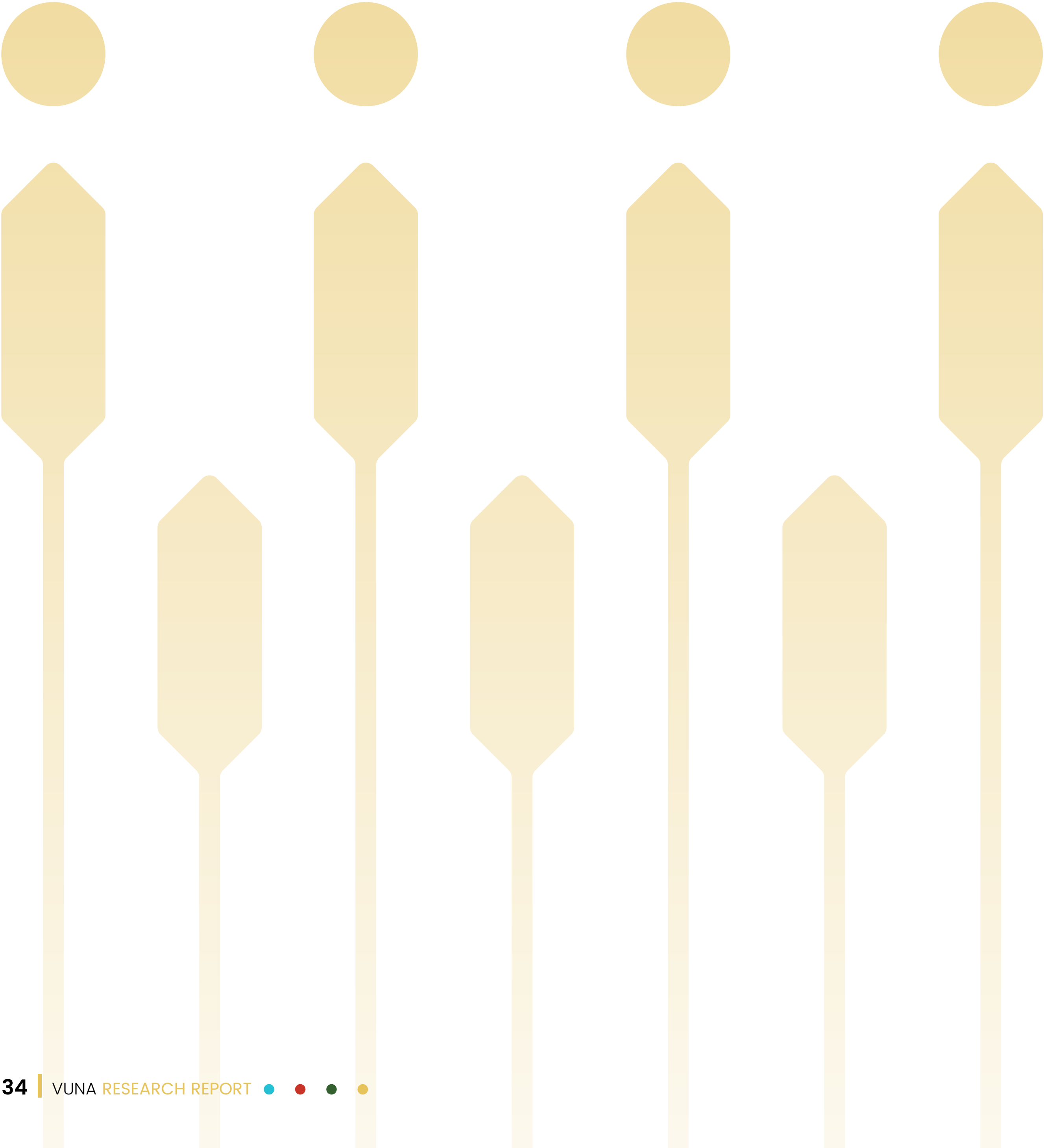
Thierfelder, C., Bunderson, T.W., Jere, Z.D., Mutenje, M., Ngwira, A., 2016. Development of Conservation Agriculture (Ca) Systems in Malawi: Lessons learned from 2005 to 2014. Experimental Agriculture 52 (04), 579–604. 10.1017/S0014479715000265.

Thierfelder, C., Mwila, M., Rusinamhodzi, L., 2013. Conservation agriculture in eastern and southern provinces of Zambia: Long-term effects on soil quality and maize productivity. Soil and Tillage Research 126, 246–258. 10.1016/j.still.2012.09.002.

Thierfelder, C., Wall, P.C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research 105 (2), 217–227. 10.1016/j.still.2009.07.007.

Valbuena, D., Erenstein, O., Tui, S.H.-K., Abdoulaye, T., Claessens, L., Duncan, A.J., Gérard, B., Rufino, M.C., Teufel, N., van Rooyen, A., 2012. Conservation Agriculture in mixed crop–livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field Crops Research 132, 175–184.

Winter-Nelson, A., Stack, J., Mvumi, B., Pedzisa, T., 2013. Impact Evaluation of Fertiliser Microdosing in Zimbabwe. Technical Report. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.



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