Adoption and intensity of adoption of conservation farming practices in Zambia

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Adoption and intensity of adoption of conservation farming practices in Zambia

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This paper analyses the determinants of farmer adoption of conservation farming practices using panel data from two rounds of the Rural Incomes and Livelihoods Surveys that were implemented in 2004 and 2008. Conservation farming (CF) has been actively promoted in seven of Zambia's nine provinces since the 1980s. CF has the technical potential to contribute to food security and adaptation to climate change; however, rigorous analyses of the determinants of adoption/dis-adoption of these practices, are still scarce. This paper fills this gap by combining rich panel data with historical rainfall data to understand the determinants of adoption and intensity of two CF practices: minimum/zero tillage and planting basins. Controlling for the confounding effects of household level unobservables, we find that extension services and rainfall variability are the strongest determinants of adoption, suggesting that farmers use these practices as an adaptation strategy to mitigate the negative effects of variable rainfall. Eastern province shows a significantly different trend in terms of both adoption and the intensity of adoption, indicating that the long-established CF activities in the province have had some impact – though high dis-adoption rates are observed even in this province.

Key words: conservation agriculture, conservation farming, minimum tillage, technology adoption, adaptation, Zambia

JEL Codes: Q12, Q16, Q54, O33

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EXECUTIVE SUMMARY

This paper contributes to literature on agricultural technology adoption by using a novel data set that combines data from two large-scale household surveys with historical rainfall data to understand the determinants and the intensity of adoption of Conservation Farming (CF) practices in Zambia. Conservation agriculture (CA), defined as practicing minimum soil disturbance, cover crops and crop rotation, has the technical potential to contribute to food security and adaptation to climate change. It has been actively promoted in seven of Zambia's nine provinces since the 1980s in the form of CF including planting basins and dry season land preparation in addition to the 3 CA practices. Rigorous analyses of the determinants of adoption/dis-adoption of these practices, however, are still scarce. This paper fills this gap using panel data from two rounds of the Rural Incomes and Livelihoods Surveys that were implemented in 2004 and 2008 as well as (district level) historical rainfall estimate (RFE) data obtained from the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA-CPC) for the period of 1996-2011. We specifically analyse the adoption and dis-adoption of two main components of CF: minimum soil disturbance and planting basins. Considering that the Eastern Province has historically received the bulk of the CF support activities, we also do our analyses separately for this province to assess the effectiveness of these activities. We document high levels of dis-adoption (around 95%) of these practices in the whole country, while dis-adoption in the Eastern province – the hub of CF projects in Zambia – is significantly lower. Nationwide only 5% of the households practiced minimum soil disturbance/planting basins in 2008, down from 13% in 2004, which raises the question of the widespread suitability of this practice. Eastern province is the only province with a significant increase in adoption rates between the survey years: 14% in 2008, up from 8%.

Our econometric analyses based on panel data methods that control for time-invariant household characteristics fail to provide evidence for the oft mentioned determinants of adoption in the literature. We find no evidence for the role of labor constraints, age or education in adoption decisions. These results suggest that most socio-economic variables are correlated with household level un-observables (e.g. farmer ability or openness to innovation) in cross-sectional studies confounding the effects of variables included in analyses. We do, however, find that the intensity of adoption is negatively affected by land per capita – another indicator of labor constraint.

We find a very strong and robust relationship between the district level variation in historical rainfall during the growing season and adoption as well as the intensity of adoption of the CF practices in question in Zambia. This finding suggests that farmers are using minimum tillage/planting basins as a strategy to mitigate the risk of rainfall variability, providing evidence – albeit indirectly – of a synergy between these practices and adaptation to climate variability. Inasmuch as the practices analysed here are essential to the CF package, the results are indicative for the adoption of the whole CF package as promoted. Further research is needed to directly assess whether CF decreases yield variability over time as suggested by these findings.

Another robust finding is that the reach of extension services in a village (i.e. the proportion of households that received information on minimum tillage) positively affects both adoption and the intensity of adoption. A key outstanding question however, is the degree to which extension services included the provision of subsidized inputs, which is not possible to distinguish in this dataset. Understanding the respective importance of information and

subsidized input provision is essential to design future programs for CF promotion – especially in locations with highly variable rainfall.

Eastern province demonstrates a different trend than the rest of the country in that there was an upward trend in the probability of adoption for an average household and no significant downward trend in the intensity of adoption. This suggests that the long history of CF activities in the province (combined with its specific agro-ecological conditions suitable for CF) may have had an effect on adoption rates there. Given the still high dis-adoption rates in this province, however, further research is needed to understand the institutional settings of various projects and how they affect the adoption of CF practices.

To summarize: CF as practiced in Zambia seems well-suited to respond to the key agro-ecological constraint of highly variable rainfall patterns. The provision of extension services is another consistent and powerful explanatory variable in determining adoption patterns. Better information on what exactly these extension services included, and particularly the degree to which they involved subsidized inputs, is needed before an assessment of the potential effectiveness and sustainability of further extension efforts for promoting CF can be made.

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FIGURE

1. Zambia Administrative Boundaries and Agro-ecological Regions (I, IIa, IIb, III) 1

ACRONYMS

ACT	African Conservation Tillage Network
ASP	Agricultural Support Programme
CA	Conservation agriculture
CF	Conservation Farming
CFU	Conservation Farming Unit
CV	Coefficients of Variation
EPTD	Environment and Production Technology Division
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FASAZ	Farming Systems Association of Zambia
FSRP	Zambia Food Security Research Project
GART	Golden Valley Agricultural Research Trust
GLM	Generalized Linear Model
GTZ	GTZ German Technical Cooperation/German Development Agency
HYV	High Yielding Varieties
IAPRI	Indaba Agricultural Policy Research Institute
IFAD	International Fund for Agricultural Development
IIRR	International Institute of Rural Reconstruction
MACO	Ministry of Agriculture and Cooperatives
MAFF	Zambia Ministry of Agriculture, Food, and Fisheries (now called MAL)
MAL	Ministry of Agriculture and Livestock
MICCA	Mitigation of Climate Change in Agriculture
NOAA-CPC	National Oceanic and Atmospheric Administration's Climate Prediction Center
NORAD	Norwegian Agency for Development Cooperation
PCA	Principal Component Analysis
PHS	Post Harvest Survey
QMLE	quasi-maximum likelihood estimation
RFE	Rainfall Estimate data
RILS	Rural Incomes and Livelihoods Surveys
SCAFE	Soil Conservation and Fertility Project
SEA	Standard Enumeration Area
SIDA	Swedish International Development Agency
TLU	Tropical Livestock Unit
TÖB	Tropical Ecology Support Program
U.S.	United States of America
WFP	World Food Program
ZNFU	Zambia National Farmers Union

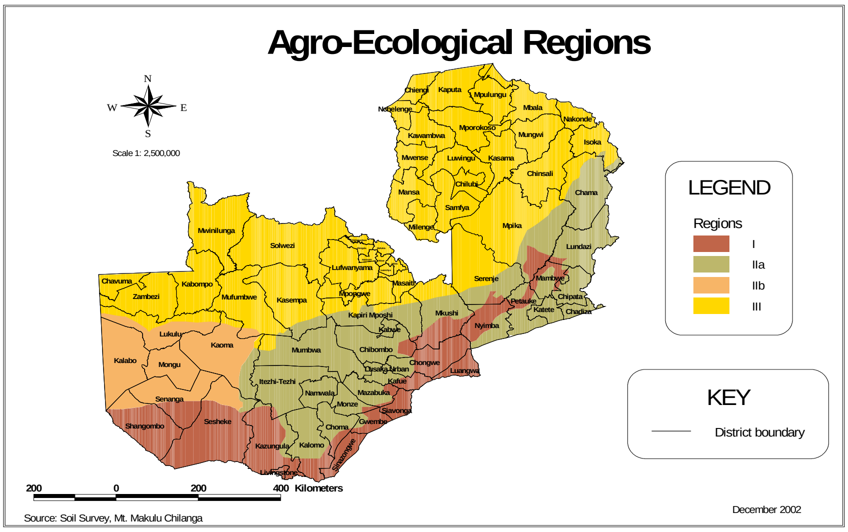
1. INTRODUCTION

Conservation Agriculture (CA), as promoted by the Food and Agricultural Organization of the United Nations (FAO), aims to sustainably improve productivity, profits, and food security by combining three principles. These three principles are: minimum mechanical soil disturbance; permanent organic soil cover; and crop rotation (FAO 2012). CA has been promoted by many international and national organizations to smallholders in Sub-Saharan Africa as a solution to soil degradation and low productivity problems (IIRR and ACT 2005; Giller et al. 2009; Mazvimavi 2011). Zambia is considered as the success story of Sub-Saharan Africa in terms of CA uptake (IFAD 2011).

In Zambia, seven of nine provinces have received active support for Conservation Farming (CF) (see next section for definition) since 1980s: Eastern, Central, Lusaka and Southern Provinces in agroecological regions I and IIa; Northern, Luapula, and Copperbelt Provinces in agroecological region III (see figure 1). The promotion of CF started as a response to low agricultural productivity on degraded soils, which was thought to be caused by intensive tillage, lack of soil cover and burning of crop residue (Baudron et al. 2007).

The first project in Zambia on CF was the Soil Conservation and Fertility (SCAFE) Project that started in 1985 in the Eastern Province (later expanded to include Lusaka) funded by the Swedish International Development Agency (SIDA) (Baudron et al. 2007). In late 1999, the Ministry of Agriculture adopted CF as an official priority, which was followed by an increase in the number of CF projects in the country funded by various institutions (Chomba 2004). In addition to SIDA, Norwegian Agency for Development Cooperation (Norad), FAO, World Bank, World Food Programme (WFP) and the European Union (EU) promoted CF in Zambia investing millions of dollars into the dissemination of conservation farming technologies. In spite of the scale of investments in CF, rigorous analyses of its adoption and impacts on productivity are still limited.

Figure 1. Zambia Administrative Boundaries and Agro-ecological Regions (I, IIa, IIb, III)



Source: FAO (CFA, Zambia Branch homepage).
Amount of rainfall received per year: Less than 700mm (I); 800 – 1000mm (IIa); 800 – 1000mm (IIb); 1000 – 1500mm (III).

Existing empirical analyses of CF in Zambia (Haggblade and Tembo 2003; Chomba 2004; Baudron et al. 2007; Tembo et al. 2007; Haggblade, Kabwe, and Plerhoples 2011; Nyanga 2012) are mostly subject to small sample sizes, cross sectional surveys, or inadequate detail in data, which prevents them from effectively capturing the multiple factors that affect farmers' decisions to adopt CF. Although it is sometimes acknowledged that most adoption is partial or incremental, adoption in this literature is usually defined as having any area under one or more CF practice due to lack of detail in data.

This paper addresses these shortcomings by using data from the Rural Incomes and Livelihoods Surveys that were implemented in 2004 and 2008.[2] More than 5,000 and 8,000 households were interviewed in 2004 and 2008, respectively. We merge the rich household panel data with historical Rainfall Estimate data (RFE) at the district level to analyse the determinants and the intensity of adoption of one of the important pillars of CF: zero/minimum tillage (planting basins).The Rural Incomes and Livelihoods Surveys (RILS) data provide us with the possibility to employ panel data econometric techniques to control for time-invariant household, community, and institutional characteristics that may affect farmers' decisions and confound the results of cross-sectional analyses dominant in the literature.

2. BACKGROUND

2.1. History of CA in the World and in Zambia

Historically, CA was born out of ecological and economic hardships in the United States (U.S.) caused by catastrophic droughts during the 1930s and became more popular among farmers due to rising fuel prices during the 1970's (Haggblade and Tembo 2003). Large commercial farmers took up minimum tillage technologies to combat the drought-induced soil erosion and save on fuel costs. Around 35% of total area in the U.S. was cultivated using minimum tillage technologies during 1980's (Haggblade and Tembo 2003). The CA experience in the U.S. gave impetus to the CA movement in South America (mainly Brazil) and Southern Africa (mainly South Africa and Zimbabwe), where government agricultural research centers established conservation tillage programs to actively promote CA (Haggblade and Tembo 2003).

CA as promoted in Zambia is called CF and consists of a package of following practices: (1) reduced tillage on no more than 15% of the field area without soil inversion, (2) precise digging of permanent planting basins or ripping of soil with a *Magoye ripper* (the latter where draft animals are available), (3) leaving of crop residues on the field (no burning), (4) rotation of cereals with legumes and (5) dry season land preparation (CFU 2007).[3] The emergence of CF in Zambia in 1990's also accompanied ecological and economic challenges. With the abrupt ending of subsidies for maize, fertilizer and farm machinery following the collapse of copper prices, Zambian farmers found themselves trying to cultivate heavily degraded soils without the extra inputs they had been using for three decades. The experiences of farmers with CA in the U.S. and Zimbabwe helped commercial maize farmers in Zambia to become interested in CA. Though the main motivation was to save on fuel costs, other benefits such as improved soil structure and productivity were also appreciated, hence

[2] We thank the Indaba Agricultural Policy Research Institute (IAPRI) and the Zambia Food Security Research Project (FSRP) for providing the data.
[3] Throughout the paper, we use the term CA when referring to the general literature, but CF for the case in Zambia.

giving incentives to a significant share of commercial farmers to use CA (Haggblade and Tembo 2003).

Following the end of subsidies, maize yields for smallholders decreased due to lack of fertilizer and area cultivated with maize has gone down by 20% (Haggblade and Tembo 2003). Reports of six to eight tons of maize yield per hectare under CA in Zimbabwe inspired Zambia National Farmers Union (ZNFU) to develop CF for smallholders in Zambia. To this end, ZNFU established the Golden Valley Agricultural Research Trust (GART), which started developing CF for smallholders in 1995, and the Conservation Farming Unit (CFU) to lead related extension activities (Haggblade and Tembo 2003).

The CFU initially promoted the CF package mainly in the arid and moderate rainfall regions I and IIa. It later expanded into region IIb and currently has field offices in 17 districts supporting 170,000 CF farmers.[4] There are no clear CF guidelines for the high rainfall regions (zone III) yet and some argue that CF is not suitable for this agro-ecological setting (Baudron et al. 2007; IFAD 2011).

2.2. Adoption of CA in the Literature

There is a well established literature on the adoption of new agricultural technologies that was primarily motivated by the need to understand the adoption of Green Revolution technologies. This literature identifies the main constraints farmers face when making farming decisions (Feder, Just, and Zilberman 1985). Early adoption studies focused on the risk and uncertainty about new technologies that may lead farmers to diversify their crop portfolios instead of adopting new varieties on a large scale (Feder 1980; Just and Zilberman 1983). Later studies identified other determinants of adoption such as agro-ecological constraints, credit constraints, labour market constraints, safety-first considerations, seed supply constraints, risk preferences, or traditional values (Bellon and Taylor 1993; Smale, Just, and Leathers 1994; Ajayi et al. 2003, 2007; Franzel et al. 2004; Phiri et al. 2004; Arslan and Taylor 2009).

As reviewed by McCarthy, Lipper, and Branca (2011), the adoption of CA is subject to most of these traditional constraints found in the literature – though which constraint will be more binding is very context-specific. Like any new technology, CA may be perceived as a risky investment as farmers will need to learn new practices and typically do not have access to insurance. Credit constraints will affect adoption, especially when initial investment costs are high (e.g., purchase of cover crop seeds, herbicides, sprayers), given the evidence that the benefits of CA are usually realized after around four years (Blanco and Lal 2008; Hobbs, Sayre, and Gupta (2008).[5] CA increases labor requirements for weeding when implemented without herbicides (as most smallholders do), therefore labor constraints may be binding for households without access to herbicides and enough labor. Agro-ecological constraints such as soils (e.g., drainage capacity) and climate (e.g., semi-arid regions with termites) are also likely to affect adoption, though there is no conclusive evidence in the literature.

Maintaining permanent soil cover can also be costly. Use of cover crops requires access to appropriate seeds, which are often not easily available in the market (Morse and McNamara

[4] http://www.conservationagriculture.org/prog.php?id=1&position=1

[5] The time required for the positive yield benefits to kick in is highly crop and location specific, and may be up to 10 years in some settings (Giller et al. 2009).

2003; Tarawali et al. 1999; Steiner 1998). Incorporating crop residue post-harvest can also present significant opportunity costs, as residue has traditionally been used for other purposes such as livestock feed, fuel, etc (Giller et al. 2009; Bishop-Sambrook et al. 2004; McCarthy et al. 2004). Tenure rights and tenure security can also affect adoption decisions. For instance, even where an individual farmer wishes to incorporate residues on her own plot, customary tenure systems often traditionally allow animals to graze freely on harvested fields in most parts of Africa, making this practice difficult in the absence of the right (and the capacity to finance) fencing. Customary rules associated with burning harvested fields also makes it difficult to keep one's own plots permanently covered, whether by crop residue or cover crops. Finally, where there are substantial cost outlays but benefits to CA are delayed, tenure insecurity will reduce farmers' incentives to adopt.

Knowler and Bradshaw (2007) have conducted a review of 23 studies in a quest to identify universal variables that explain the adoption of CA, however, they fail to find agreement in the literature. Only six out of twenty three studies they review are from developing countries, and most of them have very small sample sizes.[6] Though there is no variable that consistently explains adoption in the aggregate study, they also conduct an analysis by region and find that farm size tends to be significant in studies in Africa, whereas education tends to be significant in studies in North America. The authors take this lack of universal variables that explain adoption as an indication of the location specificity of CA.

Nkala et al. (2011) also conduct a meta-analysis of CA, focusing mainly on the constraints to successful implementation of CA projects in Southern Africa. The authors discuss such issues as the lack of infrastructure, non-farmer driven approaches, existing livestock management norms, imperfect input and credit markets and land tenure as obstacles that limit wide-spread adoption in Southern Africa. They also highlight (based on the literature they review) that adoption in this region is mostly partial and underline the importance of defining adoption in this context not only as a binary outcome, but also as a continuous process.

Most CA practices are regarded as improved soil water management practices. Minimum soil disturbance increases water productivity, mulching and crop residues improve water infiltration and planting basins maximize soil moisture buffer capacity (Giller et al. 2009; Chikowo 2011) Therefore, CA can play an important role in mitigating climate risk especially in arid and semi-arid regions. In spite of the importance of the availability and variability of rainfall in affecting farmers' adoption decisions, no previous research on CA controls for the effects of rainfall, to the best of our knowledge.

The findings in Knowler and Bradshaw (2007) demonstrate the shortcomings in the literature in terms of rigorous analyses of adoption and productivity impacts of CA. Most of the econometric analyses in this literature are subject to endogeneity and small sample bias, both of which are addressed in this paper with panel data and novel econometric approaches.

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[6] The exception is the study by Clay et al. (1998) in Rwanda on the adoption of organic inputs, which is not a conventional CA technology.

2.3. Adoption of CF in Zambia

Despite its promotion over the last fifteen years, adoption of CF in Zambia is relatively limited.[7] Haggblade and Tembo (2003) report that 20% of CF farmers in the 2002/3 season were spontaneous adopters, with the 80% majority practicing CF as a condition for receiving subsidised input packages. CFU reports that around 170,000 farmers had adopted CF on part or all of their land in 2011.

Adoption tends to be incremental and partial in Zambia. Umar et al. (2011) found that almost all farmers (out of 129 interviewed) practice both conventional and conservation farming on different plots. Haggblade and Tembo (2003) reported that 0.25 ha of carefully managed basin-planting CF can provide a minimal food security safety net for a family of four.

Primary constraints to adoption in Zambia are the use of crop residues for other purposes, labor constraints and the limited potential to grow cover crops during the dry season. Of these three constraints, a number of authors argue that labor constraint is the major constraint to CF adoption in Zambia (Umar et al. 2011; Baudron et al. 2007; Haggblade and Tembo 2003). The labor constraint manifests itself during land preparation and weeding. Preparation of the planting basins is highly labor intensive and the hiring of labor is rarely feasible due to unaffordable daily wages at peak times (also because hiring is not widely accepted culturally) (Baudron et al. 2007; Mazvimavi 2011). Weeding requirements tend to be higher on CF plots (in the absence of herbicide use) creating another labor constraint (Umar et al. 2011). Findings related to land and labor are supported by Chomba (2004). His study, based on nationwide post-harvest (1998/99-1999/2000) and supplemental household surveys (1999/2000) covering 2,524 farmers in Eastern, Southern, Central and Lusaka Provinces, found that household size and land size positively influenced adoption rates of CF during the 1998-2000 seasons. He also found that distance to markets and extension services were important. This may be particularly so given that this study uses data collected early in the promotion of CF in Zambia.

Nyanga et al. (2011) surveyed 469 farmers in 12 districts (in Southern, Central, Western, and Eastern provinces) in an effort to understand their perceptions of climate change and attitudinal and knowledge-based drivers of CF adoption.[8] The authors of this mainly qualitative study documented a widespread awareness of increased climate variability. There was a positive correlation between perception of increased climate variability and the use of CF, but no correlation between attitudes towards climate change itself and CF. Interestingly, the authors found a widespread expectation of subsidy, input packages or material rewards for uptake of CF, which they argued has developed as a result of previous program’s use of such incentives. This is concordant with a finding of Baudron et al. (2007), who reported that 50% of farmers dis-adopt CF if they no longer qualify for such incentives.

Most of these studies on the adoption of CF in Zambia rely on small samples purposefully selected from regions where CF was promoted, which risks confounding the effects of various interventions on adoption. The studies that rely on cross sectional data cannot control for potential endogeneity caused by time-invariant unobservable household characteristics that effect adoption. A limited number of studies that use multi-year data either fail to make

[7] Throughout the paper, we use the term CA when referring to the general literature, but CF for the case in Zambia.

[8] Nyanga et al. (2011) use a proxy indicator for adoption of CA and consider any farmer with some area under minimum tillage (both planting basins and animal draft power ripping) as a “CA adopter.”

use of the panel structure in their analyses (Chomba 2004; Kabwe and Donovan 2005) or have only multiple cross sections (Haggblade and Tembo 2003), hence, only provide suggestive descriptive evidence at best.[9]

Our paper contributes to this literature by using a large and rich panel data set merged with historical rainfall data that enables us to use panel data methodologies to control for some of the most common forms of endogeneity in the analyses of adoption with household data. We therefore are able to identify the variables that affect adoption and its intensity without the various confounding factors in the literature. We present our data and descriptive statistics in the next section, before we lay out our empirical methodology in section 4. We present our econometric results in section 5 and discuss policy implications in section 6.

3. DATA AND DESCRIPTIVE STATISTICS

Our main data sources are two rounds of RILS conducted in 2004 and 2008. These surveys are the second and third supplemental surveys to the nationally representative 1999/2000 Post-Harvest Survey (PHS). The supplemental surveys, carried out by the Central Statistical Office in conjunction with the Ministry of Agriculture, Food, and Fisheries (MAFF) and commissioned by Michigan State University's Food Security Research Project (FSRP), were designed to study options to improve crop production, marketing, and food consumption among small scale farmers.[10] They collected detailed production and income data for the 2002/2003 and 2006/2007 cropping seasons, and covered around 5,400 and 8,000 households, respectively.[11]

We merge RILS data with historical data on RFEs at the district level to control for the effects of the variation in rainfall on farmers' adoption decisions. RFE data are obtained from the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA-CPC) for the period of 1996-2011. RFE data we use are based on the latest estimation techniques for 10-day intervals and have a resolution of 8 km.[12] Table 1 summarizes the RFE data by province. We can see that the growing season RFE in our data conforms to the agro-ecological zoning standards presented in Figure 1. Southern region (in AEZ1) receives the least rainfall, followed by Lusaka, Eastern, and Central provinces (in AEZ 2a). Western region (mostly in AEZ 2b) receives higher than these provinces but less than the remaining provinces (Northern, Copperbelt, Luapula, and Northwestern in AEZ3).

The RILS asked farmers about the main tillage method used for each plot in both years. Unfortunately, the surveys do not allow us to analyse cover crops and residue management. The 2004 survey asked about residue management; however, this question was removed in 2008. In both years, we can also infer some information about crop rotation – though the

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[9] Chomba (2004) uses two rounds of data that can be considered as a *type of panel* data. However, the follow-up supplemental survey only covers soil and water conservation practices rather than being a real panel survey, preventing the author from using panel data econometric techniques. CF practices analysed are specifically: Planting basins, crop rotation, leaving crop residues on the field, other minimum tillage practices, intercropping and improved fallow.

[10] MAFF was called Ministry of Agriculture and Cooperatives (MACO) during the 2008 surveys, and is now called Ministry of Agriculture and Livestock (MAL). In 2011, Michigan State University has transformed FSRP into a local institute called Indaba Agricultural Policy Research Institute (IAPRI).

[11] For more details about the surveys, see CSO (2004, 2008).

[12] See http://www.cpc.ncep.noaa.gov/products/fews/RFE2.0_desc.shtml for more information on RFE algorithms.

Table 1. Growing Season RFE Averages and Coefficients of Variation (CV) by Province, 1996-2011

Province	Mean RFE	CV RFE
Central	882.95	0.26
Copperbelt	1014.44	0.27
Eastern	855.09	0.26
Luapula	1029.96	0.27
Lusaka	768.65	0.26
Northern	975.48	0.23
NWestern	1096.56	0.30
Southern	745.26	0.29
Western	898.72	0.30
Total	915.29	0.27

Source: Author calculations based on RFE data from NOAA-CPC for the period of 1996-2011.

number of farmers that practice both minimum tillage and crop rotation is extremely low to allow an analysis of the joint adoption of these two practices (we provide some descriptive information related to crop rotation below). Subject to these shortcomings in the data and keeping in mind that the minimum/reduced tillage is the main component of CF, we use only the information on tillage practices to define our CF variables in this paper. We do, however, acknowledge that the ideal definition of CF should include all practices in the CF package.

Table 2 presents information on the proportion of farmers that implemented various tillage and crop management practices in both years. Most farmers are small scale farmers (cultivating on average 2.3 and 3.4 hectares in 2004 and 2008, resp.), who use a hand hoe as their main tillage method (60% and 44% of households in 2004 and 2008, respectively). In 2004, around 3% used planting basins and 11% used zero tillage. These shares were around 2% and 3% in 2008. A third of households used a plough in both years. The RILS asked about crop residue management only in 2004 and found that 74% of farmers left the crop residue in the field. Unfortunately, we cannot establish whether livestock grazed on the fields after harvest to distinguish proper conservation agriculture practice from traditional practice of letting livestock graze on crop residues after harvest. Almost two-thirds of farmers practiced crop rotation (defined as having cultivated different crops on the same plot within the 3 year period of surveys) on at least one field. All differences between the two years, except for plough and crop rotation, are statistically significant at the 1% level.

We define two indicators of CF: CF1 equals one if the farmer used hand hoe, planting basins, or zero tillage on at least one of his/her fields, CF2 equals one if the farmer used planting basins or zero tillage on at least one field.[13] Among CF1 farmers, the proportion of farmers who practiced rotation was 68% in 2004 and decreased to 58% in 2008. Among CF2 farmers, 85% and 70% had practiced rotation in 2004 and 2008, respectively. Although these percentages seem high, the numbers of observations are very low: 442 and 129 households (out of more than 4,000) practice CF2 and rotation at the same time in 2004 and 2008, respectively. We, therefore, do not include the information on rotation in the definition of the dependent variables in the econometric analysis.

[13] CF is promoted heavily for hand hoe farmers in Zambia. Hand hoe use is included in the definition of CF1 as a control for cases where the answer of a CF farmer may have been coded as hand hoe as opposed to minimum/zero tillage as these are answers to the same question. The results of both definitions are provided throughout the paper in order to address doubts about the extent of this potential coding error.

Table 2. Various Tillage and Crop Management Practices in RILS

Practices	2004	2008
Hand hoeing	0.60***	0.44***
Planting basins	0.03***	0.02***
No tillage	0.11***	0.03***
Ploughing	0.29*	0.31*
Ripping	0.02***	0.01***
Ridging/bunding	0.23***	0.41***
Crop residue left in the field	0.74	n.a.
Rotation (diff crops for 3 years)	0.57	0.56
Intercropping	0.18***	0.11***
Intercropping with legumes	0.07***	0.03***
Fruit trees	0.04***	0.17***

Source: Author calculations based on RILS.
Note: *, **, and *** indicate that the difference between the two years is significant at 10%, 5%, and 1%, respectively.

Table 3. Proportion of Farmers that Adopted and Land Cultivated with CF1/CF2

	2004	**2008**	**Significant**
CF1: Hand hoe/planting basins/zero tillage			
Proportion of farmers	0.62	0.47	***
Proportion of land	0.58	0.59	
CF2: Planting basins/zero tillage			
Proportion of farmers	0.13	0.05	***
Proportion of land	0.31	0.48	***

Source: Author calculations based on RILS.

The proportion of households that practiced CF (for both definitions) has decreased significantly between 2004 and 2008 (Table 3). Forty seven percent of the households practiced CF1 in 2008 (down from 62%), but only 5% practiced CF2 (down from 13%). We define the intensity of adoption as the proportion of land cultivated with the practice for those who used it. The intensity of adoption of CF1 did not change, while that of CF2 has increased significantly from 31% to 48%.

Table 4 shows the breakdown of our dependent variables by Zambia's nine provinces and year. The proportion of households that practiced CF1 has decreased in almost all provinces (but in the Western province), whereas the intensity of adoption increased in the Central, Luapula, Lusaka and Western provinces. In all other provinces, the intensity of adoption decreased between the two panels. Using the stricter definition of CF (CF2), we see a sizeable decrease in the proportion of households that practiced CF2 in all but two provinces (Eastern and Southern). This decrease is most striking in the Northern province where 42% of households in the sample practiced CF2 in 2004, but only 1% did so in 2008. This result may be expected given that CF in Zambia is suitable for agroecological regions with moisture stress, and northern province is in the high-rainfall zone (Haggblade and Tembo 2003).[14] The intensity of adoption has increased in 4 provinces (Central, Luapula, Lusaka and Northern), most significantly so in Lusaka, where it increased from 32% to 80%.

Table 4. The proportion of households that adopted and the proportion of land under CF1/CF2 by province

	CF1				CF2			
	Prop. hh.		Prop. land		Prop. hh		Prop. land	
Province	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**	**2004**	**2008**
Central	0.70	0.55	0.55	0.70	0.10	0.04	0.40	0.42
Copperbelt	0.84	0.79	0.64	0.49	0.05	0.01	0.21	0.04
Eastern	0.69	0.42	0.82	0.71	0.08	0.14	0.60	0.54
Luapula	0.36	0.22	0.20	0.37	0.09	0.01	0.17	0.43
Lusaka	0.69	0.56	0.60	0.78	0.05	0.01	0.32	0.80
Northern	0.89	0.63	0.47	0.47	0.42	0.01	0.24	0.27
NWestern	0.56	0.45	0.57	0.53	0.01	0.01	0.74	0.03
Southern	0.27	0.17	0.59	0.43	0.01	0.02	0.34	0.30
Western	0.47	0.58	0.50	0.70	0.01	0.01	0.55	0.52

Source: Author calculations based on RILS.

The only province where the proportion of farmers practicing CF2 increased significantly is the Eastern Province (from 8% to 14%). Eastern province has historically been the hub of CF activities in Zambia; therefore, this difference is to be expected. Given the different history of CF in the Eastern province, we conduct all following analyses at the national level, as well as for the Eastern province only, to understand the extent to which the plethora of CF projects in this province made a difference in adoption and the intensity of CF.

Although CF was originally developed by and for commercial farmers, it has been widely promoted to smallholders in Zambia (and in Southern Africa in general). Table 5 shows the breakdown of adoption and the intensity of adoption by cultivated land size using the categorization of Ministry of Agriculture and Livestock. Households with smaller cultivated land tend to have higher adoption rates and intensities of adoption of CF1 in both years. This is to be expected given that the definition of CF1 includes the use of hand hoe, which is mainly used by smallholders. For CF2, households that cultivated between 5 and 20 hectares had the highest adoption rates (16%) in 2004, followed by households in the 1.5-5 ha. category. The decrease in adoption rates is observed for all land size categories, especially for those in the 5-20 ha. category which had the lowest adoption rate of CF2 in 2008. The intensity of CF2 adoption was the highest in the smallest land size categories in both years and it increased for all categories except the 5-20 ha category between the two years.

[14] It has been mentioned that in surveys managed by CSO may have coded the practice of shifting cultivation ("chitemene" which is mostly practiced in the northern region) as zero tillage prior to 2011 (anonymous reviewer). 198 households in the sample practiced chitemene in 2008 (85% in the Northern region). If we assume that these households had erroneously indicated that they practiced zero tillage in 2004, the share of households with CF2 in 2004 in the Northern region decreases to 26%. This adjustment does not significantly affect the results that follow.

Table 5. Adoption and Intensity of Adoption of CF1/CF2 by Land Size

Land cultivated (ha)	CF1				CF2			
	% hh		% land		% hh		% land	
	2004	2008	2004	2008	2004	2008	2004	2008
<=1.5	0.64	0.53	0.68	0.75	0.11	0.04	0.41	0.64
1.5 - 2.5	0.66	0.48	0.57	0.56	0.15	0.04	0.28	0.48
2.5 - 5	0.58	0.41	0.46	0.44	0.13	0.05	0.24	0.37
5 - 20	0.51	0.33	0.36	0.19	0.16	0.03	0.18	0.17
> 20	0.25	0.43	0.04	0.05	0.05	0.05	0.03	0.06

Source: Author calculations based on RILS.

Tables 6 and 7 present national transition matrices for both definitions of CA. Twenty six percent of farmers who did not practice CF1 in 2004, had adopted it by 2008, while around 43% of adopters in 2004 had dis-adopted the practice by 2008.[15] When we use the stricter definition of CF excluding hand hoe use (CF2), the share of new adopters decreases to 5% and that of dis-adopters increases to 96%.[16] Fifty eight percent of adopters of CF1 in 2004 were still practicing CF1, whereas this percentage of continuing adopters was only 4% for CF2.[17]

Tables 8 and 9 present transition matrices for the Eastern province only. Based on the stricter definition of CA, a higher proportion of farmers became new adopters and a smaller proportion became dis-adopters between 2004 and 2008 in the Eastern province compared to the rest of the country. The percentage of continuing adopters of CF2 are also higher in the Eastern province (12%, though only nine farmers).

Table 6. National Transition Matrix, CF1

2004		2008 No	2008 Yes	Total
No	#	1,189	424	1,613
	%	73.7	26.3	100
Yes	#	1,095	1,479	2,574
	%	42.5	57.5	100

Table 7. National Transition Matrix, CF2

2004		2008 No	2008 Yes	Total
No	#	3,498	165	3,663
	%	95.5	4.5	100
Yes	#	505	19	524
	%	96.4	3.6	100

Table 8. Eastern Province Transition Matrix, CF1

2004		2008 No	2008 Yes	Total
No	**#**	231	61	292
	%	79.1	20.9	100
Yes	**#**	303	328	631
	%	48.1	51.9	100

Table 9. Eastern Province Transition Matrix, CF2

2004		2008 No	2008 Yes	Total
No	**#**	725	122	847
	%	85.6	14.4	100
Yes	**#**	67	9	76
	%	88.2	11.8	100

Source for Tables 6-9: Author calculations based on RILS.

[15] Dis-adopters are defined as farmers who used a practice in 2004 but did not use the same practice in 2008.
[16] The adjustment for chitemene as explained above decreases the nationwide dis-adoption rate only to 95%.
[17] Kabwe and Donovan (2005) report similar dis-adoption rates for various CA practices in their descriptive study based on the 2000/01 and 2002/03 supplemental surveys conducted by the CSO. Chomba (2004), however, reports much lower adoption rates using the 1999/2000 and 2000/01 supplemental surveys. Both of these studies are only descriptive.

Although the transition matrices paint a striking picture of dis-adoption, they do not provide information on the drivers of adoption and the intensity of it. To address these questions in our econometric analysis, we draw on the rich literature on technology adoption to select a comprehensive set of explanatory variables that are known to affect farmers' decisions to adopt an agricultural technology. These variables include both production and consumption variables given the fact that most smallholders operate under imperfect market conditions that make consumption and production decisions non-separable (de Janvry, Fafchamps, and Sadoulet 1991). Table 10 summarizes our explanatory variables by CF status and year.

Adopters of CF (by both definitions) tend to come from households with significantly smaller number of adults, lower wealth indices, and less livestock in both years.[18,19] They also tend to cultivate significantly smaller land. The share of adopters that use plough on at least one field is significantly lower than that of non-adopters in both years and under both definitions of CF. Three quarters of both adopters and non-adopters of CF1 left the crop residues on the field in 2004. Based on the stricter definition of CF, the share of adopters that left the crop residues on the field is significantly higher than that of non-adopters of CF2 in 2004.

A significantly higher share of CF1 adopters practiced crop rotation in 2004, whereas the difference was not significant in 2008. This difference in rotation practice between adopters and non-adopters of CF2 is, however, significant in both years. The share of CF1 adopters that practiced intercropping and intercropping with legumes was significantly higher than that of non-adopters in 2004. In 2008, the difference was not significant for CF1 and switched sign for CF2.

[18] The agricultural wealth index is created using Principal Component Analysis (PCA) using the number of ploughs, harrows, cultivators, rippers, tractors, hand tractors, carts, pumps, mills, expellers, sprayers and shellers owned by the household. The non-agricultural wealth index is created using PCA based on the number of bikes, motorcycles, cars, lorries, trucks, televisions and wells owned by the household.

[19] Tropical Livestock Unit (TLU) is calculated using the numbers of livestock owned by the household as: TLU=(cattle+oxen)*0.5 + pigs*0.2 + (goats+sheep+chickens)*0.1.

Table 10. Explanatory Variables by CF Status and Year

	2004			2008			2004			2008		
	CF1	**NoCF1**		**CF1**	**NoCF1**		**CF2**	**NoCF2**		**CF2**	**NoCF2**	
Socio-economic variables												
Female head	0.22	0.19	**	0.25	0.22	**	0.2	0.21		0.26	0.24	
Widow head	0.01	0.01		0.02	0.02		0.01	0.01		0.02	0.02	
Polygamous head	0.11	0.16	***	0.09	0.15	***	0.1	0.13	**	0.16	0.12	
# adults (age>=15)	4.12	4.55	***	3.44	3.76	***	4.01	4.32	***	3.55	3.61	
Age head	49.80	49.05		52.68	52.43		49.89	49.46		52.29	52.55	
Education (average)	4.94	5.10	**	5.04	5.32	***	5.22	4.97	**	4.75	5.21	***
Dependency ratio	0.94	0.94		1.18	1.17		0.98	0.94		1.11	1.18	
Chronically ill (% adults)	0.07	0.06	*	0.02	0.02		0.06	0.07		0.02	0.02	
Ag-wealth index	-0.10	0.65	***	-0.16	0.6	***	-0.09	0.23	***	0.04	0.26	***
Wealth index	0.03	0.26	***	-0.06	0.15	***	0.09	0.12		-0.04	0.05	*
TLU (total)	1.40	4.58	***	1.1	4.28	***	1.57	2.75	***	1.65	2.85	***
# oxen owned	0.20	1.13	***	0.17	1.13	***	0.13	0.61	***	0.37	0.69	***
Land cultivated (ha)	2.17	2.82	***	2.98	4.34	***	2.46	2.41		3.01	3.74	**
Land title dummy	n.a.	n.a.		0.04	0.03		n.a.	n.a.		0.02	0.04	
Tillage/cropping practices												
Hand-hoe	0.92	n.a.		0.93	n.a		0.61	0.6		0.31	0.44	***
Plough	0.09	0.65	***	0.09	0.51	***	0.06	0.33	***	0.12	0.32	***
Ripping/ridging/bunding	0.20	0.30	***	0.36	0.54	***	0.33	0.22	***	0.48	0.45	
Crop residue left on field	0.74	0.74		0.75	0.73		0.81	0.73	***	0.75	0.74	
Rotation	0.64	0.46	***	0.56	0.57		0.84	0.53	***	0.7	0.56	***
Intercropping	0.22	0.12	***	0.11	0.11		0.46	0.14	***	0.07	0.11	**
Intercropping with legumes	0.09	0.03	***	0.04	0.03		0.22	0.04	***	0.02	0.03	*
Hybrid seeds (% land)	0.23	0.39	***	0.22	0.35	***	0.16	0.31	***	0.28	0.29	
Average # weedings per field	1.63	1.47	***	1.7	1.56	***	1.39	1.6	***	1.84	1.61	***
Policy variables												
ASP district dummy	0.47	0.43	***	0.43	0.5	***	0.52	0.45	***	0.52	0.46	
Received minimum tillage extension (% in the SEA)	0.29	0.30		0.32	0.36	***	0.23	0.3	***	0.54	0.33	***
Weather variables												
RFE (growing season av.)	922.05	884.48	***	927.5	888.49	***	953.4	901.25	***	850.8	909.3	***
RFE CV (1996-2011)	0.26	0.28	***	0.26	0.27	***	0.24	0.27	***	0.27	0.26	***
Observations	2571	1560		1903	2179		524	3607		184	3898	

Source: Author calculations based on RILS.

It has been mentioned in the literature that the effects of CA on production is usually confounded by the fact that adopters are also more likely to use hybrid seeds (Baudron et al. 2007). The adopters of CF1 and CF2 in the RILS data, however, are significantly less likely to use hybrid seeds in both years. One of the oft-mentioned constraints in front of adoption of CA and successful realization of yield benefits from CA is that weed pressure increases with CA during the early years of transition (due to reduced tillage and cover crops), which is especially problematic when households do not have access to herbicides. The number of weedings per field for adopters of CF1 was significantly higher than that of non-adopters in both years. Adopters of CF2, on the other hand, did significantly less weeding per field in 2004, but more so in 2008.

Two policy variables are relevant for the adoption of CF: a dummy variable that indicates the districts where the Agricultural Support Programme (ASP) was implemented and the share of households in each standard enumeration area (SEA) that received extension information regarding minimum tillage. The ASP was a SIDA-funded project in Eastern, Northern, Central, and Southern Provinces of Zambia between 2003 and 2008, which facilitated participatory agricultural development in five broad areas: entrepreneurship and business development; land, seed, crops, and livestock development (including CF); infrastructure; improved service delivery of support entities; and management information and learning systems. The adoption of CF (defined as using planting basins) is regarded as one of the successes of the ASP, which by its end had around 44,000 beneficiaries (Tembo et al. 2007). The ASP dummy we use equals one for all 20 districts where the programme operated. A significantly higher proportion of CF1 and CF2 adopters lived in an ASP district in 2004. In 2008, this relationship between adopters and non-adopters was reversed for CF1 and it was not significant for CF2. Paradoxically, the share of households in the same SEA that had received extension information on minimum tillage was higher (and significantly so) for non-adopters of CF1 in 2008 and of CF2 in 2004. In 2008, a significantly higher proportion of households had received minimum tillage extension in SEAs of CF2 adopters, as expected.

The average growing season RFE over 16 years (1996-2011) is significantly higher and its coefficient of variation (CV) significantly lower for adopters than non-adopters of CF1 in both years and of CF2 in 2004.[20] On the other hand, the average RFE was lower and its CV was higher for the adopters of CF2 in 2008. This suggests that the continuing adopters of CF2 tend to live in districts with lower rainfall and higher variability thereof, providing descriptive evidence for the argument that planting basins and reduced tillage are considered as technologies that help farmers manage soil water more efficiently – especially in areas of high rainfall variability.

The unconditional statistics above paint a picture where adopters of CF practices are poorer and smaller households with smaller amounts of land and livestock. They are more likely to practice crop rotation, less likely to use hybrid seeds and live in districts with lower and more variable rainfall. In the next section, we discuss the panel data models employed in this paper to analyse the conditional decisions to adopt and the intensity of adoption of CF.

[20] The growing season is defined as the period between the beginning of October and end of April.

4. METHODOLOGY

4.1. Adoption of CA

We model the decision of a farmer whether to adopt a practice or not using the latent variable approach, where the farmer will adopt the practice that maximizes the returns. The *return* function will be based on both production and consumption characteristics, because most farmers operate under various market imperfections that make the consumption and production decisions interdependent (non-separable) (de Janvry, Fafchamps, and Sadoulet 1991).

Let the latent variable C_{it}^* be defined as:

$$C_{it}^* = X_{it}\beta + u_{it} + v_i \tag{1}$$

where X_{it} is a 1 x K vector (with first element equal to unity), β is a K x 1 vector of parameters, u_{it} is normally distributed error term independent of X_{it}, and v_i are time invariant unobserved effects (Wooldridge, 2002, Ch. 15). We only observe an indicator variable C_{it} that represents farmer *i*'s decision at time *t* to adopt CA:

$$C_{it} = 1[C_{it}^* > 0].$$

We can express the distribution of C_{it} given X_{it} and the unobserved effect v_i as follows:

$$P(C_{it} = 1 \mid X_{it}, v_i) = \phi(X_{it}\beta + v_i), \quad t = 1,...,T$$

Estimating the parameters of interest using *fixed effects probit analysis* treats the unobserved effects (v_i) as parameters to be estimated, is computationally difficult and subject to incidental parameters problem.[21] Traditional *random effects probit model* requires an assumption that v_i and X_i are independent and that v_i has a normal distribution, i.e.,

$$v_i \mid X_i \sim N(0, \sigma_v^2)$$

We can consistently estimate the partial effects of the elements of X_t on the response probability at the average value of v_i (v_i=0) using a *conditional maximum likelihood approach.* We use this approach in modeling the adoption decisions.

4.2. Intensity of CA Adoption

We also model the intensity of adoption given the fact that most farmers adopt CF only partially and variables that may increase the intensity of adoption are relevant for policy makers. The intensity of adoption is defined as the proportion of total cultivated land that is under the CF practices as defined in this paper, hence the dependent variable is bounded by

[21] Estimating v_i (*N* of them) along with β leads to inconsistent estimation of β when *T* is fixed and $N \to \infty$ (Wooldridge, 2002, p. 484).

the [0,1] interval. We use three different models to analyse the intensity of adoption to ensure the robustness of our results: random effects tobit, pooled fractional probit, and unobserved linear fixed effects models (Papke and Wooldridge 2008).

Correlated Random Effects Tobit Model: Let the share of land that is allocated to CF by farmer *i* at time *t* be S_{it}. The two-limit *random effects tobit model* for S_{it} can be specified as follows:

$$S_{it}^* = X_{it}\beta + u_{it} + v_i$$

$$S_{it} = \begin{cases} 0 & if\ S_{it}^* \le 0 \\ S_{it}^* & if\ 0 < S_{it}^* < 1 \\ 1 & if\ S_{it}^* \ge 1 \end{cases}$$

where the dependent variable takes the values of 0 and 1 with positive probabilities (i.e., the choices to allocate all or no land to CF are legitimate corner solutions). We allow v_i and X_i to be correlated using a Chamberlain-like model by assuming

$$v_i \mid X_i \sim N(\psi + \bar{X}_i\xi, \sigma_a^2)$$

where σ_a^2 is the variance of a_i in the equation $v_i = \psi + \bar{X}_i\xi + a_i$, and $\bar{X}_i \equiv T^{-1}\sum_{t=1}^{T} X_{it}$ is the 1x*K* vector of time averages (Chamberlain 1980). We can write S_{it} in the [0,1] interval as:

$$S_{it} = \psi + X_{it}\beta + \bar{X}_i\xi + a_i + u_{it}$$

$$u_{it} \mid X_i, a_i \sim N(0, \sigma_u^2)$$

$$a_i \mid X_i \sim N(0, \sigma_a^2)$$

The addition of $\bar{X}_i$ on the right hand side of the random effects tobit model takes care of the unobserved heterogeneity problem and allows us to estimate $\sqrt{N}$ -consistent estimates of $\psi, \beta, \xi, \sigma_u^2$, and σ_a^2 (Wooldridge, 2002, Ch. 16).

Pooled Fractional Probit Model: The share of land cultivated with CF is by definition a fractional response variable, whose properties are not fully taken into account by the random effects tobit model described above. Papke and Wooldridge (1996) used a quasi-maximum likelihood estimation (QMLE) to obtain robust and efficient estimators in their seminal contribution to the empirical literature on fractional response variables. Similar to the tobit model described above, this model allows for corner solutions. We use pooled QMLE suggested by Papke and Wooldridge (2008) for panel data applications. More specifically, we assume,

$$E(S_{it} \mid X_{it}, v_i) = \Phi(X_{it}\beta + v_i),\ t = 1,...,T$$

where $\Phi(.)$ is the standard normal cumulative distribution function (that leads to computationally simple estimators with unobserved heterogeneity). In order to consistently estimate the β and the average partial effects (APE) we need to assume that conditional on v_i, X_{it} is strictly exogenous and that v_i, conditional on X_{it} is distributed normally:

$$v_i \mid (X_{i1}, X_{i2}, ..., X_{iT}) \sim N(\psi + \overline{X}_i \xi, \sigma_a^2)$$

We can consistently estimate the β (up to a scale parameter) and the APE, provided that there are no perfect linear relationships among X_{it} and that there is time variation in all elements of it.[22] We use the pooled Bernoulli quasi-MLE estimator obtained from the pooled probit log-likelihood, which is called *the pooled fractional probit* estimator. The estimating equation is given by:

$$S_{it} = f(1, X_{it}, \overline{X}_i)$$

and is estimated using a Generalized Linear Models (GLM) approach, with adjustments to the standard errors to allow for arbitrary serial dependence across *t*.

Linear Unobserved Fixed Effects Model: We compare the results of the previous two specifications to the results of a simple linear unobserved fixed effects model. This model is equivalent to using pooled OLS to estimate the same equation as in the pooled fractional probit model above. The results of this model are directly comparable to those of the QMLE as long as the APE are adjusted by the scale parameter. The model predictions do not necessarily fall in the [0,1] interval, which is a similar problem to the one caused by using an OLS for a binary dependent variable. We, therefore, present the results of this specification for comparison purposes only.

[22] The coefficients need to be adjusted using the scale parameter after estimation to make them comparable with the coefficients of the random effects tobit and linear unobserved FE models (Papke and Wooldridge 2008).

5. RESULTS

5.1. Adoption

Table 11 presents the results of the random effects probit models described above for four different specifications: two different CF definitions each for the whole sample and for the Eastern province. Most socio-economic variables are not significant in determining the adoption of CF1. The number of adults (older than 15 years of age) is positive and only weakly significant in the whole sample. Other variables that are indicators of labor availability (i.e., dependency ratio and the percentage of adults that were chronically ill in previous 3 months) are not significant, failing to provide evidence for labor constraints in front of adoption in our sample.

Table 11. Probability of Adoption of CF1/CF2 (Marginal Effects of Random Effects Probit Models)

	Whole Sample		Eastern Province	
Variables	**CF1**	**CF2**	**CF1**	**CF2**
Female head	0.027	-0.011	0.164*	0.153
Widower head	0.092	-0.109	0.493*	-0.088
Polygamous head	-0.059	-0.057	-0.053	-0.194
# Adults (age>=15)	0.017*	-0.006	0.027	0.039
Age (head)	0.002	0.001	0.003	0.001
Education (average)	0.001	0.009	-0.022	0.006
Dependency ratio	0.013	0.002	0.010	-0.024
Chronically ill (% adults)	0.148	0.011	0.378	0.455
Land per capita	-0.005	0.018	-0.161**	-0.024
Ag-wealth index	-0.231***	-0.020	-0.193	0.051
Wealth index	0.040*	0.012	0.076***	-0.192
TLU (total)	0.009	0.014***	-0.015	-0.018
# Oxen owned	-0.154***	-0.115***	-0.269***	-0.137**
ASP district dummy	-0.123***	-0.067	0.099	-0.096
Received minimum tillage extension (% SEA)	0.097	0.940***	0.780***	0.311
RFE CV (1996-2011)	-0.292	7.002***	7.079***	9.105***
2008 dummy	-0.446***	-0.661***	-0.883***	0.314***
Central	0.158	0.477**		
Copperbelt	0.385***	-0.146		
Eastern	-0.130	0.798***		
Luapula	-1.117***	0.418**		
Northern	0.256**	1.670***		
NWestern	-0.509***	-0.461*		
Southern	-0.929***	-0.357*		
Western	-0.370***	-0.428*		
Constant	0.600**	-3.967***	-1.538**	-3.993***
Number of observations	8,208	8,208	1,835	1,835

Source: Author calculations based on RILS.

The coefficient of the agricultural wealth index is negative and significant, whereas that of other wealth index is positive and significant. This suggests that while mostly households with little agricultural machinery adopt CF1 (keeping in mind that hand hoe is included in the definition of CF1), otherwise better off households with higher wealth indices (i.e., more household durables) are more likely to adopt.

Number of oxen owned is the only variable that is consistently significant: households with more oxen are significantly less likely to adopt CF in all specifications. Households in ASP districts are significantly less likely to adopt CF1, but this variable is not significant in all other specifications, failing to support the claim that ASP successfully promoted CF in the districts it operated in. The proportion of households in an SEA that received extension information on minimum tillage significantly increases the adoption of CF2 in the whole sample and CF1 in the Eastern province, underlining the importance of extension in promoting adoption.

We find that the higher the coefficient of variation of rainfall in the district, the more likely that households will adopt CF in all specifications but CF1 in the whole sample. This supports the hypothesis that farmers perceive CF as a technology that can mitigate the effects of variable rainfall and improve the efficiency of soil water management. Although we cannot establish directly that CF decreases the yield variability due to water stress over time, our finding that adoption is significantly higher in areas of high rainfall variability provides evidence for a synergy between CF and adaptation to climate variability. This finding is strongly robust to various specifications.

The probability of adoption for CF1 has significantly decreased between 2004 and 2008 in the whole sample and the Eastern province as indicated by the significant and negative coefficient on the 2008 dummy variable. This variable indicates a similar trend in the adoption of CF2 in the whole sample, but an opposite trend in the Eastern province, where the probability of adoption of CF2 has increased significantly between the two panels. The provincial dummy variables also show that households in the Eastern province are significantly more likely to adopt CF2 compared to households in the reference province of Lusaka. These findings support our approach of modeling the Eastern province separately in our analysis.

5.2. Intensity of Adoption

Although most applied literature on CA tends to define adoption as a binary outcome (e.g., having some area under minimum tillage), it has been accepted that adoption is not a binary process and tends to be partial and incremental (Baudron et al. 2007; Umar et al. 2011). In this section, we present the results of our analysis of the intensity of adoption using the three different econometric models as described in section 4 above to ensure the consistency of results.

Interestingly, most of the socio-economic variables that were not significant in determining adoption of CF1 are significant in determining the intensity of CF1 (Table 12). Household head’s age and average education significantly increase the intensity of adoption in all specifications. Cultivated land per capita decreases the intensity of adoption, indicating that labor constraints play a role in farmers’ decisions on how much land to allocate to CF1. The coefficient on the dependency ratio also supports this argument, though it is not significant in the random effects tobit specification. Agricultural wealth index negatively affects the

Table 12. Adoption Intensity of CF1/CF2 in the Whole Sample

Variables	CF1 Random effects Tobit	CF1 Fractional Probit	CF1 Linear Unobserved effects	CF2 Random effects Tobit	CF2 Fractional Probit	CF2 Linear Unobserved effects
Female head	0.065	0.069	0.035	-0.208	-0.253	-0.018
Widower head	0.107	0.158	0.040	-0.339*	-0.478**	-0.026*
Polygamous head	-0.056	-0.084	-0.025	0.004	-0.109	-0.011
# Adults (age>=15)	0.004	-0.015	-0.003	0.005	0.009	0.001
Age (head)	0.006**	0.009**	0.003**	-0.005	-0.004	-0.000
Education (avg.)	0.029***	0.035***	0.011***	0.019	0.019	0.001
Dependency ratio	-0.023	-0.064**	-0.016*	0.016	-0.010	0.001
Chronically ill (% adults)	0.066	0.055	0.014	-0.087	-0.180	-0.018
Land per capita	-0.053**	-0.403***	-0.023***	-0.009	-0.172***	-0.002*
Ag-wealth index	-0.118***	-0.182***	-0.020***	0.046	0.050	0.001
Wealth index	0.020	0.028	0.003	0.019	0.026	0.000
TLU (total)	-0.004		-0.001	0.007	-0.003	-0.000
# Oxen owned	-0.029	-0.034	-0.000	-0.039	-0.061	-0.000
ASP dummy	-0.027	-0.001	-0.011	-0.068*	-0.046	-0.013*
Minimum tillage extension (% SEA)	-0.112	-0.101	-0.042	1.057***	1.242***	0.058***
RFE CV	-0.435	-0.872	0.077	5.330***	7.878***	0.625***
2008 dummy	-0.234***	-0.269***	-0.089***	-0.421***	-0.371***	-0.019***
Central	-0.112	-0.060	-0.011	0.442	0.433	0.030**
Copperbelt	-0.069	-0.029	-0.001	-0.257	-0.444	-0.012
Eastern	-0.057	0.033	-0.004	0.726*	0.819***	0.061***
Luapula	-1.115***	-1.497***	-0.415***	0.211	-0.135	-0.004
Northern	-0.327***	-0.429**	-0.119	1.099***	1.011***	0.074***
NWestern	-0.539***	-0.601***	-0.208***	-0.360	-0.621*	-0.028**
Southern	-0.746***	-0.824***	-0.238***	-0.168	-0.413	-0.012
Western	-0.372***	-0.404*	-0.157**	-0.337	-0.502	-0.026**
Constant	0.769***	0.498	0.534***	-2.963***	-4.430***	-0.158***

Source: Author calculations based on RILS.

intensity of CF1 adoption, this is expectable because the definition includes hand hoe use, which is correlated with low agricultural wealth. This variable is not significant when we use the stricter definition (CF2).

Although the number of oxen was significant in determining adoption, it is not significant in determining the intensity of it. The ASP dummy is not significant, indicating that this program did not affect the intensity of adoption of CF1. The share of other households in the SEA that received extension services on minimum tillage does not significantly affect the intensity of CF1, neither does the coefficient of variation of historical rainfall in the district.

The 2008 dummy indicates that the intensity of adoption of CF1 decreased significantly between the two panels, holding everything else constant. The provincial dummies are negative and significant, indicating a general downward trend in the intensity of CF1 in all provinces except in the Eastern and Copperbelt Provinces.

With regard to CF2, the most robust and significant variables that increase the intensity of adoption are the share of households in the village that received minimum tillage extension and the CV of RFE. Both of these variables positively affect the probability of CF2 adoption as well as its intensity significantly. The RFE coefficients provide evidence for a synergy between CF and adaptation as perceived by farmers.[23]

Table 13 reports the results for the Eastern province only. The results are similar to the nation-wide results in that most of the socio-economic variables are not significant in determining the intensity of adoption. Land per capita is negative and significant in almost all specifications, indicating that large landholders allocate a smaller share of their land to CF. The ASP dummy is positive but only significant in one specification for CF1, and negative but not significant in affecting the CF2 intensity, failing to provide evidence that the ASP was effective in promoting CF in its areas of operation.

As in the nation-wide results, the variables with the most robust coefficients are the minimum tillage information provision for CF1 and the CV of rainfall for CF2. The higher the share of households that received extension information on minimum tillage in a households SEA, the higher the intensity of adoption of CF1. This variable is significant only in the tobit specification for CF2. Households in districts with higher CV of historical rainfall allocate

Table 13. Adoption Intensity CF1/CF2 in the Eastern Province

	CF1			CF2		
Variables	**Random effects Tobit**	**Fractional Probit**	**Linear Unobserved effects**	**Random effects Tobit**	**Fractional Probit**	**Linear Unobserved effects**
Female head	0.407	0.579	0.119*	0.042	0.006	0.000
Widower head	-0.153	-0.300	-0.075	-0.986	-1.120***	-0.110
Polygamous head	-0.261	-0.237	-0.063	-0.615*	-0.586***	-0.073***
# Adults (age>=15)	-0.009	-0.031	-0.005	0.075	0.058	0.008
Age (head)	-0.003	-0.002	-0.001	0.005	0.006	0.000
Education (avg.)	0.005	0.008	0.002	0.036	0.035	0.005
Dependency ratio	-0.132**	-0.207**	-0.027	-0.086	-0.038	0.001
Chronically ill (% adults)	-0.105	-0.227	-0.023	0.388	0.090	-0.003
Land per capita	-0.422***	-1.045***	-0.084**	-0.182	-0.321**	-0.017**
Ag-wealth index	-0.039	-0.157	0.005	0.119	0.072	0.005
Wealth index	-0.015	0.100	-0.011	-0.045	-0.028	-0.001
TLU (total)	-0.023	-0.079**	-0.006	-0.055	-0.041	-0.002
# Oxen owned	-0.129*	-0.186	-0.017	-0.124	-0.106*	-0.005
ASP dummy	0.237*	0.459	0.073	-0.136	-0.071	-0.016
Minimum tillage extension (% SEA)	1.436***	2.213***	0.365***	1.015**	0.680	0.075
RFE CV	7.049***	11.137	2.140	11.240***	8.807**	1.114**
2008 dummy	-1.168***	-1.680***	-0.326***	0.246	0.158	0.018
Constant	-1.115	-2.515	-0.014	-4.682***	-3.929***	-0.226

Source: Author calculations based on RILS.

significantly bigger shares of their total cultivated land to CF2 further supporting the role of CF in managing soil moisture in semi-arid climates.

[23] These results are robust to the exclusion of the Northern province to accommodate the coding issues related to the practice of chitemene. The results without the Northern province can be provided upon request.

We find that the intensity of adoption decreased significantly in the Eastern Province only for CF1 as indicated by the coefficient of the 2008 dummy. For CF2, on the other hand, the trend was positive, though not significant. Eastern province, therefore, seems to be on a different path than the rest of the country both in terms of adoption and its intensity.

5.3. Adoption and Intensity of Adoption in the 2008 Cross-section

The panel data models presented above are limited to some extent in terms of explanatory variables, because they can only utilize information that was collected in the same way in both years. The RILS in 2008 collected a richer set of household variables that may play a role in farmers' adoption decisions, as well as a community survey that collected important information from village headmen. The household variables of interest that only exist in 2008 are: the ownership status of cultivated land; household's kinship ties to the village chief; households' status as a local; and access to cell phones. We would expect that households would be more likely to adopt CF on their own land given the time delay in realizing most of the benefits of CF. A household with kinship ties to the village chief or one that considers itself as an established local household may have better access to extension information that is usually provided by lead-farmers. Access to a cell phone is also expected to improve households' access to information on prices and markets as well as extension services related to CF.

The 2008 community survey includes information on the share of land that is not allocated to individuals also whether cultivable land is available in the village. Both of these variables capture the scale of land scarcity in the community, which we expect would affect adoption decisions. There would be less scope for shifting cultivation and land expansion in communities with smaller unallocated and cultivable land, making households more likely to undertake activities to improve their productivity on existing land. We, therefore, expect both of these variables to negatively affect adoption and its intensity. We also have data on communities' distances to a tarmac road and a marketplace. Access to roads and markets may make a household more likely to participate in non-farm activities, hence less likely to adopt new technologies on-farm. They may, on the other hand, improve access to seeds, open up new venues for sales, and act as centers of information exchange, which in turn would increase the incentives to adopt new technologies. The expected effects of these variables are therefore ambiguous. The number of local selling points is expected to increase adoption by giving farmers incentive to increase production that they can market. The number of households in the village is also relevant to control for the effects of social networks and incentives for common property management. For example, the bigger the community the harder it would be to establish or change communal norms to control livestock grazing after harvest, which is one of the main impediments to leaving crop residue on the plot as part of CF. Bigger communities may also make it harder for information to diffuse from farmer to farmer, negatively affecting incentives to adopt.

Unconditional differences in these variables between adopters and non-adopters of CF2 are presented table 14. All household variables but the share of own land in cultivated land have the expected sign in unconditional differences. Community variables also show mostly expected differences between adopters and non-adopters. Adopters live in villages that have significantly smaller shares of unallocated land and are more isolated. They also are closer to local markets and have more selling points in the community.

Table 14. Additional Household and Community Variables by CF2 Status in 2008

	Non- CF2	CF2
Household variables		
Share of own land in cultivated land	0.97	0.97
HH has kinship ties to the chief	0.47***	0.57***
HH is considered local	0.81***	0.88***
HH has access to a cell phone	0.44**	0.51**
Community variables		
Unallocated land (%)	25.77***	20.83***
Cultivable land available	0.44	0.47
Distance to tarmac road (km)	40.73**	48.65**
Distance to market (km)	20.33**	17.06**
# of local selling points	1.39***	3.52***
# of households	87.05	85.91

Source: Author calculations based on RILS.

In order to understand the conditional effects of these variables on adoption and its intensity, we use the same model specifications as above but only for 2008, for which we have the rich set of variables as discussed above and a much larger sample than the panel sample. Although the panel data models used above have significant advantages over the more commonly found cross-sectional analyses in the literature, we can still gain some insights into variables affecting farmers' adoption decisions using only the cross-sectional variation in the larger sample and the richer set of variables available in the 2008 survey.

For the cross sectional analysis we only present the results of one specification for each outcome variable for the stricter definition of CF (CF2) in table 15: probit model for adoption probabilities, and the pooled fractional probit (GLM) model for the intensity of adoption.[24]

We find that female headed households are more likely to adopt CF and allocate bigger shares of their land to CF in the Eastern province, though this effect was muted in panel regressions that control for household fixed effects. Cross-sectional coefficients of land per capita indicate that although labor is not a constraint in front of adoption, it is negatively correlated with the intensity of adoption both in the whole sample and in the Eastern province. We find that households with lower agricultural wealth indices are significantly less likely to adopt and allocate less land to CF in the whole sample, though this variable also loses significance when we control for household fixed effects, therefore only suggestive. The negative and significant effect of the number of oxen owned we found in panel models of adoption stays equally significant in cross sectional models, indicating that number of oxen is a very robust predictor of adoption of CF practices and their intensity in Zambia. The percentage of households in the SEA that received extension information on minimum tillage is another variable with similarly robust effects on adoption in both cross-sectional and panel models. The higher this percentage, the more likely are households to adopt and the bigger the share of land they devote to CF.

[24] The results of the other specifications for CA2 and all specifications for CA1 can be provided upon request.

Table 15. Cross-sectional Models for Probability and Intensity of CF2 Adoption, 2008

	Whole Sample		Eastern Province	
Variables	**Adoption**	**Intensity**	**Adoption**	**Intensity**
Female head	0.055	0.100	0.217**	0.167*
Widower head	-0.217	-0.328	0.084	-0.409
Polygamous head	0.043	0.041	0.013	-0.044
# Adults (age>=15)	0.011	0.003	0.074*	0.036
Age (head)	0.002	0.002	0.002	0.003
Education (avg.)	0.004	-0.000	-0.026	-0.022
Dependency ratio	-0.025	-0.019	-0.007	-0.041
Chronically ill (% adults)	0.208	0.325	0.620	0.635
Land per capita	0.008	-0.140**	0.024	-0.251**
Ag-wealth index	-0.091**	-0.076*	-0.041	-0.038
Wealth index	-0.001	0.057	-0.275	-0.235
TLU (total)	0.008	-0.003	-0.005	0.003
# Oxen owned	-0.094**	-0.099**	-0.228***	-0.200***
ASP dummy	0.008	-0.113	-0.127	-0.188
Minimum tillage extension (% SEA)	0.832***	0.835***	0.700*	0.649*
RFE CV	6.167**	3.550	3.903	3.203
Additional variables				
Own land (%)	-0.043	-0.257	-0.334	-0.505*
Kinship ties to the chief	0.040	0.024	0.193*	0.089
Local household	-0.110	-0.114	-0.403	-0.310
Cell phone	0.047	0.062	0.199*	0.125
Village unallocated land (%)	-0.001	-0.001	0.001	-0.001
Cultivable land available	0.200*	0.210**	0.159	0.204
Distance to road (km)	0.003**	0.001	0.003	0.002
Distance to market (km)	0.000	0.000	0.003	0.001
# of local selling points	0.023**	0.021***	0.023**	0.021***
Number of Observations	7,343	7,343	1,478	1,478

Source: Author calculations based on RILS.
Note: All standard errors are clustered around standard enumeration areas to control for the error correlation across households in the same SEA. The coefficients for the number of households are not presented because it was nil and insignificant in all specifications.

One of our main findings based on panel models was that both adoption and its intensity increase with the CV in historical rainfall. Cross sectional results presented above fail to support this hypothesis (except in the case of adoption in the whole sample) suggesting that some unobservable time-invariant household characteristics that are correlated with both the historical rainfall and adoption decisions (such as the ability to respond to weather shocks) confound the effect of rainfall variation in the cross-sectional models above.

The main point of this cross-sectional exercise is to create suggestive evidence for effects of variables that could not be included in panel models of adoption and its intensity. The proportion of owned land in total cultivated land was expected to affect both adoption and its intensity positively as farmers have more incentives to invest in long term projects on their own land. However, the coefficient of this variable is not significant, except in the intensity model in the Eastern province, suggesting that farmers are less likely to adopt and do so less intensively if they own more of their cultivated land there. Households with kinship ties to the village chief are significantly more likely to adopt CF in the Eastern province, suggesting that kinship ties may help improve access to extension or equipment in this province. The indicator variable for local households is not significant in any of the specifications.

The probability of adoption and its intensity are significantly higher in communities where the headman indicate that cultivable land is available in the community if a new household would like to settle there. The coefficient on the distance to a tarmac road is only significant in the adoption regression in the whole sample, though the coefficient is very small. The only new variable that is strongly significant across the board is the number of selling points in the village. The more selling points in the village the more likely are the households to adopt and on bigger portions of their land. This finding strongly indicates that having more opportunities to sell farm products gives farmers incentives to adopt practices to increase productivity. The lack of opportunities to market the output from cover crops has been mentioned as one of the constraints for adoption of CA in the literature. Though we do not have data on cover crops, the finding that adoption and its intensity are higher in villages with more selling points suggests that the marketability constraint plays a role in farmers' adoption decisions.

6. CONCLUSIONS

This paper contributes to literature on agricultural technology adoption by using a novel data set that combines data from two large-scale household surveys with historical rainfall data to understand the determinants and the intensity of adoption of two main components of CF in Zambia: minimum/zero tillage and planting basins. We document high levels of dis-adoption (around 95%) in the whole country, while dis-adoption in the Eastern province – the hub of CA projects in Zambia – is significantly lower. Nationwide only 5% of the households practiced CA in 2008, down from 13% in 2004, which raises the question of the widespread suitability of this practice. Eastern province is the only province with a significant increase in adoption rates between the survey years: 14% in 2008, up from 8%.

Our econometric analyses based on panel data methods that control for time-invariant household characteristics fail to provide evidence for the oft mentioned determinants of adoption in the literature. We find no evidence for the role of labor constraints, age, or education in adoption decisions. These results suggest that most socio-economic variables are correlated with household level un-observables (e.g., farmer ability or openness to innovation) in cross-sectional studies confounding the effects of variables included in analyses. We do, however, find that the intensity of adoption is negatively affected by land per capita – another indicator of labor constraint.

We find a very strong and robust relationship between the district level variation in historical rainfall during the growing season and adoption as well as the intensity of adoption of the analysed CF practices in Zambia. This finding suggests that farmers are using minimum tillage/planting basins as a strategy to mitigate the risk of rainfall variability, providing evidence – albeit indirectly – of a synergy between these practices and adaptation to climate variability. Further research is needed to directly assess whether CF decreases yield variability over time as suggested by these findings.

Another robust finding is that the reach of extension services in a village (i.e., the proportion of households that received information on minimum tillage) positively affects both adoption and the intensity of adoption. A key outstanding question however, is the degree to which extension services included the provision of subsidized inputs, which is not possible to distinguish in this dataset. Understanding the respective importance of information and subsidized input provision is essential to design future programs for CF promotion – especially in locations with highly variable rainfall.

Eastern province demonstrates a different trend than the rest of the country in that there was an upward trend in the probability of adoption for an average household and no significant downward trend in the intensity of adoption. This suggests that the long history of CF activities in the province (combined with its specific agro-ecological conditions suitable for CF) may have had an effect on adoption rates there. Given the still high dis-adoption rates in this province, however, further research is needed to understand the institutional settings of various projects and how they affect the adoption of CF practices.

To summarize: CF as practiced in Zambia seems well-suited to respond to the key agro-ecological constraint of highly variable rainfall patterns. The provision of extension services is another consistent and powerful explanatory variable in determining adoption patterns. Better information on what exactly these extension services included, and particularly the degree to which they involved subsidized inputs, is needed before an assessment of the potential effectiveness and sustainability of further extension efforts for promoting CF can be made.

The results should be interpreted with a caveat in mind: this paper analyses the adoption and dis-adoption of two CF practices, not the whole package. Inasmuch as minimum soil disturbance practices analysed here are an essential component of CF, results are still important for understanding the determinants of farmer decisions regarding CF. Future research will try to incorporate more CF practices as permitted by our main data source, use higher resolution RFE data, as well as use other geo-referenced variables such as soil nutrient availability and the historical delays in the onset of the rainy season.

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