Determinants of Adoption of Minimum Tillage by Cotton Farmers in Eastern Zambia

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The views expressed or remaining errors and omissions are solely the responsibility of the authors.

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EXECUTIVE SUMMARY

Conservation agriculture (CA) is heralded as a means to increase yields and reverse land degradation in Sub-Saharan Africa. Low adoption levels have led to a polarized debate about the merits of conservation agriculture with critics questioning the suitability of the technology and proponents calling for increased and better promotion. Combining quantitative and qualitative analysis, this study examines the determinants of adoption of hand-hoe and oxen-draw minimum tillage in Eastern Zambia and the motivations for farmers' decisions to implement or reject the technologies. The focus is on cotton farmers, who make up the largest group of spontaneous adopters among smallholder farmers because of active CA promotion by the cotton companies, especially Cargill and NWK. A survey was carried out with 245 farmers in 15 communities across Eastern Province where CA adoption was expected to be relatively high. Furthermore, in-depth interviews were carried out with 34 farmers, 18 distributors from NWK and 11 buyers and chairpersons from Cargill. Despite farmers' favorable opinions, adoption remains low and disadoption is common. Nearly 50% of the farmers in the study have tried some form of minimum tillage for at least one season, but it is only used on 12% of cotton area and 20% of maize area.

The main reasons farmers use minimum tillage (MT) are to improve their yields and to reduce their vulnerability to droughts. As one NWK lead farmer explained, "[Farmers using MT] are trying to be better off. Now these days the rains are less and with MT, even if the rains are less they harvest well." Specifically MT improves drought tolerance through early planting. As one Cargill buyer put it, "Those who have rippers and use this method, they recommend it because … they can plant early, the weeding is done early. The production is higher than those who do plant after the rains. …they capture a lot of moisture. So their crops, despite the dry spell, they still look very good." In addition, several farmers explained that when they saw their yields declining with conventional agriculture they switched to MT to redress the situation. From the survey data it is clear that cotton farmers in general believe that basins and ox-ripping result in higher yields, better soil fertility, better crop performance during drought years and reduced erosion.

While these direct benefits of MT seem to be the primary motivation for adoption among cotton farmers, there are also a number of challenges keeping more farmers from using the technology. Farmers who had disadopted basins described digging them as "heavy work", "painful," and "too hard to dig". The reasons farmers gave for disadopting basins show that changes in circumstances that alter the value of household labor directly impact the relative utility of using that labor to dig basins. Over half of the ripper disadopters who were interviewed had borrowed the ripper, and they explained that the lack of availability of the ripper led them to not rip in the 2012/13 season. The five ripper owners who disadopted had a diverse set of reasons for discontinuing MT including lack of herbicides, lack of fertilizer, increased erosion, and because of unavailability of the trained household member during the time for ripping.

The reasons why farmers do not start using MT fall into four main categories:

1. Equipment costs - Many farmers expressed a desire to use ox-ripping but they said they were unable to afford the equipment and/or were unable to obtain oxen. While many farmers are interested in getting rippers on credit, they must be willing to take the risk of a relatively large loan and their distributor or buyer must deem them creditworthy.
2. Increased effort - Because ripping can be done throughout the dry season one would expect a well-developed rental market by those who own the equipment. However,

ripping rental service provision is not common because dry-season ripping is seen as too taxing for the oxen. Basins are also perceived as too much work by many non-adopters.

3. Information needs - While most farmers were aware of basins, ripping is a newer and less familiar technology to the average smallholder farmer and training on ripping was commonly requested.
4. Lack of motivation - Because farmers are primarily motivated to use MT because of concerns with drought or soil fertility it is logical then that those who are satisfied with their harvests are less likely to adopt MT.

The regression results confirm the qualitative findings. A multinomial logistic regression was used to estimate how marginal changes in household characteristics affect the probability that they will fall into one of four categories: 1) Ox-ripper farmers (who may also use basins); 2) Basin farmers (who do not use ox-ripping); 3) Disadopters (anyone who previously used MT before the 2012/13 season); and 4) Farmers who have never used any type of MT. The results indicate that farmers who use ripping tend to be better-off, enabling them to invest in the new equipment and take the risk of a new technology. Farmers who use basins tend to be educated and experienced farmers who either have relatively more labor or who need to use their labor intensively for food production. Farmers who have never tried MT have less land, use less fertilizer, and have more non-agricultural income sources, which suggest they may be poorer and have more diverse livelihood strategies. Disadopters tend to be better off than those who never tried MT. They are also less educated and have less labor than basin users and use less fertilizer than ripper users.

The results of this study show that farmers are not stuck in traditional hoeing and plowing but are carefully evaluating the benefits and costs of using minimum tillage given the information they have available to them. Widespread adoption will require adapting existing technologies to overcome technical challenges and developing new ones to match a broader range of resource endowments. The process of developing agricultural technologies suitable for African smallholders could be greatly improved by drawing on farmers' experiences with the promoted technologies, recognizing them as active learners with valuable insights on the constraints and possible adaptations.

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ACRONYMS

CA	Conservation agriculture
CFU	Conservation Farming Unit
CM	Centimeters
FAO	Food and Agricultural Organization of the United Nations
HH	Households
IAPRI	Indaba Agricultural Policy Research Institute
Kg	Kilogram
MSU	Michigan State University
MT	Minimum Tillage
NGOs	Non-governmental Organizations
NWK	NWK Agri-services (previously known as Dunavant)
TLU	Tropical Livestock Units
USAID	United States Agency for International Development

1. INTRODUCTION

Currently Sub-Saharan Africa is home to 76% of the world's ultra-poor (121 million people) who live on less than 50 cents a day (Barrett 2010). Most of these people live in rural areas and agriculture is their primary livelihood strategy (Barrett 2010). Typically smallholder farmers in Africa use few modern inputs and achieve very low yields. Growing demographic pressure on farmland and the resulting reduced fallow periods result in increasing land degradation, soil erosion and nutrient mining (Todaro and Smith 2009; Crawford et al. 2003; Morris et al. 2007).

Sub-Saharan Africa is one of the few parts of the world that has not experienced growth in food crop productivity over the past 40 years (World Bank 2007; Morris et al. 2007), but in recent years governments and international donors have committed to increasing their investment in agricultural development (Hazell 2013; Diao et al. 2012). An important part of the strategy to raise agricultural productivity for the poor will be improved agricultural technologies with the potential to increase smallholders' productivity and improve their quality of lives (Pretty 2011; World Bank 2007).

Conservation agriculture (CA) – a set of management practices including minimal soil disturbance, permanent soil cover, and rotation with legumes (FAO 2001) – has dominated the discourse around how to sustainably improve the crop management practices of smallholder farmers in Sub-Saharan Africa. CA has demonstrated the potential to increase agricultural productivity and food security while preventing erosion and maximizing the ecological functions of the soil (Kassam et al. 2009). Proponents argue that it is the best means of sustainably managing the soil to raise yields and reverse land degradation (Rockström et al. 2009; Kassam et al. 2009; Hobbs 2007). They point to widespread adoption throughout the world – 106 million ha worldwide according to Kassam et al. (2009) – as evidence of its promise.

In contrast, CA is being used on less than 1% of arable land in southern Africa after 20 years of promotion (Hove et al. 2011), leading many to question the suitability of CA technologies to smallholder farmers (Giller et al. 2009). This has led to a polarized debate with CA advocates asserting that low adoption levels are to be expected during the initial phase of an S-shaped diffusion process (FAO 2001), and that the *take-off* phase will start when promotion efforts are coordinated and policies are supportive (Friedrich and Kassam 2011). Critics point out the inadequacy of a single solution for the complex problem of land degradation on smallholder farms (Baudron et al. 2012; Wall 2007).

CA adoption studies in southern Africa tend to focus on minimum tillage (MT), which is the component of CA that is typically emphasized during promotion. Some adoption studies evaluate program interventions (for example in Zambia - Nyanga 2012; Kasanga and Daka 2013) but they are typically biased in favor of the program by focusing on adoption and ignoring the possibility of subsequent disadoption (Andersson and D'Souza 2014). The other group of adoption studies utilizes econometric analysis of multi-purpose household surveys to analyze the determinants of adoption (such as Arslan et al. 2014; Ngoma, Mulenga, and Jayne 2014) without providing a detailed understanding of the underlying reasoning shaping farmers' adoption decisions (Andersson and D'Souza 2014). Giller et al. (2011) highlight the need for mixed methods research to understand farmers' reasons for adoption or disadoption of CA.

This study addresses this gap in the literature by combining econometric analysis of the determinants of CA adoption with qualitative data that provide an understanding of the motivations behind farmers' decisions to use or reject MT, the part of CA typically promoted first. The focus is on areas in Eastern Province, Zambia, where it has been successfully promoted and adopted without heavy use of incentives. Zambia is the country with highest number of CA farmers in southern Africa and is often seen as the exemplar for CA adoption (Hove et al. 2011; Haggblade et al. 2010). This focus allows the study to provide extensive details on the performance of the technology and the constraints to its use where it is known that promotion has been adequate, the environment is reasonably suitable, and adoption is more than a temporary response to material incentives. The study does not aim to estimate national or even provincial adoption levels.

Assuming farmers make rational decisions about MT given their individual objectives and constraints, the hypotheses tested are that labor, wealth, experience, and technical challenges with the technology may all constrain farmers' use of MT. The goal is to determine the perceived benefits and limitations of the MT technologies in order to focus innovation and adaptation. The population participating in the study is smallholder cotton farmers in Eastern Province, Zambia, a location and sub-section of farmers where adoption has been relatively high. The results not only provide guidance on how to overcome challenges related to CA adoption but also have implications for sustainable intensification efforts in general.

In the next section a brief introduction to CA and its promotion and adoption in the context of Zambia is provided. After describing the research methods used, the results are presented in three major sections: adoption estimates, farmers' reasons for adoption, disadoption and non-adoption and the econometric analysis. The results are summarized in the discussion and policy recommendations are outlined in the conclusion.

2. CONSERVATION AGRICULTURE

2.1. Minimum Tillage

The three principles of conservation agriculture (minimal soil disturbance, permanent soil cover and rotating or intercropping with legumes) are complementary in that the overall benefits are greatest when they are all used together (Thierfelder et al. 2013b). In practice, however, farmers prefer to adopt technological packages in a step-wise fashion starting with those that are most beneficial for their own specific situations (Byerlee and de Polanco 1986; Kasanga and Daka 2013). In southern Africa the principle of minimizing soil disturbance has received the most attention, often with some neglect of the other two principles (Andersson and D'Souza 2014; Baudron et al. 2007).

A variety of technologies can be used to prepare the land while minimizing soil disturbance, all of which fall under the term minimum tillage. In Zambia three specific MT technologies have been promoted - hand hoe basins, ox-drawn ripping and tractor ripping (Grabowski et al. 2014a; Nyanga 2012). Basins are dug in a precise grid and each hole is 20 centimeters (cm) deep, 30 cm long, and the width of a hoe blade. Farmers with animal traction can use a ripper to open up a trench 5 cm wide and 15 cm deep where the seeds can be sown. The Magoye ripper, developed at Magoye research station, is the primary tool being promoted in Zambia (Kabwe, Donovan, and Masazaka 2007). Where tractors are available, tractor-drawn rippers can be used. A fourth technology for minimizing soil disturbance that is available to hand hoe farmers is that of simply cutting into the previous year's ridge and planting. This farmer-led innovation, which we call *direct seeding*, was observed but is not the focus of this analysis.

Minimizing soil disturbance offers two types of important benefits to farmers: improved soil fertility and increased water use efficiency. Improvements to the soil tend to be long term and are the result of reducing the decomposition of soil organic matter and preventing some of the erosion that is common with tilled soils on sloping land (Rockström et al. 2009; Verhulst et al. 2010; Thierfelder, Cheesman, and Rusinamhodzi 2013a). In the short term MT may allow for more efficient application of fertilizer and manure by concentrating nutrients in the crop's root zone (Haggblade and Tembo 2003). MT can increase water use efficiency by improving water infiltration, especially with mulch (Thierfelder and Wall 2009) or when a hard pan is broken (Haggblade and Tembo 2003). In addition, unlike plowing MT takes place during the dry season, enabling earlier planting and increased cotton and maize yields on the order of 100 to 200 kg per week (Haggblade and Tembo 2003; Haggblade, Kabwe, and Plerhoples 2011).

Some of the most commonly identified constraints for minimum tillage include increased labor requirements for basins and the challenge of weed control without soil inversion (Giller et al. 2009; Grabowski and Kerr 2014; Wall 2007). The retention of dry season biomass is problematic due to uncontrolled fires and grazing by free range livestock (Giller et al. 2009; Baudron et al. 2007). Rotation or intercropping with legumes tend to be low at least in part due to low prices, high seed costs, high labor requirements and poor access to improved varieties (Snapp et al. 2002).

2.2. Conservation Agriculture Promotion in Zambia

CA has been promoted for smallholders in Zambia since 1996 by the Conservation Farming Unit (CFU). International donors, the Zambian government, and numerous Non-governmental Organizations (NGOs) have created major initiatives to promote adoption

(Haggblade and Tembo 2003). Food aid and other incentives have been used to encourage farmers to try CA (Nyanga, Johnsen, and Aune 2011; Haggblade et al. 2010). Most of the initial emphasis was on basins, in part because cattle corridor disease had reduced the availability of animal traction in the mid-1990s (Haggblade and Tembo 2003). In the early 2000s there was increased emphasis on promoting the Magoye ripper with cotton farmers (Kabwe, Donovan, and Masazaka 2007).

This research focuses on cotton farmers, who make up the largest group of spontaneous adopters among smallholder farmers. Private sector cotton companies have actively promoted CA and provided inputs on contract to smallholder growers. NWK Agri-services (previously known as Dunavant) and Cargill are the largest cotton companies and strongest private sector promoters of MT (Arulussa 1997; Haggblade et al. 2010). NWK has been promoting basins since the 1990s and encourages each of its distributors to have a CA demonstration plot to use for training in the communities. Cargill buyers hold what are called cotton schools to train farmers on CA and cotton production practices. Both companies were involved in promoting Magoye rippers in Eastern Province as early as 2002 (Kabwe, Donovan, and Masazaka 2007) and have increased their efforts over the last few seasons as herbicides and equipment have become more available to farmers on credit (Grabowski et al. 2014a).

2.3. Agriculture in Eastern Zambia

Eastern Province is a high agricultural potential region with the highest incidence of smallholder farmers (24% of all households), 75% of whom were food insecure in 2004 (Siegel 2008). In this context CA holds the potential to dramatically increase the productivity of smallholder farmers and increase their well-being (Siegel 2008). This explains why numerous development agencies have promoted CA in Eastern Province (Baudron et al. 2007; Arslan et al. 2014). The Province has a unimodal rainfall pattern with annual precipitation varying between 600 and 1200 millimeters between November and May. Though overall population density is relatively low, localized land scarcity exists, especially around some large villages. Eastern Province can be divided into two major agro-ecological zones. The lower elevation *valley* zone has lower rainfall, higher temperatures and lower cattle populations because of tsetse fly infestation. The upland *plateau* regions have greater population density and higher rainfall. This study focuses only on the plateau regions.

Of the 257,000 small and medium scale farming households in Eastern Province in 2012, 97% grow maize and 64% grow cotton (Tembo and Sitko 2013). Cotton is a demanding crop in terms of labor and management with regular pest monitoring and pesticide sprays. On average cotton farming households have larger cultivated areas, own less cattle and earn a larger portion of their income through agriculture than households that do not grow cotton (Haggblade, Kabwe, and Plerhoples 2011). Smallholder farmers access the inputs to grow cotton on credit through contracts with cotton companies that deduct these costs from payment at harvest time (Haggblade, Kabwe, and Plerhoples 2011). NWK uses a system of distributors who are lead farmers who link between 50 and 100 cotton farmers with the company by providing training, distributing seed and chemicals, monitoring fields and buying the harvest. They earn a commission on the production from their farmers with bonuses for high volume, yields, and loan repayment rates. Cargill on the other hand employs buyers who may or may not be farmers to carry out similar functions but overseeing 200 to 500 farmers.

2.4. Minimum Tillage Adoption in Zambia

Both promotion and adoption of CA have clustered geographically (Grabowski et al. 2014a; Kasanga and Daka 2013). Despite at least 10 years of heavy promotion of CA in Zambia's moderate-rainfall zones, national adoption rates have not skyrocketed and even CA adopters typically use only some of the principles on a portion of their land (Arslan et al. 2014; Grabowski et al. 2014a). Two separate surveys suggest that MT use remains low but has been expanding gradually in Eastern Province over the last decade, from 8% of households in 2004 to 14% in 2008 (Arslan et al. 2014) and from 2.9% in 2008 to 7.4% in 2012 (Ngoma, Mulenga, and Jayne 2014). Another survey of cotton farmers with Dunavant showed MT use increasing from 5.9% in 2002 to 10.4% in 2011 with most of the increase coming through ox-ripping while basin use rates were level (Grabowski et al. 2014a). A higher adoption estimate for Eastern Province of 17.4% came by stratifying communities by level of CA promotion (Kasanga and Daka 2013).

MT adoption correlates with promotion and higher rainfall variability, suggesting that farmers use MT to reduce their vulnerability to an unpredictable climate (Arslan et al. 2014; Ngoma, Mulenga, and Jayne 2014). For communities where cotton is grown, adoption correlates with greater herbicide availability, longer promotion and better demonstrations by lead farmers (Grabowski et al. 2014a).

Adoption is often temporary, particularly when development agencies provide material incentives to adopters. Arslan et al. (2014) report that in Eastern Province 88% of the 78 MT users in the sample in 2004 disadopted by 2008. The authors attribute disadoption to the expectation of free inputs to use CA and the discontinuation of those incentives, as has been documented elsewhere in Zambia (Ngoma, Mulenga, and Jayne 2014; Nyanga, Johnsen, and Aune 2011; Baudron et al. 2007; Haggblade and Tembo 2003). Adoption studies that focus on evaluating projects promoting CA tend to be biased towards adopters and ignore disadoption that takes place when promotion ends (Andersson and D'Souza 2014).

3. DATA AND METHODS

This research combines qualitative and quantitative methods to gain an in-depth understanding of the factors affecting MT use by smallholder farmers Zambia's Eastern Province. Given highly clustered promotion and adoption of MT, this study used results of a nationwide census of lead cotton farmers to stratify zones in Eastern Province according to their intensity of MT adoption (Grabowski et al. 2014a). A complex survey design (including clustering and two levels of stratification) was used in order to efficiently collect adequate data from a wide range of adoption levels. A survey was carried out with 245 farmers in 15 communities across Eastern Province where CA adoption was expected to be relatively high. Respondents provided data about their household characteristics and farming practices for the 2012/13 agricultural season. In-depth interviews were used with 63 farmers and cotton buyers in 10 communities with varying levels of adoption. Thematic analysis was used to analyze the qualitative data. Econometric analysis using a multinomial logistic model was used to analyze the survey data.

3.1. Selection of Respondents

3.1.1. Community Selection

Communities were randomly selected from lists stratified by CA adoption rates using 2011 data (for details see Grabowski et al. 2014a). Communities with high- and medium-adoption of various MT technologies were selected, in order to understand the determinants of adoption where it was known that non-adoption was not simply the result of lack of promotion or the unsuitability of the environment (Table 1). High-adoption communities are in the top quartile of adoption rates for each technology and medium-adoption communities are those with adoption levels above the lowest quartile of overall MT use (including any combination of basins, ripping, or tractor ripping) but not in the high adoption categories. The data for this study come from plateau areas and should not be generalized to the lower elevation and lower rainfall areas of Eastern Province known as the valley, which has a fundamentally different farming system.

Table 1. Community Stratification by Company and Adoption Level

	NWK		Cargill	
Strata	**Total**	**Surveyed**	**Total**	**Surveyed**
High tractor ripping	5	4	0	0
High ox ripping	61	2	22	5
High basins	38	1	16	1
Medium CA	116	2	35	0
Low/Zero CA	408	0	102	0
Total number of groups	628	9	175	6

Source: Authors' calculations.

3.1.2. Farmer Selection within Each Community

To ensure that the sample included an adequate number of farmers using all types of land preparation methods, farmers were categorized by their most distinctive (unique) land preparation method. Most farmers hoe some of their land so only those who exclusively hoe were categorized as hoe farmers. If farmers used any type of MT they were categorized by the MT technology used. If they used ox-ripping and basins they were categorized as ox-rippers and if they used tractor ripping with any other type of MT they were categorized as tractor rippers. Some farmers also used direct seeding but this was not known *a priori*. The categorization was accomplished through key informant interviews with distributors and buyers at the community level.

3.2. Data Collection

3.2.1. Qualitative Data

In-depth interviews were carried out with 34 farmers, 18 distributors from NWK and 11 buyers and chairpersons from Cargill. Interviews with farmers focused on their farming practices for the previous season and distributors, buyers and community leaders were also asked about general community-level issues. In addition three group interviews with a total of 122 farmers (69 males and 53 females) and ad hoc interviews with seven survey respondents were also carried out. All interviews were recorded and transcribed. The transcripts, together with researcher notes and comments written on surveys, were coded using thematic analysis to facilitate retrieval of similar information across the data.

3.2.2. Surveys

The survey was piloted and adapted during the in-depth interviews with adjustments made according to the results emerging from the interview responses. Four enumerators were hired to carry out the survey with the primary researcher using the local language Chinyanja. Distributors and buyers invited the selected farmers to participate in the research by meeting in a central location. If selected farmers did not show up they were visited at their home as time allowed.

The survey questions asked farmers about their farming practices for every plot cultivated during the 2012/13 rainy season. Plots were defined as contiguous areas with a single land preparation method and a single primary crop. Household level questions were used to understand the household composition, education level of the adults, total landholding size, years of cotton experience, crops typically sold, types of non-agricultural income sources they were engaged in, the number of all types of livestock they owned and ownership of a variety of agricultural and household items. Farmers also were asked their opinions comparing hoeing to basins and ripping to plowing.

The total value of household equipment at the time of deciding whether or not to use MT was calculated by including only equipment that had been owned longer than the decision to adopt or disadopt was made. For those who never used MT the value was calculated for equipment owned over 3 years, which is the average amount of time adopters have used MT. This retrospective ownership variable provides an indicator of how previous asset levels correlated with decisions to adopt, disadopt or not adopt MT. Finally, farmers also were asked their opinions comparing hoeing to basins and ripping to plowing.

Table 2. Response Rates of Farmers by Stratification Category

Stratum	Selected	Surveyed	Response Rate	Analyzed	Actual Practice[a]
Chairman	4	4	100%	4	-
Hoe Farmer	52	35	67%	34	34
Plow farmer	62	40	65%	39	118
Basin farmer	22	14	64%	15	33
Ox-ripper	73	62	85%	56	45
Tractor plower	9	6	67%	6	2
Tractor ripper	31	17	53%	17	4
Disadopter	5	4	80%	4	-
Unknown	83	63	76%	61	-
Total	342	245	72%	236	236

Source: Authors' calculations.
a: This is how the farmers in the sample are categorized based on their actual responses.

Table 2 presents the response rates by stratum as well as the breakdown of the actual land preparation categories of the farmers in the sample.

3.2.3. Community Level Data

Distributors and buyers at each location provided quantitative information about how long CA has been promoted and about their own farming practices. In order to examine the influence of the use of MT by distributors and buyers on the practices of their farmers a variable was created by multiplying the percent of area the buyer farmed with MT and the years they have used MT.

In addition some community-level variables were obtained through other sources. The percent of farmers using animal traction was obtained from the 2011 census data (Grabowski et al. 2014a), which was available for all locations. Population density was obtained from the 2010 census information at the ward level. Elevation was measured using the global positioning system.

Finally, some community-level values were generated by aggregating household-level responses in the community. Two of these were used as part of the cluster analysis (see below): the average fertilizer application rate for maize and the percent of plots whose residues had been heavily grazed the previous dry season.

3.3. Statistical Analysis

In order to analyze the determinants of adoption in areas where CA has been promoted and where general environmental suitability of the technology is not a question, this study focuses on medium- and high-adoption communities. The population being generalized about through the statistics is cotton farmers in Eastern Province selling to Cargill or NWK in communities where MT is used and where adoption rates are in the top three quartiles.

A multinomial logistic regression was used to estimate how marginal changes in household characteristics affect the probability that they will fall into one of four categories: 1) Ox-ripper farmers (who may also use basins), 2) Basin farmers (who do not use ox-ripping), 3) Disadopters (anyone who previously used MT before the 2012/13 season) and 4) Farmers who have never used any type of MT. Tractor farmers were excluded from the analysis because tractor use among sampled farmers was much less than anticipated.

While other adoption studies typically explore adoption as a binomial variable (Arslan et al. 2014; Ngoma, Mulenga, and Jayne 2014; Nyanga 2012) this multinomial analysis allows for greater insight by distinguishing between ox-ripping and basins (as is done in Ngoma, Mulenga, and Jayne 2014) and between dis-adopters and those who never tried MT.

A multinomial logistic regression estimates how a marginal change in the independent variables will affect the probabilities of fitting into any one category relative to another.

The multinomial logistic model can be presented formally as:

$$\ln \Omega_{m|b}(x) = \ln \frac{\Pr(y = m \mid x)}{\Pr(y = b \mid x)} = x\beta_{m|b} \qquad \text{(equation 1)}$$

for land preparation categories m = 1 to J where b is the base category (Long and Freese 2001).

3.3.1. Sampling Weights

In order to estimate the parameters of the population (cotton farmers in medium- to high-adopting communities), in the analysis, the observations were weighted by the inverse of the probability of being sampled. Using weights in the analysis reduces bias when generalizing to the broader population and cannot be ignored when stratified by the dependent variable (Elliott 2008) as was done here. Outlier weights in this study were trimmed to five times the median weight (following Pedlow et al. 2003). This ad-hoc way of trimming has been shown to be just as effective as more advanced trimming methods that use simulation and modeling (Chowdhury, Khare, and Wolter 2007).

3.3.2. Cluster Analysis to Control for Community Fixed Effects

Cluster analysis using k-means was used for grouping similar communities into four groups according to five variables: population density, elevation, the percent of farmers using animal traction, the average fertilizer application rate to maize and the percent of plots where residues were heavily grazed. Dummy variables for the clusters were used in the regression to control for fixed effects at the community level.

4. RESULTS AND DISCUSSION

4.1. Adoption Rates

Even in the surveyed areas of medium and high adoption, over 50% of the farmers have never tried any form of MT and another 24% tried it previously but did not use it during the 2012/13 season (Table 3). Of the 24% of farmers who are using MT, about half are using ripping and half are using basins with a few using both.[1] Households that have adopted MT utilize it only on a portion of their land. Only an estimated 12% of cotton area and 20% of hybrid maize area were prepared using minimum tillage methods (Figure 1). Groundnuts and other crops are only rarely planted on MT plots, which contrasts with another study that found over 20% of MT users with one fifth of their MT plots being planted to legumes (Kasanga and Daka 2013).

Farmers who had used tractors for ripping were interviewed in four of the five communities in Eastern Province where NWK has provided tractor loans. In one community the tractor had been in an accident in the dry season of 2012 and was not used for land preparation for the 2012/13 season. In the other three communities the distributors claimed that a total of 79 farmers had used the tractor for ripping in 2012/13 (about 8% of the 956 farmers they collectively oversee). However, 31 of these 79 farmers were sampled and only 4 of the 16 who came to the interview were actually using the tractor for ripping. All four were either the tractor owner himself or a family member, which suggests actual usage is relatively insignificant even in communities where tractors exist. Because of the low response rate and low usage rate for tractors the rest of the analysis focuses on farmers' decisions whether or not to use ox-ripping and basins.

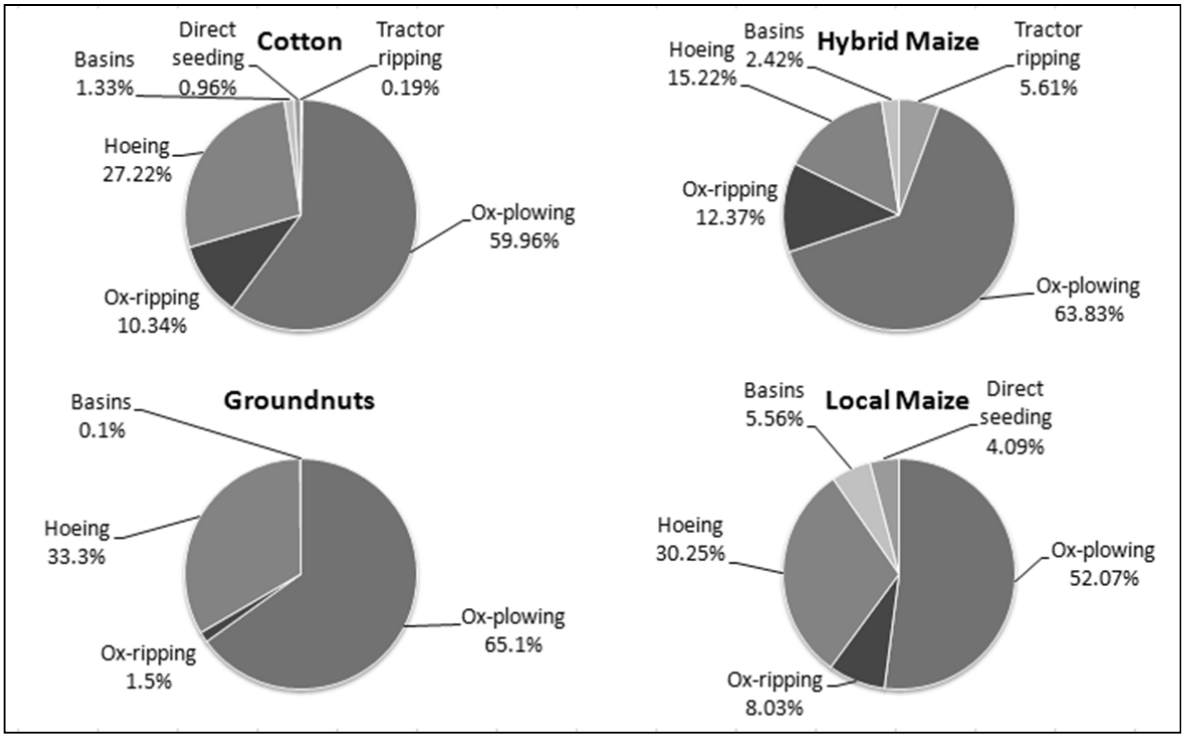
Table 3. Land Preparation Method Use Rates and Rates of Disadoption for Cotton Farmers in Areas of Medium and High Adoption in Eastern Province

	Proportion of households		95% confidence interval
Basins as only form of MT	12.8%		(4.3% - 21.3%)
Ox-ripping with or without basins	11.8%		(6.1% - 17.5%)
Both basins and ox-ripping		*2.0%*	*(0.1% - 4.9%)*
Disadopted all MT	23.7%		(15.3% - 32.0%)
Now only hoes		*5.3%*	*(0.6% - 10.0%)*
Now plows		*18.4%*	*(8.5% - 28.3%)*
Never used MT	51.7%		(27.3% - 76.2%)
Only hoes; never used MT		*17.1%*	*(10.5% - 23.7%)*
Plows; never used MT		*34.6%*	*(13.4% - 55.9%)*
Total	100%		

Source: Survey of NWK and Cargill farmers, 2013.
Note: The rows in italics are additional ways of grouping the data.

[1] For details on how farmers in this dataset combine MT with the other principles of CA as well as other agronomic practices see Grabowski et al. (2014b).

Figure 1. Percent of Area under Each Land Preparation Method for the Four Largest Crops



Source: Survey of NWK and Cargill farmers 2013.

4.2. Farmers' Motivations for Adopting MT

The main reasons for using MT is that farmers want to improve their yields and reduce their vulnerability to droughts. Fifteen out of 20 key informants (distributors or buyers) specifically mentioned drought tolerance as a motivating factor. "[Farmers using MT] are trying to be better off. Now these days the rains are less and with MT[2], even if the rains are less they harvest well… like our other fields the maize wilts but now with MT, it looks like the rains were still falling." One NWK farmer who had heard of basins for 10 years started using MT recently, explaining, "My friends were harvesting very well despite drought, it was resistant and it still grew very well and thrived, good maize, healthy maize. So I thought, let me take it as well."

Early planting is a key aspect of minimum tillage that helps farmers achieve the goals of higher yields and drought tolerance (Haggblade and Tembo 2003). Seven out of 20 key informants specifically mentioned early planting as a general motivation for using CA. As one Cargill buyer put it, "Those who have rippers and use this method, they recommend it because they plant early. Because for them by the time the rains come they have already done the ground work. So they can plant early, the weeding is done early. The production is higher than those who do plant after the rains. … Those who ripped, they capture a lot of moisture. So their crops, despite the dry spell, they still look very good."

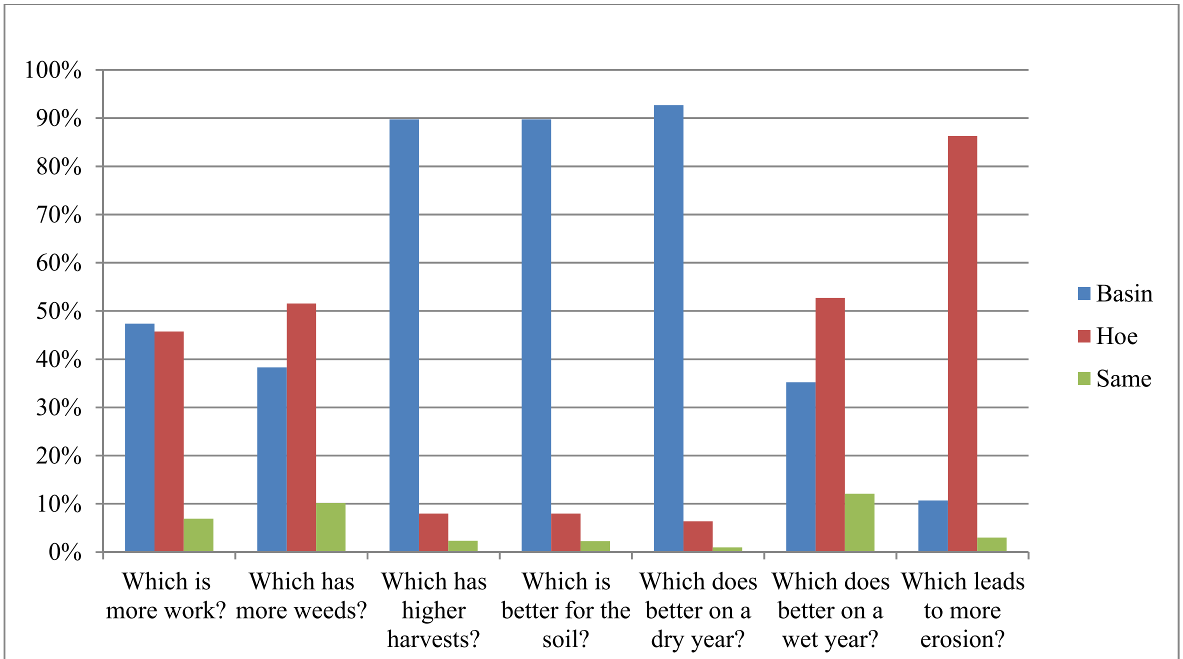
[2] *Gamphani* is the Chinyanja word commonly used for minimum tillage (literally it is the imperative form of the verb to dig, though it is used as a noun) and it is translated as MT for all quotes in this study. While it originally referred to basins, in these interviews *gamphani ya maenje* (MT with holes) and *gamphani ya ng'ombe* (MT with cattle) were used to distinguish basins and ripping.

Several farmers explained that when they saw their yields declining with conventional agriculture they switched to MT to redress the situation. As was explained by one man, "So what made me start using MT, for many years I had been making ridges [by hoe], but I was not finding food well enough. Harvests were down. So I tried MT and I found it. I harvested two ox-carts."

From the survey data it is clear that cotton farmers in general believe that basins and ox-ripping result in higher yields, better soil fertility, better crop performance during drought years and reduced erosion (Figures 2 and 3). Interestingly most also think that conventional tillage does better in wet years. There is less agreement about how the amount of work and the amount of weeds differ between minimum tillage and conventional tillage.

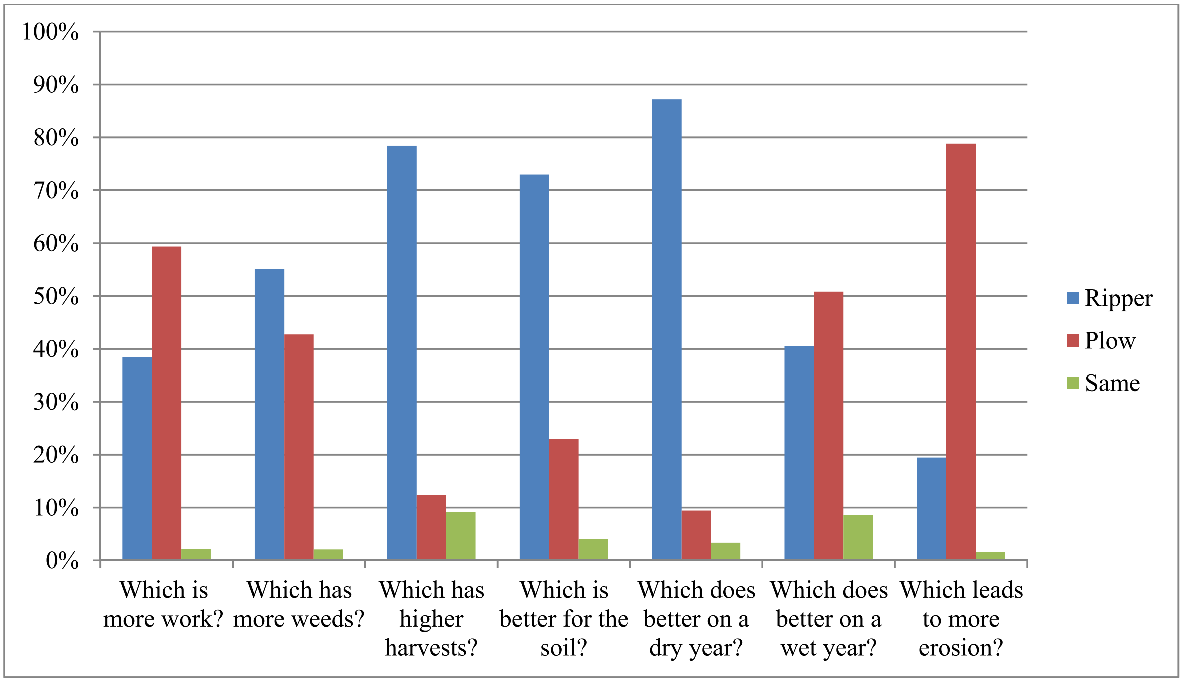
When the responses to these questions are broken down by whether the farmer uses minimum tillage, has disadopted it or never used it, the responses to only two questions have statistical differences between the groups. Farmers who never used basins are more likely than the other groups to say that hoeing does better than basins in a wet year. Disadopters are more likely than other groups to say that erosion is worse with both basins and ripping.

Figure 2. Farmers' Opinions about Hand Hoeing vs. Basins



Source: Survey of NWK and Cargill farmers 2013.

Figure 3. Farmers' Opinions about Ox-plowing vs. Ox-ripping



Source: Survey of NWK and Cargill farmers 2013.

4.3. Understanding Farmers' Reasons for not Using MT

While these direct benefits of MT seem to be the primary motivation for adoption among cotton farmers, there are also a number of challenges keeping more farmers from using the technology.

4.3.1. Incentives

It is important to note that among respondents adoption does not seem to be closely associated with receiving material incentives (such as fertilizer, seed, or equipment). Only one distributor, a ripping disadopter, suggested that the primary reason that farmers use MT is to get inputs from agencies promoting it. While this is certainly the case in some contexts (e.g., Grabowski and Kerr 2014), most Zambian cotton farmers are receiving no incentives for using MT, though some received them in the past. In the interviews only two farmers were receiving incentives from an NGO and in both cases this was a reward for their teaching about MT, not simply for using it.

Both of these respondents identified jealousy of the incentives they received as one of the reasons why others were not adopting MT. As one of them put it, "They want to receive their own things, seed, fertilizer. They say, 'They should give me something to follow it.' But we say, 'We won't give you anything.'" One farmer explained that the apparent favoritism being showed led him to reject using basins: "What has made me not try MT, is that those leaders who are in front, they can write your name but then later they take the fertilizer. That makes it so that I would be lacking wisdom to do that work with them. …So we refuse to do it. For me to dig those basins, there is nothing for me to put in them." When a group of farmers was asked about the possibility of non-adoption due to jealousy of incentives one farmer explained, "Some may get angry seeing others who get something small and then think, 'How can I do MT without anything?' Others may think like that, but it is not all."

In three communities distributors explained how disadoption was widespread once incentives stopped. One distributor explained, "You find that when they [organizations] have been funded, there are certain incentives that have been given, like bicycles. So they [farmers] concentrate just for the purpose of getting a bike. Then after that thing, that funding goes, they will forget." The positive coefficients on incentives in the regression results (section 4.5. and Figure 6) support this finding that many who received incentives disadopted. The observation that those who received incentives are also more likely to be basin users, stems from the history of typical basin promotion which included incentives.

4.3.2. Reasons for Disadopting Basins

Labor is the primary issue driving the disadoption of basins. Farmers who had tried it and stopped described digging basins as "heavy work", "painful" and "too hard to dig". Of the 20 farmers who stated their reasons for disadopting basins, 12 of them said it was the hard work of digging the basins that made them stop. Three of those 12 stopped using basins when they started using animal traction. Another farmer stopped when his wife passed away. A fourth farmer stopped when he started having regular employment. A fifth stopped when she moved from the village to a farm where she had larger fields, explaining, "It needs too much power to do basins on a large area." All of these show how changes in circumstances that alter the value of household labor directly impact the relative utility of using that labor to dig basins. The importance of labor for basin use can also be seen in the regression results in section 4.5. where farmers with higher household labor per hectare have significantly greater probability of using basins than of never using MT or disadopting MT, holding all other variables constant.

Other reasons for disadopting basins included lack of access to manure to put in the basins, loss of the Chaka hoe (a specialized tool to make basin digging easier), unavailability of the trained household member during land preparation months and waterlogging. One disadopter explained that from his perspective basins are only worthwhile if you do not have fertilizer, so once he could afford it, he disadopted basins.

4.3.3. Reasons for Disadopting Ripping

Of the 11 farmers interviewed that disadopted ripping, six of them had borrowed the ripper. They explained that the lack of availability of the ripper led them to not rip in the 2012/13 season. As one previous ripper borrower explained it, "the owner is busy using it. The time may go by when you are supposed to use it. That is the main problem." One disadopter who borrowed a ripper explained that the loss of one of his oxen prevented him from ripping in 2012/13. According to the regression results, farmers with lower value of owned equipment at time of adoption were more likely to disadopt than to rip (section 4.5. below), which supports this finding that many ripper disadopters are those who could not afford their own ripper.

The five ripper owners who disadopted had a diverse set of reasons for discontinuing MT. One explained that he could not use ripping without herbicides. "If you use the ripper the weeds are many. But if we make ridges the weeds stay small. So that is why I used the ripper one year and then stopped and kept making ridges." Another ripper owner said that he only used the ripper with fertilizer, which he could not afford last year. He asserted that unless fertilizer was added he saw no difference between plowing and ripping. One tractor ripper stopped ripping after the first year because he has sloping land and after the first rains all of his seed was washed out of the rip line and ended up at the bottom of his field, despite ripping across the slope. Since then he has chosen to plow. Two farmers who own rippers and disadopted said that they failed to rip in 2012/13 because the trained household member was busy during land preparation months.

These reasons for disadopting basins and ripping show that disadoption can be an active rejection of the technology due to challenges such as labor, weeds and erosion or a more passive decision to temporarily not use it due to the unavailability of equipment or trained household members. This diversity of disadopters needs to be kept in mind in interpreting the characteristics of disadopters in the statistical analysis below.

4.3.4. Equipment Costs as a Reason for Non-adoption

The reasons why farmers do not start using MT fall into four main categories: high equipment costs, increased effort, information needs and lack of motivation.

Many farmers expressed a desire to use ox-ripping but they said they were unable to afford the equipment and/or were unable to obtain oxen. Altogether the total cash outlay required for the equipment is around $150 (including a longer trek chain to connect the ripper to the yoke). If a farmer has an extra plow frame she need only buy the ripper attachment and chain (about $55). With a mean per capita gross household income of only $390 for smallholders in Eastern Province (Tembo and Sitko 2013) such an investment would require significant tradeoffs in other expenditures. The importance of being able to buy equipment for ox-ripping can also be seen in the significance of the wealth indicator variables in the regression results in section 4.5. below.

Of the 50 ripping farmers that participated in this study 30 of them own a ripper. Most of them bought their rippers on credit from the cotton companies, though some bought them with cash shortly after harvest and a few others received them from NGOs. With low cotton prices, it can be difficult for farmers who take a ripper on loan to repay. Loan defaults occurred on 20% of the 40 ripper loans provided in three Cargill depots in 2011, causing the company to reclaim the equipment. Many farmers took rippers on loan hoping the high prices in 2011 would continue. However a low price in 2012 caused many to default and many others to be extremely cautious about taking on too large of a loan during the 2012/13 season. While many farmers are interested in getting rippers on credit, they must be willing to take the risk of a relatively large loan and their distributor or buyer must deem them creditworthy. Also many farmers without oxen made requests for oxen loans so that they too could start ripping.

4.3.5. Increased Effort as a Reason for Non-adoption

Because ripping can be done throughout the dry season one would expect a well-developed rental market by those who own the equipment. However, ripping rental service provision is not common. One of the main reasons why those who own the equipment do not extensively rip for others with their oxen (as is common for plowing at the start of the rains) is that dry-season ripping is seen as too taxing for the oxen. As one distributor put it, “Well, ripping, you know, it ruins the oxen... It is very dry below so they need to be strong.” Feed for oxen also tends to be running out in the dry season as the grasses and crop residues largely disappear due to burning, tilling and grazing, so the oxen are at their weakest (Wall 2007).

The concern for oxen health has even kept some people from using ripping at all. A farmer who was previously a ripping trainer for CFU explained, "They think it is causing problems to their oxen; to make them dig deep like that is to cause problems for their oxen. They prefer to do it during the rainy season…. But they say, 'Ah during the dry season, my oxen can't manage that!'" A plow farmer who drives oxen for their owner explained, "Ripping it needs the dry season… But we see that it can tire the cattle, because with ripping it is dry underneath. On the neck of the cattle it wears a lot. So that is why we want to make ridges by plowing with oxen. Once the rains have come and we are safe, the cattle have it easier." In a similar way the increased effort needed for dry season minimum tillage has kept many people from trying basins and, as described above, has caused others to give up on using them. This finding is also confirmed by the significant and positive coefficient on household labor per hectare in the regression results described in section 4.5. below.

4.3.6. Information Needs as a Reason for Non-adoption

While most farmers were aware of basins, ripping is a newer and less familiar technology to the average smallholder farmer, and training on ripping was commonly requested. The need for training, over and above equipment needs, is shown by the surprising fact that 13% of those who had invested in a ripper had never used it, though most had owned it for more than a year. One of these was a distributor who explained that he needed more support in learning how to use the ripper effectively. The regression results also confirm the importance of training for use of ripping (see section 4.5. below). Even with basins, many farmers requested training so that they could start using them.

Five of the fifteen farmers (33%) who explained their motivation for adoption said that what persuaded them to use ripping or basins was the combination of receiving training and observing the benefits of MT in the fields of earlier adopters. As one farmer put it: "When I went to a training and saw a friend who did a 50 by 50 [meter] field without fertilizer, he had very good maize and it was MT. So I decided to try it and I saw it as beneficial. Even though it is tough labor, I saw benefits." These comments suggest that the uncertainty of a new technology and the perception that MT is too challenging can be reduced through training that is accompanied by real life observation.

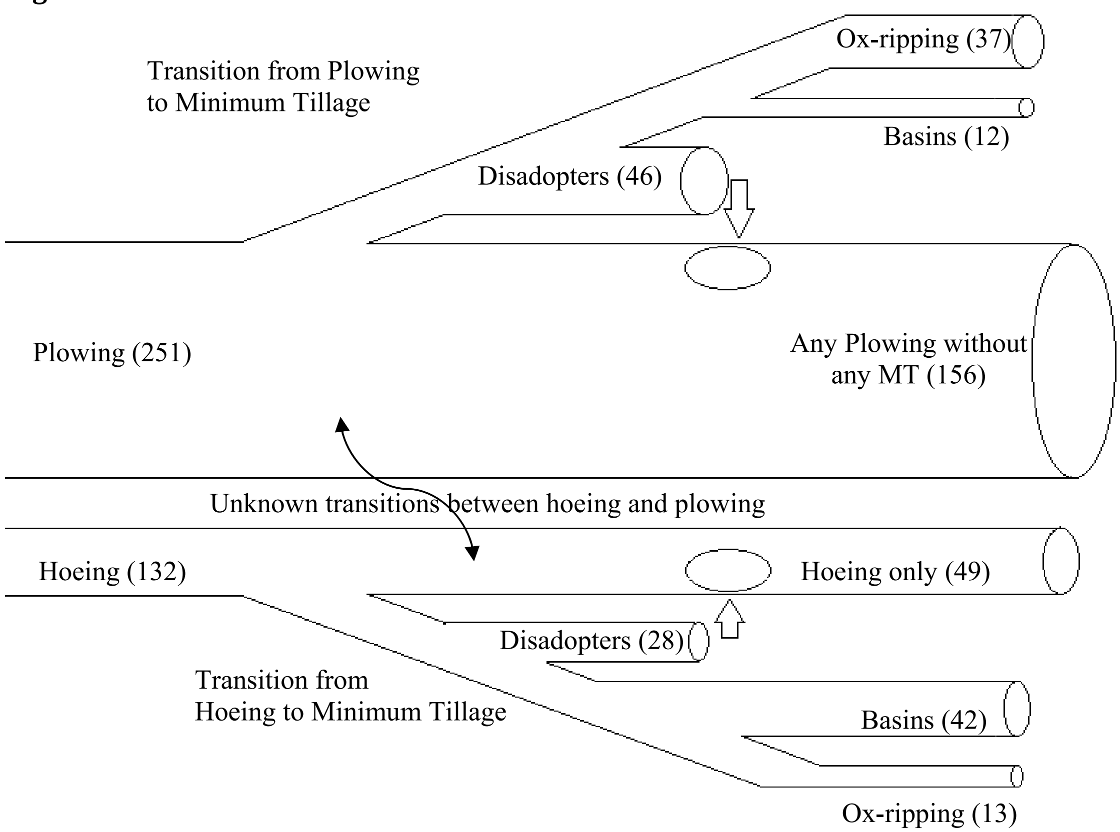
4.3.7. Lack of Motivation as a Reason for Non-adoption

Because farmers are primarily motivated to use MT because of concerns with drought or soil fertility it is logical then that those who are satisfied with their harvests are less likely to adopt MT. A NWK distributor identified this as one of the key differences between MT users and non-MT users: "What helps them do ripping is to be searching, and wanting to improve… [They say,] 'Maybe we can do better than ridging with oxen, maybe the yields can go up.'" When asked why he had never tried MT, a hoe farmer responded, "Because we don't really believe what we have heard. I am still interested in hoeing. When I plant on the ridge I see that the maize grows well and if the fertilizer D [compound] and Urea are there it will do well." Similar ideas were communicated by the non-adopting farmers who participated in the three group interviews.

4.4. Transitions in Land Preparation Methods

Analyzing the frequency of transitions in land preparation methods (including disadoption) allows for a greater understanding of who is using each type of MT and why, what they were doing previously, and what future adoption trajectories may be. In this study all MT users and disadopters were asked if they used oxen or hoed before they started using MT. The results show that most current basin users previously hoed and most current ripper farmers previously used oxen for plowing and making ridges (Figure 4). This suggests that oxen ownership and animal traction experience are likely to determine if a household uses ripping or not. It is also striking that a larger proportion of disadopters previously plowed with their own oxen before they tried using MT. Many of these disadopters received incentives to dig basins, which suggests that they used MT primarily for the incentives.

Figure 4. Illustration of Farmers' Transitions to MT[a]



Source: Authors' survey 2013, unweighted data including observations from low adoption communities.
[a] Pipe diameters are proportional to the number in each category with that number provided in parentheses.
Note: For simplicity, disadoption is not disaggregated into basins and ripping in the figure. Of the 46 disadopters who previously plowed, 38 used basins and 15 ripped (seven did both). Of the 28 disadopters who previously hoed, 24 used basins and seven ripped (three did both).

4.5. Household-level Regression Results

The challenges identified through the qualitative data are confirmed by the regression results. Household-level and community-level explanatory variables were used to carry out the multinomial logistic model, where households were categorized by whether they chose to use ripping, use basins, disadopt all MT or to never use any MT. In the final regression 215 observations had no missing values for any of the explanatory variables. There were 86 respondents who had never tried MT, 53 who had disadopted MT, 33 who used basins but not ripping in 2012/13 and 43 who used ox-ripping (with or without basins) in 2012/13. The means of the explanatory variables and their standard deviation and range are presented in the appendix. The results are presented in Table 4.

One of the challenges with interpreting the results of this multinomial regression on four categories of households is that marginal effects for each explanatory variable must be considered for all pairs of comparisons. In Table 4 the coefficients for only the four most relevant comparisons are presented. An odds ratio plot (also known as a factor change plot) makes it easy to visualize how a change in each variable (holding the others constant) affects the probability that a household will fall into any category relative to the others.

For dummy variables the odds ratio between a pair of choices *m* and *n* can be calculated as $Z = e^{\beta}$. The interpretation of the odds ratio for a dummy variable is that when X=1 the odds of a household being in category *m* versus *n* are expected to change by a factor of Z, holding all other variables constant.

For continuous variables the odds ratio plots below show standard deviation changes. The odds ratio for a standard deviation change can be calculated as $Z = e^{(\beta * s.d)}$. The interpretation for continuous variables is that when there is a standard deviation change in X the odds of a household being in category *m* versus *n* are expected to change by a factor of Z, holding all other variables constant.

Table 4. Factors Affecting Household use of MT, Multinomial Logistic Regression Results with Robust Standard Errors

Explanatory Variables	Rip vs. Never			Rip vs. Disadopt			Basins vs. Never			Basins vs. Disadopt		
Household Level												
Female Headed HH (Y/N)	-2.29	**	(1.04)	-1.30		(1.12)	0.17		(1.09)	1.17		(1.17)
Age of head	0.35	**	(0.15)	0.26	*	(0.15)	0.13		(0.14)	0.04		(0.14)
Age squared	-0.004	***	(0.00)	-0.004	**	(0.00)	-0.002		(0.00)	-0.002		(0.00)
Economic variables												
Adults in hh / Operated Area	1.21	**	(0.51)	0.73		(0.52)	1.46	***	(0.45)	0.98	**	(0.44)
Total Operated Area	0.46	*	(0.27)	0.08		(0.23)	0.64	**	(0.27)	0.26		(0.23)
Sources of non-ag. income	-0.81	*	(0.48)	-0.92	*	(0.50)	-0.68	**	(0.33)	-0.79	**	(0.35)
Total fertilizer (1000 kg)	3.41	***	(1.17)	0.99		(0.68)	1.96		(1.35)	-0.46		(0.92)
Equipment value ($)	8.99	***	(2.83)	5.58	***	(1.82)	5.62	**	(2.58)	2.21		(1.74)
Oxen	-0.29		(0.30)	-0.48		(0.30)	0.01		(0.26)	-0.18		(0.25)
Total Livestock (TLU)*	-0.12		(0.12)	0.06		(0.13)	-0.24	**	(0.12)	-0.06		(0.11)
Capacity variables												
Trained in CA (Y/N)	4.39	***	(0.98)	3.50	***	(1.10)	1.14		(1.15)	0.26		(1.12)
Years of schooling	0.07		(0.12)	-0.06		(0.12)	0.38	***	(0.13)	0.26	*	(0.14)
Cotton experience (years)	0.05		(0.08)	-0.04		(0.07)	0.19	***	(0.07)	0.10		(0.07)
Received incentives (Y/N)	0.79		(1.76)	-2.31		(1.74)	5.36	***	(1.05)	2.26	**	(0.90)
Community Level												
Years CA promoted	0.20		(0.17)	0.06		(0.16)	0.06		(0.22)	-0.08		(0.24)
Buyer CA practice	0.23		(0.43)	0.37		(0.44)	-0.57		(0.39)	-0.43		(0.38)
Cluster 1	-0.39		(1.12)	-0.05		(1.07)	-0.50		(1.36)	-0.16		(1.30)
Cluster 2	0.74		(0.91)	1.60	*	(0.85)	-0.29		(1.06)	0.57		(1.00)
Cluster 4	-1.78		(1.38)	-0.71		(1.24)	-0.83		(1.16)	0.24		(1.17)
Constant	-17.07	***	(4.64)	-9.38	**	(4.41)	-10.82	***	(3.41)	-3.13		(3.48)

Observations 215 — Wald Chi^2 (57) = 177.00 — Pseudo R^2 = 0.3903

Prob > chi^2 = 0.0000 — Log pseudolikelihood = -12,661.594

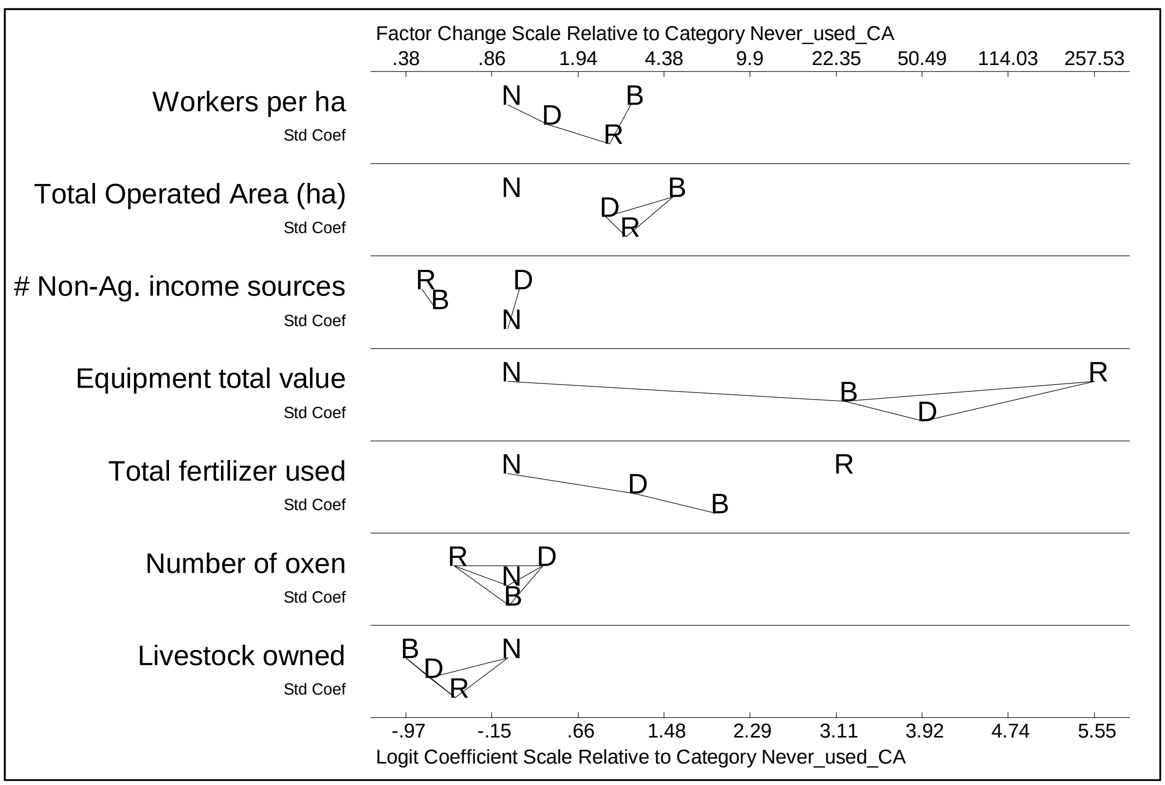
Source: Authors' survey of NWK and Cargill farmers 2013. *Note: (TLU) Tropical Livestock Units - cattle have a value of 0.7, goats and sheep have a value of 0.1, pigs have a value of 0.2, poultry have a value of 0.01 and donkeys have a value of 0.5 (Jahnke 1982).

In the following figures the household categories are represented by their first letter (B = Basins, R = Ripping, D = Disadopter, N = Never used MT). When there is a line between two letters a there is no statistically significant (p=0.1) difference in the probabilities of being in either category. The category of Never used MT is the base category so all the N's are lined up at the value of 1 on the top axis (which shows the odds ratio) and 0 on the bottom axis (which shows the β's from the regression results). When a category is to the left of the base category it means that an increase in the explanatory variable leads to reduced probability of a household being in that category, thus requiring the odds ratio to be inverted. So when a category is at 0.1 on the top axis it means it is 10 times less likely than the base category.

A standard deviation increase in the number of adult workers per hectare of land farmed makes it 4.3 times more likely that the household uses basins and 3.3 times more likely to use ripping than to have never tried MT (Figure 5). Labor is a key challenge for land preparation with basins and for weeding in the absence of herbicides for any MT.

A standard deviation increase in total farmed area makes a household 3.6 times more likely to use basins and 2.5 times more likely to use ripping than to have never tried MT. This matches the findings of Ngoma, Mulenga, and Jayne (2014). Households without much land should need to make it more productive but may not be as focused on farming if small fields require them to diversify their livelihood strategies. Households with less land may also have less resources available for investing. A standard deviation increase in the number of non-agricultural income sources makes a household over 2 times less likely to use ripping or basins. Households with more diverse livelihood strategies may not be able to focus attention on learning and implementing MT.

Figure 5. Odds Ratio Plot for Economic Indicator Variables



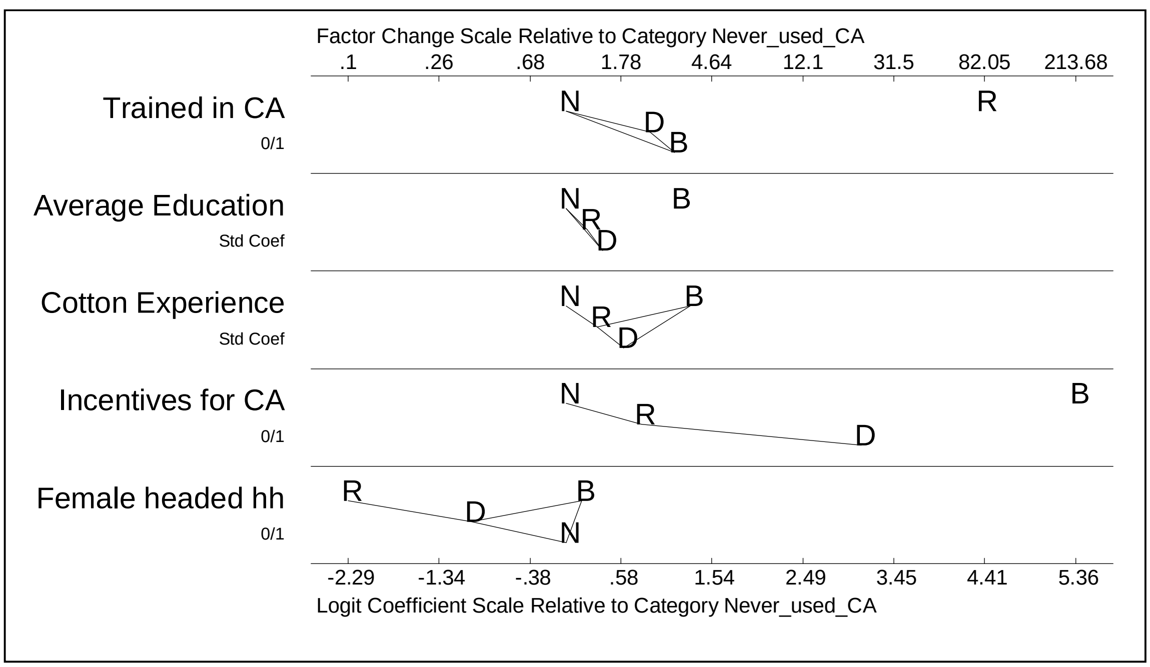
Source: Authors' Survey 2013.

A standard deviation increase in total value of equipment owned at the time of adoption makes a household 257 times more likely to use ripping than to never try MT and 50 times more likely to become a disadopter than to never try MT. Beyond the fact that equipment ownership makes the equipment available to the household, it is an indicator of wealth that makes the household better able to risk trying out a new technology.

A standard deviation increase in total fertilizer use makes a household 22 times more likely to use ripping than to never try MT and approximately 3 times more likely to use ripping than basins. An increase in fertilizer use also increases the probability of using basins relative to never trying MT. Total fertilizer use is another indicator of wealth and one that especially reflects a household's ability to find cash at the beginning of the season, which is a major challenge for smallholders (Andersson and D'Souza 2014). This liquidity of wealth may reduce the risk aversion associated with resource-poor households. One farmer disadopted ripping when he was unable to purchase fertilizer because he felt that without fertilizer, ripping had no advantage. If this opinion is widespread it may also help explain why ripping is used by those households that use more fertilizer.

Surprisingly, a standard deviation increase in oxen has no effect on the probability of a household falling into any of these categories (Figure 6). While oxen are essential for ripping, many households that do not rip use oxen for plowing. The fact that half the basin users also plow with oxen indicates that basin use is not mutually exclusive with oxen ownership. While hand-hoe farmers may be the best candidates to adopt basins (since plowing and ripping are not easy options for them), they also have limited labor for land preparation and many start hoeing in the dry season. Also a standard deviation increase in total livestock ownership makes a household about 3 times less likely to use basins than to have never tried MT.

Figure 6. Odds Ratio Plot for Capacity Indicators and other Variables



Source: Authors' Survey 2013.

Conservation agriculture has been described as a knowledge-intensive technology (Kassam et al. 2009) and as such the training and experience of the household is important for its ability to make use of the technology. A household that has been trained is 81 times more likely to use ripping than to have never tried using MT. Most households in high- and medium-adoption communities (64%) have received some training but not necessarily in ripping which is more technical and has been less promoted than basins. Nearly all households using ripping (97%) have received training, suggesting that without it adoption is highly unlikely. A standard deviation increase in years of schooling makes a household 3.3 times more likely to use basins than to have never tried MT. A standard deviation increase in a farmer's years of cotton experience makes a household 3.4 times more likely to use basins than to have never tried MT. Cotton companies have promoted basins for many years and those with more experience have heard the message and been able to observe the performance of the technology longer.

In addition to these economic and capacity indicators, there is also the issue of direct incentives. While most farmers in this study did not receive incentives, those who did were typically basin farmers. If a household has ever received incentives for doing MT it is 214 times more likely to use basins than to have never tried MT and 22 times more likely to have tried it and disadopted than to have never tried MT. The effect on ripping is smaller, which fits with the history of MT promotion - basins have been promoted longer and by more NGOs than ripping. The effect of incentives on disadoption matches well with the qualitative data, suggesting that once incentives are removed disadoption is common. Only 10% of disadopters said they received incentives, so the other challenges merit attention as well.

The characteristics of the head of the household play an important role in the MT adoption decision. Female-headed households are 10 times less likely to use ripping than to have never tried using MT and 12 times more likely to use basins than ripping (Figure 6). This matches the findings of Ngoma, Mulenga, and Jayne (2014), where a male-headed household was more likely to rip and a female-headed household was more likely to use basins. The age of the household head has a non-linear effect (age and age-squared need to be considered jointly) on the probability of the household using ripping versus having never tried MT. The marginal increased probability for ripping peaks at age 41 but is positive over the entire range, which means that for any age being older makes one more likely to use ripping.

4.6. Summary

Cotton farmers in Eastern Zambia are generally aware of minimum tillage and think highly of its potential for higher yields, especially due to earlier planting, increased drought tolerance and efficient nutrient application. Despite farmers' favorable opinions about MT, farmers' explanations and the statistical analysis both suggest that technical and economic problems significantly limit the use of both basins and ripping.

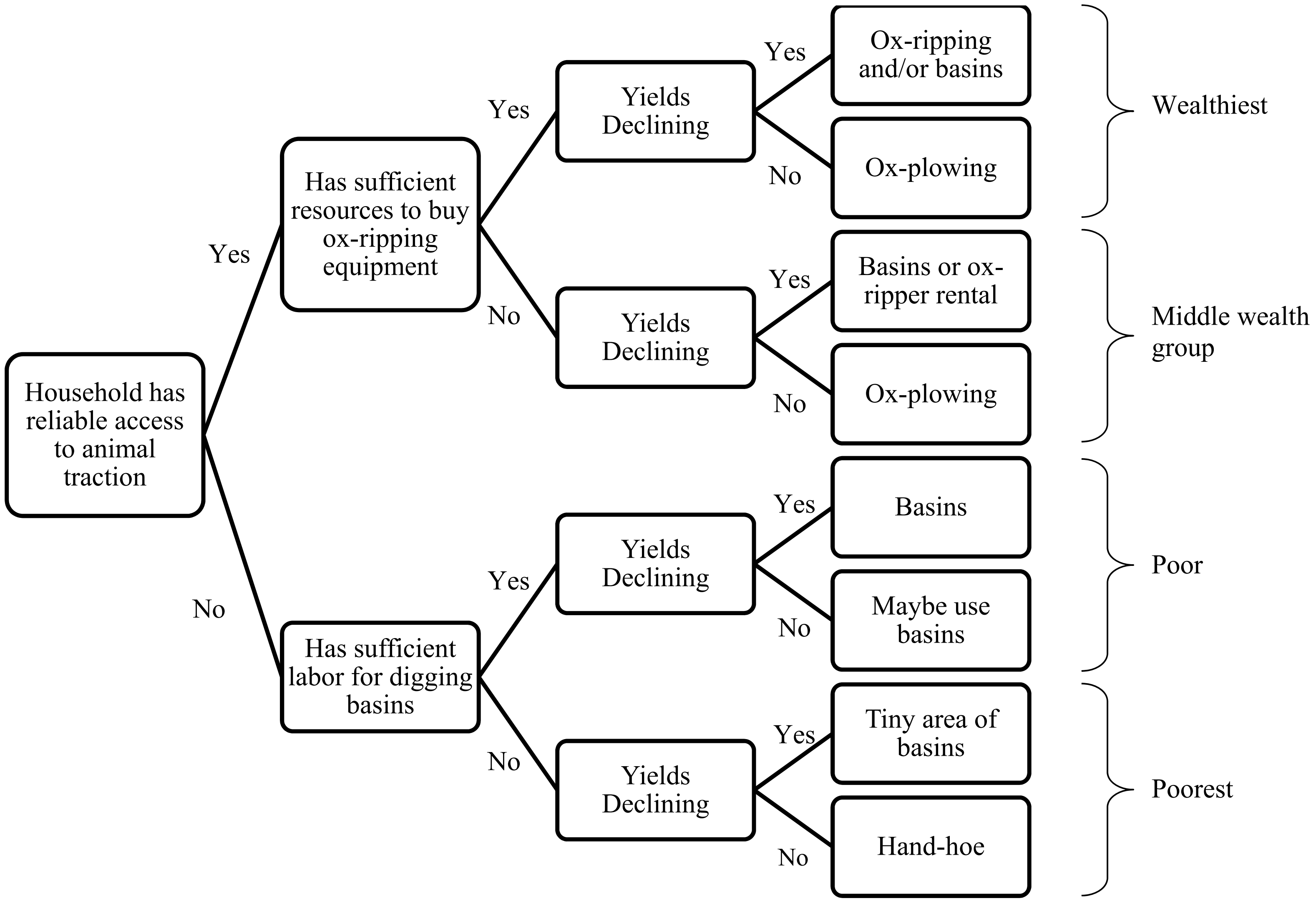
For basins, labor limitations for land preparation constrain its use to those who have relatively more labor availability or greater need to use that labor intensively for food production, such as female headed households. Many have tried using basins and stopped, primarily due to the labor involved. While these limitations imply that the use of basins by hand-hoe farmers is unlikely to take off exponentially, it does not mean that basins are not worth promoting. As Zambian smallholders face increasing land scarcity in pockets of higher population density there will be less opportunity to fallow and greater need to make land more productive, such as through the labor-intensive method of basins.

For ripping the primary constraints relate to the cost of investment in the equipment and the associated risks of investing in a new (to the farmer) technology. Ox-ripping rental services are not widely available, primarily because of concerns for the health of oxen while they are laboring to do dry season minimum tillage when feed is scarce. Improving the health of oxen may help reduce this challenge and the promotion of forage crops may aid in this while simultaneously reducing the competition between using residues for mulch or for feed (Giller et al. 2011). The lack of effective demonstration and training on how to rip limits its use among those who can afford the equipment. Training and personal observation of ripping appear to help farmers overcome the challenges of learning a new land preparation technique.

Basins and rippers are used more for maize than for cotton, which reflect farmers' priority for food production over cash crop production. Basins are especially used for local maize, both of which are accessible to the poor and are complementary in that precise manure application and early planting can result in significant yield gains without any purchased inputs. Local maize takes longer to mature than hybrid maize, so farmers have great motivation to plant it as early as possible.

In sum, ripping tends to be used by better-off farmers with the ability to invest in the new equipment and take the risk of trying a new technology, while basins tend to be used by those educated and experienced farmers who either have relatively more labor or who need to use their labor intensively for food production (Figure 7). Farmers who have never tried MT have less land, use less fertilizer and have more non-agricultural income sources, which suggest they may be poorer and have more diverse livelihood strategies. Disadopters tend to be better off than those who never tried MT. They are also less educated and have less labor than basin users and use less fertilizer than ripper users.

Figure 7. Decision Tree Summarizing the Interactions between Farmers' Resources and Priorities and Land Preparation Decisions.



5. CONCLUSION

The results of this study lead to a number of lessons that will help make sustainable intensification efforts more effective at improving smallholder food security in Africa.

First, the diversity of smallholder cotton farmers in Eastern Province observed in this study should give caution to those seeking simple technological solutions to low productivity. Any particular technology is likely to be a good match for some farmers and bad match for many others because of the variation in their skills, assets, livelihoods strategies and agro-ecological conditions. Providing a basket of choices (Chambers 1997) to farmers is much more likely to yield long-term change than promoting one or two narrow solutions. Currently the labor demands of basins are beyond the reach of many of the poorest farmers who do not focus exclusively on agriculture. There also may be a technological gap for those farmers who do not see basins as worth their effort but cannot afford ox-ripping.

This leads to the second lesson of the need to encourage evidence-driven adaptation of technologies drawing on farmers' experiences. More farmers would use ox-ripping on more area if the average team of oxen could rip a field through the dry season without over-exertion. Adaptations to the equipment or to how it is being used should be prioritized. CFU promotes ripping shortly after harvest, while the soils are still moist, but this is the season when farmers are busy processing and marketing their harvests, causing nearly all CFU participants to be unable to follow these guidelines (Kasanga and Daka 2013). Farmers who currently rip large areas could be a good source for ideas on how to improve ripping efficiency. Including farmers in the decision-making process through bottom-up participatory approaches utilizes their experiences and makes it more likely that technologies can be adapted to match with their actual needs and constraints.

Finally, this study provides guidance on how MT can most effectively be promoted. Policy makers considering subsidizing the use of conservation agriculture should be aware of the perverse effects this may have on adoption. Those providing incentives for CA use may be hoping to get the ball rolling but may actually be distracting farmers from evaluating the technology. The evidence in this study suggests that disadoption is common after incentives cease. Moreover, jealousy of those receiving incentives discourages more widespread adoption. Farmers using MT highlighted the importance of combining training with real life observations of their peers benefiting from using the technologies. This is especially needed for ox-ripping, which is less well-known and more technical than the basins.

The clear reasoning that farmers provided in this study about their decisions show that they are not stuck in the tradition of cultivating the land but wrestling with a complex set of potential benefits and challenges associated with MT. Therefore, MT promotion should not be one of top-down behavior change messages but rather one that follows adult education principles of facilitating experiential learning in a respectful way and drawing on farmers' lived experiences.

As development agencies interact with smallholder farmers in Africa to increase their productivity through agricultural technologies they need to remember that 1) given the diversity of livelihood strategies of the rural poor, a basket of technologies will make it more likely that all types of farmers can benefit, 2) technology development is an on-going process that can be improved by drawing on farmers' experiences and 3) farmers are active learners rationally drawing on their observations and life experiences to evaluate technologies. Taking these lessons into account will help make sustainable intensification efforts more effective at improving smallholder food security in Africa.

APPENDIX

Table A1. Description of Variables Used in the Household-level Regression on MT Use in High and Medium Adoption Communities

	Mean	Standard Deviation	Minimum	Maximum
Household Level Variables				
Household Composition				
Female Headed HH (Y/N)	0.083	0.276	0.00	1.00
Age of head	42.44	14.03	17	81
Age squared	1997.4	1314.4	289	6561
Economic qualities of household				
Adults in hh / Operated Area	1.11	0.80	0.178	6.294
Total Operated Area	3.91	2.43	.98	16
Number of non-ag. income sources	1.00	1.00	0	5
Total fertilizer used (1000 kg)	0.26	0.35	0	2.6
Equipment value ($) at time of adoption/disadoption				
Oxen	1.50	1.77	0	8
Total Livestock (TLU)*	3.70	4.06	0	23.27
Capacity qualities of household				
Trained in CA (Y/N)	0.73	0.44	0	1
Ever received incentives for CA (Y/N)	0.10	0.31	0	1
Years of schooling	5.18	3.08	0	12
Cotton experience (years)	10.54	6.95	1	40
Community Level Variables				
Years CA has been promoted	5.23	2.81	2	13
Buyer CA practice	1.33	1.70	0	6.48
Cluster 1	0.22	0.42	0	1
Cluster 2	0.23	0.42	0	1
Cluster 4	0.25	0.44	0	1

Source: Authors' Survey of NWK and Cargill farmers 2013.
*Note: (TLU) Tropical Livestock Units - cattle have a value of 0.7, goats and sheep have a value of 0.1, pigs have a value of 0.2, poultry have a value of 0.01 and donkeys have a value of 0.5 (Jahnke 1982).

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