Minimum tillage uptake and uptake intensity by smallholder farmers in Zambia

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Abstract

Minimum tillage has been promoted for about two decades as a way to conserve soils and to increase agricultural productivity in Zambia and sub-Saharan Africa. However, the extent of its uptake by smallholder farmers remains debatable. This paper assesses factors influencing the uptake and uptake intensity of minimum tillage, using large household survey data for the period 2010 to 2014 in Zambia. We apply double-hurdle models to account for corner solution outcomes resulting from the limited uptake of minimum tillage. Less than 5% and 10% of smallholders used minimum tillage per year as the main tillage method at the national level and in the top 10 districts with the highest use rates respectively. Low seasonal rainfall and being in districts where minimum tillage has been promoted for over 10 years increase the likelihood of minimum tillage uptake and uptake intensity, but not for all its components. These results have implications for targeting future programmes aimed at promoting minimum tillage.

Key words: conservation agriculture; minimum tillage; adoption; Zambia

1. Introduction

Conservation agriculture has been promoted actively as a viable means for smallholder farmers in sub-Saharan Africa to raise agricultural productivity, stabilise crop yields under variable rainfall conditions and adapt agriculture to climate change (IPCC 2014; Thierfelder et al. 2015). Despite almost two decades of promoting its core principles of minimum tillage, in-situ residue retention and crop rotation, the often claimed high adoption and diffusion is contested (Giller *et al*. 2009; Andersson & D'Souza 2014). Debates on the extent of adoption of conservation agriculture principles have led to questions on their suitability for smallholders in the region (Giller *et al*. 2009; Andersson & D'Souza 2014), and on the relevance of blanket salesmanship or one-size-fits-all promotion approaches (Andersson & Giller 2012). In part, inconsistent definitions of adoption (or the lack of it), the lack of comparable adoption estimates across countries and time, and the lack of sufficient details on adoption figures drive the adoption debates.

There are large variations in existing adoption estimates for conservation agriculture principles in sub-Saharan Africa, and most studies neither define adoption consistently nor provide sufficient details on their estimates (Andersson & D'Souza 2014). For example, recent estimates from Zambia ranged from 2% to 71% across different years between 2008 and 2012 (see Ngoma *et al*. (2014) for details). A similar picture of widely varying adoption estimates emerges at the regional level (Mazvimavi & Twomlow 2009; Andersson & D'Souza 2014). Understanding why adoption estimates vary so much in the same countries or regions and over the same periods is a fundamental issue and one that cross-section data, as in this study, may not answer fully. However, this paper addresses two critical issues that may be limiting a better understanding of the true extent of minimum tillage uptake among smallholders in sub-Saharan Africa. First, we distinguish between conservation agriculture and minimum tillage and focus on the latter, and between adoption and use. Adoption is the sustained use of technologies over time and requires panel data to measure, while technology use includes incentivised testing and experimentation phases, which may or may not lead to adoption. Second, we use survey data that is statistically representative at the national and district level to compute weighted minimum tillage uptake or use rates, even in districts where minimum tillage has been promoted for over a decade. This paper makes two main contributions to debates on the uptake of conservation agriculture in sub-Saharan Africa. First, we highlight trends and spatial patterns in the use of minimum tillage as the main tillage by smallholder farmers in Zambia from 2010 to 2014. Second, we test the influence of being in promotion areas and seasonal rainfall on uptake decisions, and account for the potential endogeneity of the location of programmes promoting minimum tillage on farmer uptake decisions. We return to this issue in the methods section.

We define minimum tillage as the use of either ripping or basins, or both.[1] Minimum tillage is the basis for, and the main component of, conservation agriculture. Its core principles – of planting basins and ripping – minimise soil disturbance by only tilling in permanent planting stations. Planting basins are made with hand hoes, while rip lines are made with animal draft or mechanical-drawn rippers. In this study, a smallholder household used ripping or planting basins only if they reported these practices as the main tillage method on at least one plot for any field crop. We focused on minimum tillage use for any field crop in order to capture all farmers using minimum tillage.

We measured promotion with a dummy variable (= 1) if a household is in a district where minimum tillage has been promoted for at least 10 years prior to the survey year, and rainfall variability by deviations from long-term rainfall. The promotion of conservation agriculture for smallholders started in Zambia in the mid-1990s and initially targeted low rainfall and agriculturally important agro-ecological regions 1, 2a and 2b, which are located in parts of the Central, Eastern, Lusaka, Southern and Western provinces (Haggblade & Tembo 2003). These agro-regions were facing declining land productivity caused by hardpans and excessive use of government-subsidised inorganic fertilisers in the 1980s. Moreover, these areas were more accessible. The Ministry of Agriculture, non-governmental organisations and private companies promote conservation agriculture in Zambia, using lead farmers, demonstration plots and farmer training. Although the promotion targets specific areas, the selection of beneficiaries is not random, since each farmer chooses whether to use conservation agriculture or not. Overall, 55% of all smallholders accessed conservation agriculture extension services in 2011 (CSO/MAL/IAPRI 2012). (See Arslan *et al*. (2014) and Whitfield *et al*. (2015) for detailed historical perspectives on conservation agriculture in Zambia.)

2. Context, data and sampling

This study used the crop forecast survey data collected by the Ministry of Agriculture and the Central Statistical Office. The crop forecast survey data are representative of small- and medium-scale farming (also called the smallholder sector) conditions at the national, provincial and district levels, and therefore has the best statistical representation of minimum tillage use rates as main tillage among smallholder farmers in Zambia, including within districts where minimum tillage has been promoted

[1] We excluded zero tillage, because it was likely confounded by traditional farming practices in surveys prior to 2012.

most actively. Crop forecast surveys ask about the main tillage method used on each plot for each farmer[2] and use standard enumeration areas as primary sampling units. In total, 680 standard enumeration areas were sampled using probability proportional to size sampling, with 20 households from each sampled enumeration area selected for interviews. This resulted in annual samples of about 13 600 households, with about 90% coverage. (See GRZ (2011) for details on sampling procedures for crop forecast surveys.)

This study used data from about 61 000 smallholder households that cultivated field crops over the period 2010 to 2014. These were independent cross-sectional surveys over the five years that were pooled in the analysis. Enumerators conducted face-to-face interviews using structured questionnaires to collect crop forecast survey data. The enumerators were trained enough to be able to capture the exact tillage methods reported by the farmers, and their field reference manuals contained detailed explanations of all tillage methods, including pictures. Figure 1 shows the extent of coverage by crop forecast surveys in Zambia.

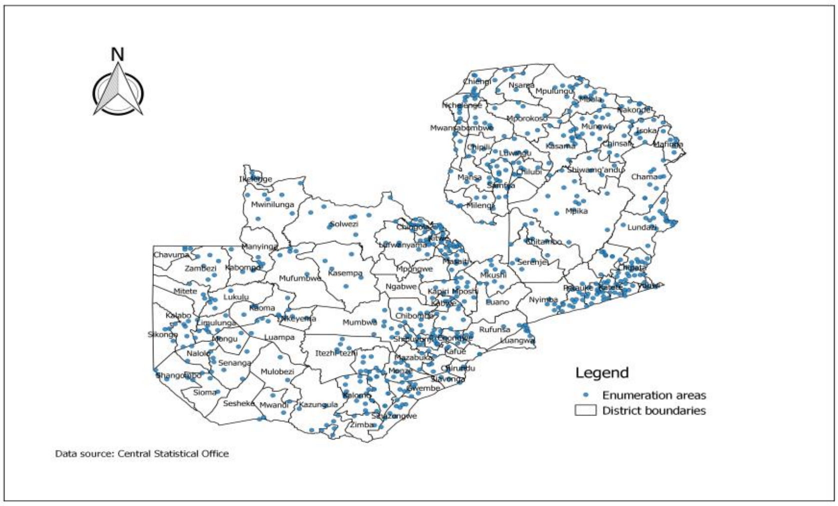

Figure 1: Spatial location of enumeration areas and extent of coverage by crop forecast surveys in Zambia

Source: Authors' compilation

Regarding the identification of household use of minimum tillage practices in our models, it is important to note that the crop forecast surveys are production-oriented and do not capture all household socio-economic and demographic variables. Nevertheless, we controlled for the main determinants of technology adoption used in the literature.

We also used dekad (10-day period) spatial rainfall data from the Climate Hazards Group Infrared Precipitation with Station database (CHIRPS). CHIRPS is a quasi-global spatial database (50'S to 50'N) with a resolution of 0.05' (Funk *et al*. 2014). We merged the spatial rainfall data with household data at the standard enumeration area level.[3] We supplemented this data with two complementary sets of focus group discussions held to understand district- and household-level factors influencing variable minimum tillage use rates from the farmers' perspectives. In total, 126 smallholders from the Chama, Chipata, Choma, Chongwe and Petauke districts participated in focus group discussions in January 2013 and in August 2014.

[2] This includes farmers who used minimum tillage as the main tillage for at least one plot, but excludes all those who only used it partly. Therefore, asking if a plot used minimum tillage is different from asking if minimum tillage was the main tillage method.

[3] Since household coordinates were not collected the time.

3. Methods

3.1 Theoretical framework

Although promoted as part of conservation agriculture principles, the components of minimum tillage (planting basins and ripping) are distinct tillage options available to smallholder farmers. Smallholders face discrete investment choices when they consider whether or not to use minimum tillage (extensive margin), and continuous land allocation decisions regarding how much land to allocate to minimum tillage (intensive margin) (Feder *et al*. 1985). Assuming that farmers derive utility (or profits) from their tillage choices, we can use utility or profit maximisation to evaluate their tillage choices. This analysis lends itself to the random utility theory, which links discrete choices to utility-maximising behaviour based on the assumption of rational preferences (Train 2002).

Consider a rational risk-averse farmer i faced with a choice of tillage method from J options (including minimum tillage (MT) and other conventional tillage options). Assume this farmer obtains utility U_{iMT} from choosing MT-, the j^{th} option, where $j = 1, \ldots, J$. The decision rule is that the farmer chooses the tillage option that provides the greatest utility, i.e. the farmer will choose MT if and only if $U_{iMT} > U_{ik}$ for $k \neq MT$. However, we cannot observe utility saving for some tillage attributes S_{iMT}, and a vector of factors $\boldsymbol{X}_i$ influencing farmers' choices. Following Train (2002), we can define an indirect utility function for the choice of MT tillage as $V_{iMT} = V(S_{iMT}, \boldsymbol{X}_i)$ to relate the observed factors to farmer utility, since we cannot observe U_{iMT}; $V_{iMT} \neq U_{iMT}$. Assuming that utility is an additive separable, we can decompose it as $U_{iMT} = V_{iMT} + \varepsilon_{iMT}$, where ε_{iMT} captures other factors besides minimum tillage use that affect utility but that are not included in V_{iMT}. Because ε_{ij} is unknown for all J, it is treated as random, with a joint density $f(\varepsilon_i) = (\varepsilon_{ij}, .., \varepsilon_{iMT}, \ldots, \varepsilon_{iJ})$. The probability that farmer i chooses minimum tillage is given by

$$\begin{aligned} P_{iMT} &= \Pr\left(U_{iMT} > U_{ik}, \forall_{k \neq MT}\right) \\ &= \Pr\left(V_{iMT} + \varepsilon_{iMT} > V_{ik} + \varepsilon_{ik}, \forall_{k \neq MT}\right) \\ &= \Pr\left(\varepsilon_{ik} - \varepsilon_{iMT} < V_{ik} - V_{iMT}, \forall_{k \neq MT}\right) \\ &= \int \left(\varepsilon_{ik} - \varepsilon_{iMT} < V_{ik} - V_{iMT}, \forall_{k \neq MT}\right) f\left(\varepsilon_i\right) d\varepsilon_i. \end{aligned} \quad (1)$$

Different assumptions on the distribution of the density $f(\varepsilon_i)$ lead to a wide choice of limited dependent variable models to estimate equation (1). We used a double hurdle model, which assumes that $f(\varepsilon_i)$ has a truncated normal distribution.

3.2 Empirical model

Since the main interest of this paper was to model farmer decisions regarding minimum tillage use and use intensity (how much land is cultivated under each MT option), corner solution models were appropriate to estimate equation (1) to account for a large proportion of valid zero responses, because most farmers in the sample did not use minimum tillage. The Tobit model was an option, although its major limitation is the assumption that the same factors determine minimum tillage use and use-intensity decisions, and that these factors have equal coefficients and the same signs across the two decision levels. We used the double hurdle model, which relaxes the Tobit assumption by allowing different or the same factors to affect minimum tillage use and use-intensity differently (Wooldridge 2010).

The first stage in estimating double hurdle models is a binary probit model of minimum tillage use. The second stage is a truncated normal regression for minimum tillage use intensity (cultivated land under minimum tillage) among users only. The specific explanatory variables (in Table 1 and described in section 3.4) were selected based on previous studies on the adoption of conservation agriculture (Haggblade & Tembo 2003; Andersson & D'Souza 2014; Arslan et al. 2014), and on results from our focus group discussions.

We specified the two equations in the double hurdle as

$$\Pr(MT_{ij}=1)=\beta_0+Dpromo\beta_1+\boldsymbol{rainfall}\boldsymbol{\beta}_2+land\beta_3+\boldsymbol{X}_1\boldsymbol{\beta}_4+\boldsymbol{X}_2\boldsymbol{\beta}_5+\boldsymbol{year}\boldsymbol{\beta}_6+\varepsilon \quad (2)$$

and

$$MTland_{ij}\mid MTland_{ij}>0=\beta_0+Dpromo\beta_1+\boldsymbol{rainfall}\boldsymbol{\beta}_2+land\beta_3+\boldsymbol{X}_1\boldsymbol{\beta}_4+\boldsymbol{X}_2\boldsymbol{\beta}_5+\boldsymbol{year}\boldsymbol{\beta}_6+\mu, \quad (3)$$

where $MT_{ij} = 1$ if farmer *i* used minimum tillage option *j*, and *j* = basins, ripping or both (minimum tillage). On average, 3%, 1% and 4% of the sample used basins and ripping or minimum tillage respectively over the five-year period considered in this paper. $MTland_{ij}$ is land area under basins, ripping or minimum tillage for household *i*, which averaged 0.02, 0.03 and 0.05 hectares (ha) per farm household respectively. We estimated one model for the combined effects on minimum tillage and two other models for ripping and planting basins separately, since these are distinct principles. *Dpromo* is a dummy capturing minimum tillage promotion districts, ***rainfall*** is a vector of rainfall variability measures, *land* is total landholding size, $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$ are vectors of demographic and agro-ecological variables, ***year*** is a vector of dummies for the survey years, and ε and μ are error terms in the participation and the intensity-of-use equations respectively. The $\boldsymbol{\beta}$'s are model parameters. Section 3.4 gives further details on these variables.

3.3 Empirical strategy: Dealing with the endogeneity of minimum tillage promotion

A priori, we would expect minimum tillage use to be positively related to the location of major minimum tillage promotion programmes. Therefore, there may be programme placement effects, such that minimum tillage programmes choose to operate in particular areas based on some unobservable criteria. If these unobservables (not captured in survey data) are correlated with farmer decisions to use minimum tillage, then including a right-hand-side variable (*Dpromo*) that specifies whether major minimum tillage-promotion programmes were operating in the area would result in endogeneity bias of the estimates, since programme placement and minimum tillage use decisions at farm level will be determined jointly.

We used the control function approach of Wooldridge (2010) to address this potential endogeneity problem, and used distance from the homestead to the nearest district business centre (*dboma*) as an instrumental variable. A similar instrument was used in Abdulai and Huffman (2014). Theoretically, distance to the nearest district business centre (where most district administrative offices, development project offices and agro-dealers within a district are located) directly influences farmers' exposure to minimum tillage promotion programmes, but not necessarily their individual farm-level decision to use a given practice. This is because households closer to district business centres are likely to access more information on conservation agriculture promotion from several sources, including agro-dealers selling and advertising conservation agriculture equipment and other inputs. Such households are also more likely to be within the promotion areas. As a first step, we estimated a reduced-form equation of the endogenous variable, *Dpromo*, as a function of the instrumental variable - *dboma* and all exogenous variables in equations 2 and 3.

$$Dpromo = \beta_0 + \boldsymbol{rainfall}\boldsymbol{\beta}_1 + land\beta_2 + \boldsymbol{X}_1\boldsymbol{\beta}_3 + \boldsymbol{X}_2\boldsymbol{\beta}_4 + \boldsymbol{year}\boldsymbol{\beta}_6 + dboma\alpha + \eta, \quad (4)$$

where η is the error term, and α is the parameter associated with the instrumental variable and should be significant for *dboma* to be a relevant instrument. All other variables are as described above. We then computed generalised residuals, which were included as additional regressors in the final models. The significance of the parameter on the residuals both tests and corrects for endogeneity (Wooldridge 2010). We estimated the double hurdle models simultaneously, using maximum likelihood estimation with Burke's (2009) *craggit* command in Stata with bootstrapped standard errors.

3.4 Variables and hypotheses

Table 1 gives the summary statistics for variables used in the regressions. *Dpromo* is a dummy = *1* if a household is in a district where minimum tillage has been promoted consistently for at least 10 years preceding the survey year. This variable was constructed based on information from the Conservation Farming Unit and literature on minimum tillage promotion in Zambia (see Haggblade & Tembo 2003; Ngoma *et al*. 2014). It includes 17 districts in Zambia covered by several conservation agriculture promoters and comprises about 39% of the sample. A priori, we expected farmers in these areas to be more likely to use minimum tillage. ***Rainfall*** is a vector of rainfall variability measures – the standard precipitation index (SPI) and rainfall stress periods computed at period *t-1* from the spatial growing season (November to March) rainfall data.[4] Following Patel *et al*. (2007), $SPI_i = R_{t-1} - \mu/\sigma$, where $\boldsymbol{R}_{t-1}$ is the rainfall record for the previous growing season, μ and σ are the 10-year average rainfall and standard deviation of rainfall respectively, and *i* is the current year. A negative and positive SPI indicates a drought (lower than average rainfall) and above-average rainfall (floods) respectively, with more negative or positive values showing severity. Rainfall stress is the number of 20-day periods within a growing season with less than 40 mm of rain. A priori, we expected rain stress to have positive effects on minimum tillage use. We might expect high SPI to affect minimum tillage use negatively due to flooding and waterlogging. These rainfall variability measures also capture the effects of covariate production risk.

Land is total landholding, which averaged 4.3 ha in the entire sample, and 4.7 and 3.6 ha among ripping and planting basin users respectively, and was used as a proxy for wealth. The vector $\boldsymbol{X}_1$ captures household demographics – the sex and education level of the household head, the number of adults aged 15 to 65 years, and the age of the household head (44 years on average). We hypothesised that male-headed households, more education and high labour availability facilitated minimum tillage use, but that age reduced it. About 79% of the sample households were male headed and household heads spent an average of 6.2 years in school. The number of adults per household (3.11 on average) is a proxy for household labour availability. Other labour indicators in $\boldsymbol{X}_1$ are dummies = 1 if the household head is monogamously married (71%) or polygamously married (8%). We hypothesised that polygamously married heads might have more family labour available than monogamously married heads.

$\boldsymbol{X}_2$ is a vector of agro-ecological region dummies and = *1* if a household is in agro-ecological regions 1, 2a, 2b or 3.[5] We hypothesised that households in lower rainfall agro-ecological regions 1, 2a and 2b were more likely to use minimum tillage than those in region 3. $\boldsymbol{X}_2$ also includes eight provincial dummies to account for the effects of spatial location. ***Year*** is a vector of year dummies to control for year-specific effects. Other variables are quadratic terms for age, education, number of adults and

[4] Computed at t-1 to approximate anticipated rainfall in the following season.
[5] Regions 1, 2 and 3 receive < 800 mm, 800 to 1 000 mm and > 1 000 mm of rain respectively.

landholding size to check for quadratic effects and an interaction term between agro-region 2a and negative SPI.

Table 1: Definitions and summary statistics of dependent and explanatory variables used in regression models

Variable name	Description	Mean	Std. dev.
Dependent variables			
MT	Minimum tillage (yes = 1)	0.04	0.19
MT_ripping	Ripping (yes = 1)	0.01	0.12
MT_basins	Planting basins (yes = 1)	0.03	0.16
MTland	Size of land under minimum tillage (ha)	0.05	0.44
MTland_ripping	Size of land under ripping (ha)	0.03	0.36
MTland_basins	Size of land under basins (ha)	0.02	0.23
Explanatory variables			
sex_hh	Male-headed household (yes = 1)	0.79	0.41
age_hh	Age of household head (years)	44.24	14.70
age2	Age of household head squared	2173	1476
edu_hh	Education of household head (years)	6.20	3.83
edu2	Education squared	53.11	56.76
p_married	Polygamously married (yes = 1)	0.08	0.27
m_married	Monogamously married (yes = 1)	0.71	0.45
adults	Number of adults, 14 to 65 years	3.11	1.81
adults2	Number of adults squared	12.97	17.50
land_size	Land holding size (ha)	4.27	11.07
land2	Land holding size squared	141	5873
rain_st	Rainfall season stress periods (#)	0.59	0.74
spirain	Standard precipitation index	0.06	1.06
aer1	Agro-region 1 (yes = 1)	0.22	0.41
aer2a	Agro-region 2a (yes = 1)	0.27	0.44
aer2b	Agro-region 2b (yes = 1)	0.15	0.36
aer 3	Agro-region 3 (yes = 1)	0.36	0.48
aer2aspi	In agro-region 2a and experienced negative spi (drought)	-0.10	0.30
Dpromo	MT promoted at least 10 years (ye s =1)	0.39	0.49
dboma	Distance from homestead to nearest main town (km)	34.76	27.35

Source: Crop forecast surveys 2010 to 2014; authors' computations

4. Results and discussion

4.1 How do minimum tillage users compare to non-users?

As a first step, we compared minimum tillage users and non-users on key variables. The results (available from the authors) suggest statistically significant differences in terms of exposure to rainfall variability, incidences of droughts or floods and household labour availability. A larger proportion of minimum tillage users were located in areas that experienced more rainfall stress and droughts (as indicated by the negative standard precipitation index). Of all farm households that used minimum tillage, a higher proportion were in the low-rainfall agro-ecological regions 2a and 1, and minimum tillage users had fewer adult household members, at 3.31 on average compared to 3.41 among non-users.

4.2 Minimum tillage uptake by smallholders: 2010 to 2014

About 61 000 farmers, or 4.40% of the smallholders in Zambia, used minimum tillage (basins and/ or ripping) as the main tillage method for any field crop in 2014, compared to about 3.55% in 2010 (Table 2). About 2.41% of smallholders used planting basins in 2010 and 3.00% in 2014, while about 1.14% and 1.42% used ripping in 2010 and 2014 respectively. On average, less than 10% of smallholder farmers used minimum tillage per year in promotion and top-ten districts (with highest use rates) (Table 2). However, a larger proportion of farmers used minimum tillage in promotion districts than in non-promotion districts over the study period (Table 2), suggesting a positive effect of promotion. See Figure 2 for the spatial distribution of the five-year average uptake rates across districts.

Table 2: Proportion of smallholder farmers using minimum tillage and its components as main tillage at national level, in promotion and non-promotion districts, and in the top 10 districts, 2010 to 2014

	Percentage of smallholders farmers									
	National level			Promotion districts			Non-promotion districts			Top 10 districts*
Year	MT	Planting basins	Ripping	MT	Planting basins	Ripping	MT	Planting basins	Ripping	MT
2010	3.55	2.41	1.14	5.33	3.49	1.84	2.37	1.67	0.69	7.39
2011	3.11	2.34	0.77	4.19	3.34	0.85	2.37	1.67	0.70	6.49
2012	3.88	2.97	0.91	5.44	3.72	1.72	2.75	2.44	0.32	8.22
2013	3.25	2.30	0.96	4.37	2.58	1.80	2.44	2.04	0.40	5.92
2014	4.40	2.98	1.42	6.19	3.81	2.38	3.11	2.36	0.76	9.26

Notes: MT is minimum tillage, * ranked by percentage of MT use rate.
Source: Crop forecast surveys 2010 to 2014, authors' computations

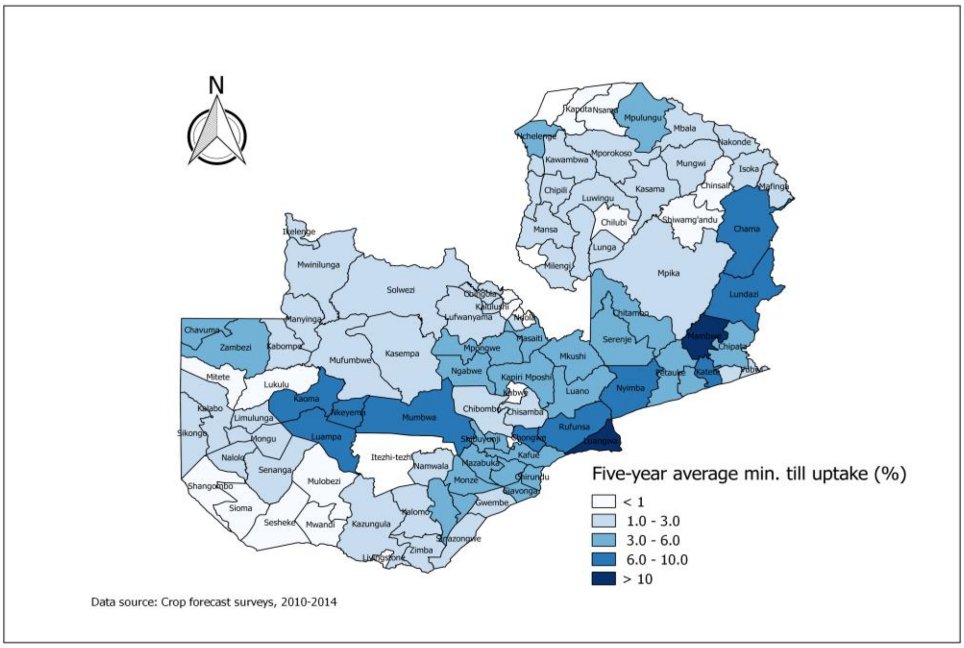

Figure 2: Spatial distribution of district-level minimum tillage uptake by smallholder farmers in Zambia, 2010 to 2014

Source: Authors' compilations

However, there were large variations in uptake rates by district and by year, posting an increase and decrease of about 30 and 19 percentage points in districts with the highest positive and negative changes respectively, between 2010 and 2014 (Figure 3). Section 4.3 explores plausible reasons for these variations in minimum tillage uptake.

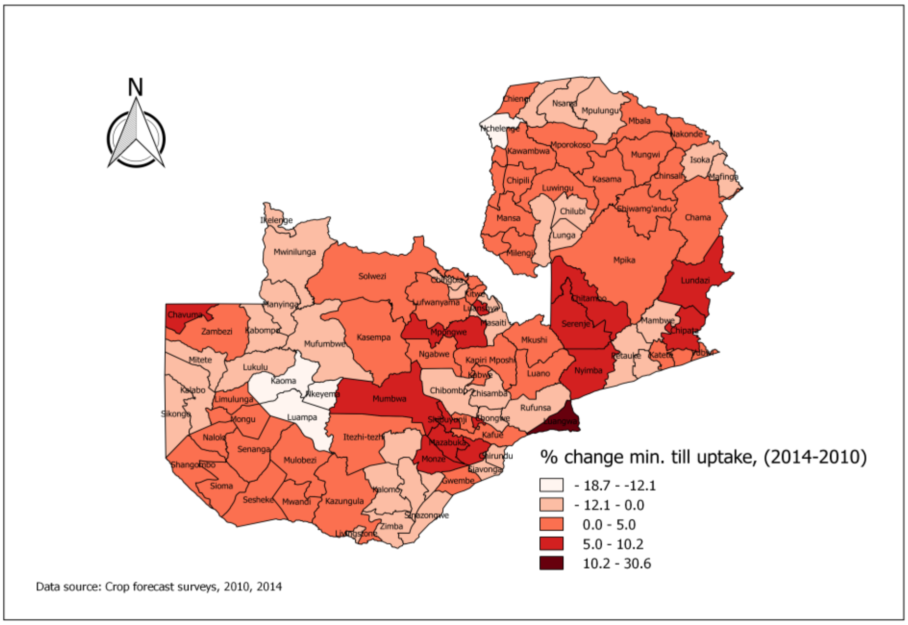

Figure 3: Change in district-level minimum tillage uptake rates by smallholder farmers in Zambia, 2010 to 2014

Source: Authors' compilations

Further, the use of minimum tillage remains partial, with an uptake intensity of about 58% among users, and only about 2.5% in the whole sample on average and over the study period. Of the 2.1 million hectares cultivated by smallholder farmers in 2014, only about 2.8%, 1.49% and 1.35% were under minimum tillage, ripping and basins respectively (Table 3).

Table 3: Proportion of land cultivated under minimum tillage by smallholder farmers in Zambia, 2010-2014

		Cultivated land under (ha)			% of cultivated land under		
Year	Total	Planting basins	Ripping	Minimum tillage	Planting basins	Ripping	Minimum tillage
2010	1 935 204	22 260	16 157	38 417	1.15	0.83	1.99
2011	1 973 337	24 573	14 901	39 474	1.25	0.76	2.00
2012	2 051 925	27 809	19 021	46 830	1.36	0.93	2.28
2013	2 048 082	25 218	20 796	46 015	1.23	1.02	2.25
2014	2 173 374	29 251	32 333	61 584	1.35	1.49	2.83

Source: Crop forecast surveys 2010 to 2014, authors' computations

4.3 Why does minimum tillage use vary across years? Insights from focus group discussions

The focus group discussions suggested that the number of projects promoting minimum tillage at any given time influences uptake rates. Although this effect is positive, it is only temporal in some instances, hence the variations in uptake rates across years. In the context of our findings in Table 2, the higher use rates in 2010 and 2012 coincided with a time when there were several projects promoting minimum tillage. However, other projects were scaling down over the same period, and this partly explains the decline in minimum tillage uptake in 2011 and 2013.[6] The combined effects of old projects and new ones like the Conservation Agriculture Scaling Up project could explain the surge in uptake rates in 2014. (See Whitfield *et al*. (2015) for an overview of conservation agriculture projects in Zambia.) Other than capacity development, some projects provide start-up support in terms of inputs and implements. However, the farmers explained that such support was usually too little in

[6] For example, the FISRI and CASSP projects.

value and for too short a period (lasting no longer than two years) for farmers to be able to finance their future conservation agriculture activities. This partly explains the perplexing tendency whereby some farmers only implement conservation agriculture with project support. However, this does not preclude dependence.

The focus group discussions also revealed that inter-household differences in resource endowments explain why some farmers use minimum tillage practices only with project support. High labour requirements associated with minimum tillage (especially basins), resource constraints faced by smallholders, and distortionary project effects were identified as the main factors impeding the uptake of minimum tillage. The farmers explained that it was easier for wealthier farmers to finance their minimum tillage activities, such as buying the requisite implements, inputs and herbicides. Commenting on household resource constraints, one participant said, “We have received enough training in conservation agriculture and we keep wondering whether training alone would enable us to overcome the costs associated with implementing conservation agriculture”. Another participant added, “Continuous training in conservation agriculture without adequate start-up support is like fishing with a hook but without a bait”. In addition to higher cash outlays, the focus group discussions suggested that minimum tillage requires more labour for land preparation and weeding compared to conventional tillage.

4.4 Empirical results

Table 4 presents national-level estimates for determinants of minimum tillage use and use intensity in Zambia.[7] Columns 1, 2 and 3 show participation, and conditional and overall (unconditional) average partial effects (APEs) respectively for the minimum tillage model, while columns 4 and 5 show the overall APEs for basins and ripping models. We found weak evidence (significant at 10%) suggesting that being in promotion areas is endogenous to basin tillage uptake but not ripping, and to minimum tillage in general.[8] (See the estimates for *residuals* in Table 4.) Consequently, we dropped the residual terms in the minimum tillage and ripping models. Estimation is done with standard errors clustered at the standard enumeration area level to account for intra-group correlations.

[7] As robustness checks, we also estimated the basin models without the IV and the MT models on a sub-sample of households in the top 10 districts, and using the Tobit model. The main results are robust to alternative estimations.
[8] The IV-*dboma* was relevant ($\chi^2 = 14.66; p = 0.00$) and excludable by the instrument falsification test of Di Falco *et al*. (2011) ($\chi^2 = 1.79; p = 0.41$). The full results are available from the authors.

Table 4: Double hurdle results of factors influencing uptake and uptake intensity of minimum tillage by smallholder farmers in Zambia, 2010 to 2014.

	(1)	(2)	(3)	(4)	(5)
	Participation APEs (= 1 if MT)	**Conditional APEs (ha under MT)**	**Unconditional APEs (ha under MT)**	**Unconditional APEs (ha under basins)**	**Unconditional APEs (ha under ripping)**
Promotion district [dpromo] (yes = 1)	-0.003	0.235**	0.006***	-0.134***	0.009*
	(0.004)	(0.103)	(0.002)	(0.031)	(0.006)
Std. Precipitation index [spirain]	-0.005***	-0.049	-0.009***	-0.004***	-0.009***
	(0.002)	(0.069)	(0.003)	(0.002)	(0.003)
Rain stress [rain_st]	0.005**	-0.091	0.002	0.008***	0.001
	(0.002)	(0.063)	(0.005)	(0.002)	(0.002)
In agro-region 2a and drought [aer2spi]	0.007	-0.125	0.003	0.008*	0.007
	(0.006)	(0.147)	(0.009)	(0.004)	(0.007)
Agro-region 1 [aer1] (yes=1)	0.020*	1.077**	0.071***	0.077***	0.120***
	(0.011)	(0.471)	(0.003)	(0.020)	(0.032)
Agro-region [aer2a] 2a (yes = 1)	0.038***	0.964**	0.088***	0.115***	0.129***
	(0.011)	(0.459)	(0.005)	(0.026)	(0.031)
Agro-region [aer2b] 2b (yes = 1)	0.021**	0.479	0.047***	-0.005	0.097***
	(0.009)	(0.437)	(0.010)	(0.005)	(0.027)
Male-headed hh [sex_hh] (yes = 1)	0.005	0.146	0.013*	0.001	0.011
	(0.004)	(0.175)	(0.008)	(0.004)	(0.009)
Age hh head [age_hh]	-0.001	-0.020	-0.002*	-0.001*	-2.5E-04
	(0.000)	(0.016)	(0.001)	(0.000)	(0.001)
Age squared [age2]	6.3E-06	1.4E-04	1.5E-05	7.3E-06*	2.2E-05
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Education hh head [edu_hh]	3.3E-04	-0.023	-0.001	-0.002***	0.001
	(0.001)	(0.020)	(0.002)	(0.001)	(0.001)
Education squared [edu2]	- 9.4E-06	1.4E-04	-9.0E-07	1.2E-04***	-1.1E-04
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Polygamously married [p_married]	-0.001	-0.051	-0.003	0.003	-0.005
	(0.005)	(0.186)	(0.013)	(0.005)	(0.009)
Monogamously married [m_married]	-0.006	-0.022	-0.008	0.003	-0.007
	(0.005)	(0.184)	(0.013)	(0.004)	(0.010)
# adults 14 to 65 years [adults]	0.001	-0.106*	-0.003**	1.8E-04	-0.001
	(0.002)	(0.063)	(0.001)	(0.002)	(0.004)
# adults squared [adults2]	2.0E-04	0.016***	4.6E-04**	-2.5E-05	1.9E-04
	(0.000)	(0.005)	(0.000)	(0.000)	(0.000)
Land size [land_size]	-6.7E-06	0.008	3.4E-04	3.2E-04	2.6E-04
	(0.000)	(0.008)	(0.001)	(0.000)	(0.000)
Land squared [land2]	-9.2E-09	-5.6E-05	-2.4E-06	-1.2E-06	-1.4E-06
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Residuals from first stage IV estimation	-	-	-	0.075***	-
	-	-	-	(0.018)	-
Province fixed effects	*Yes*	*Yes*	*yes*	*Yes*	*yes*
Year fixed effects	*Yes*	*Yes*	*yes*	*yes*	*Yes*
Joint prov. LR test	*58.70****			*242.37****	*239.98****
Joint year LR test	20.93***			*36.78****	*45.91****
Observations	60,958	2,397	60,958	60,958	60,958
Mean of dependent variable	0.04	1.23	0.05	0.02	0.03

Notes: Robust standard errors in parenthesis; ***, ** and * significant at 1%, 5% and 10% respectively; base agro-region, year and province are region-3, 2010, and Western. MT is minimum tillage. Full results for basin and ripping model are available from the authors. Variable names are in square brackets.

Source: Crop forecast surveys 2010 to 2014, authors' computations

4.4.1 Effects of promotion and seasonal rainfall on minimum tillage uptake

Consistent with a priori expectations, we found strong correlations between farmer tillage choices and rainfall variability and the promotion of minimum tillage (Table 4). All else being constant, an additional rainfall stress period increased the likelihood of minimum tillage uptake by 0.05 percentage points, while incidences of floods (above average rainfall) reduced the likelihood of minimum tillage uptake by a similar margin and uptake intensity by 0.01 ha. These results are statistically significant at 1% to 5%. Being in areas in which minimum tillage was promoted increased minimum tillage and ripping uptake intensity by about 0.01 ha, and these results are significant at the 1% and 10% levels of significance. Moreover, the effects are larger at 0.24 ha among farmers already using minimum tillage (Table 4). However, being in promotion areas reduced the intensity of basin uptake by 0.13 ha. Our findings of strong correlations between minimum tillage choices and rainfall variability indicate that farmers appreciate minimum tillage as a way of adapting to droughts, suggesting that minimum tillage maybe a viable option for smallholders to adapt to low rainfall in Zambia. However, the negative results on basin tillage could be because of its arduousness (Rusinamhodzi 2015), which constrains uptake (Thierfelder *et al*. 2015). This is line with the descriptive results in Table 3, which show that, as of 2014, there was more land under ripping than basins in Zambia. In the context of scaling-up uptake, the mixed effects of being in promotion areas on uptake suggest a need for future promotion to review the mix of principles that are promoted to identify what works in particular areas and to adapt interventions.

4.4.2 Other drivers of minimum tillage uptake and uptake-intensity

In line with a priori expectations, farmers in agro-ecological regions 1, 2a and 2b (relative to region 3) were two to four percentage points more likely to use minimum tillage, and the marginal effects on uptake intensity were larger for ripping than for basins (Table 4). These findings corroborate the results of Nyamangara *et al*. (2014) and Thierfelder *et al*. (2015), which suggests that conservation agriculture principles are more beneficial in low rainfall environments. Furthermore, older households and the number of adults reduce the intensity of minimum tillage uptake, and there are significant provincial and year effects on minimum tillage choices (Table 4).

The foregoing empirical results confirm and contradict some of the popular beliefs in the conservation agriculture literature. For example, our finding that the number of adults (labour availability) negatively affects the likelihood of minimum tillage uptake is counterintuitive. On the one hand, this may indicate binding labour constraints and, on the other hand, may reflect the drudgery of the use of family labour in minimum tillage, or that family labour has high opportunity costs. The focus group discussions revealed that it is often difficult to hire in labour for labour-intensive minimum tillage practices like planting basins, as the drudgery involved scares away would-be workers, even when a higher wage is offered. By extension, this suggests that adult family members would opt to work off the farm. Therefore, and in line with Vaiknoras *et al*. (2015), if realised, labour saving from adopting minimum tillage may increase its uptake.

5. Conclusion and implications

This study used national household survey data and spatial rainfall data to assess trends in the uptake of minimum tillage, and factors influencing uptake and uptake intensity among smallholders in Zambia for the period 2010 to 2014. On average, the uptake of minimum tillage as the main tillage was lower than is generally believed, at less than 5% on average and per year at the national level and less than 10% in the top 10 districts with the highest use rates. These results are consistent with concerns stated in the 2013 Nebraska declaration on conservation agriculture, which highlighted the low uptake of conservation agricultural principles among smallholders in sub-Saharan Africa (Stevenson *et al*. 2014). Despite the low and variable minimum tillage uptake rates across years, the trend is positive and increasing over time in Zambia. However, minimum tillage use remained partial, at about 3% of all cultivated land, among smallholders over the study period, and at only about 58% among those using it. The empirical results suggest that rainfall variability and the location of programmes promoting minimum tillage, inter alia, affect farmer choices regarding minimum tillage. The anticipation of low rainfall was associated with increased minimum tillage uptake and uptake intensity, and being in promotion areas increased uptake intensity for some components of minimum tillage.

Two main implications follow from these results. First, there is a need to tailor the future promotion of minimum tillage to the needs of target populations in terms of both the mix of technologies and existing farmer resource constraints. Second, given the growing trend in the use of ripping, and its higher maize yield effects (Ngoma *et al*. 2015), mechanised ripping services, inter alia, could be more accessible to farmers. Future research could assess ripping service provision, develop long-term panel studies to better capture adoption dynamics, and evaluate the impacts of specific promotional programmes on uptake.

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