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Does minimum tillage with planting basins or ripping raise maize yields? Meso-panel data evidence from Zambia

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Abstract

Despite nearly two decades of promoting minimum tillage (MT) in Zambia, there is little empirical evidence on its maize yield effects under typical smallholder conditions. We use nationally representative survey data from nearly 48,000 smallholder maize plots for the period 2008-2011 to estimate the maize yield effects of planting basins and ripping. After controlling for unobserved heterogeneity at the enumeration area level, yields were significantly higher on ripped plots compared to conventionally plowed plots if tillage is done before the rains. The gains average 577 kg/ha nation-wide and 821 kg/ha in low rainfall agro-ecological zones. The gains from planting basins relative to hand hoe tillage average 191 kg/ha when tillage is done before the onset of the rains. Thus, MT with early land preparation can raise smallholder maize yields in Zambia; however, further research would determine whether these yield benefits are large enough to offset the higher costs of MT.

Keywords: *minimum tillage, ripping, planting basins, maize yields, correlated random effects, Zambia*

JEL codes: Q12, Q18, C5

1. Introduction

Food and agricultural systems in sub-Saharan Africa (SSA) are under mounting pressure. Throughout the region, smallholders must increasingly contend with the interrelated challenges of climate change and increasing climate variability, declining soil fertility, and declining land availability. At the same time, rising and more volatile food prices, coupled with increased food demand resulting from population and per capita income growth, place increased pressure on domestic production systems (Deininger, 2013; Laurance *et al.*, 2013). Under these conditions, it is essential to develop strategies to substantially increase crop yields, while at the same time increasing the resilience of rain-fed farm systems to climate variability. Farm productivity levels in SSA suggest that significant opportunities exist to meet this challenge. For example, Deininger (2013) demonstrates that current smallholder productivity is less than 25% of its potential in Africa's sparsely populated countries such as the Democratic Republic of Congo, Zambia, Tanzania and Sudan.

Conservation agriculture (CA) technologies are increasingly seen as a potentially effective strategy to address low agricultural productivity in SSA, while enhancing smallholders' capacity to mitigate and adapt to the effects of climate change (Thierfelder and Wall, 2010; Giller *et al.*, 2011; Friedrich *et al.*, 2012; Verhulst *et al.*, 2012; Corbeels *et al.*, 2014). CA technologies are based on the three core principles of: (i) no or minimal mechanical soil disturbance; (ii) permanent soil cover or crop residue retention; and (iii) crop diversification or rotation (Haggblade and Tembo, 2003).

Despite the potential benefits of CA and almost two decades of active promotion of it in SSA (Umar *et al.*, 2011; Grabowski and Kerr, 2013), CA adoption in the region remains low (Kassam *et al.*, 2009), even in Zambia and Zimbabwe - the two countries that are often highlighted for heightened diffusion of CA technologies (Knowler and Bradshaw, 2007; Giller *et al.*, 2009; Andersson and D'Souza, 2014; Arslan *et al.*, 2014). For example, in the case of Zambia, Arslan *et al.* (2014) found a 5% CA tillage use rate in 2008 while Ngoma *et al.* (2014) found less than

10% minimum tillage use rates between 2008 and 2012 in districts with the highest use rates. These rates are far below the government target of 40% CA adoption by 2016 (GRZ, 2013). Generally, it has been found that less than 1% of cropland is under CA in Zambia and Zimbabwe compared to over 50% in South America (Corbeels *et al.*, 2014). Furthermore, adoption of CA practices in SSA tends to be only partial, with farmers incorporating only one or two of the three core CA principles (Umar *et al.*, 2011; Grabowski and Kerr, 2013; Andersson and D'Souza, 2014). For example, Arslan *et al.* (2014) found that only 3% of the farmers used the two principles of minimum tillage and crop rotation in 2008 in Zambia.

Although current adoption rates are low, the promotion of CA practices remains a cornerstone strategy among some donor organizations in SSA for raising smallholder crop productivity in the context of heightened climatic variability. Yet, the empirical evidence on the productivity impact of CA among smallholder farmers in SSA is mixed (Giller *et al.*, 2009; Andersson and D'Souza, 2014; Brouder and Gomez-Macpherson, 2014). Indeed, if CA is having little or no impact on smallholder productivity, this may be one reason for low uptake of the technology. While some studies suggest that CA offers clear, well-established pathways towards increasing agricultural productivity among resource poor smallholder farmers because it optimizes input use, reduces peak season labor demands and improves water harvesting potential (Haggblade *et al.*, 2011; Friedrich *et al.*, 2012; Umar *et al.*, 2012), other studies question the suitability of CA for real smallholder farm conditions. This latter body of literature contends that there is little empirical evidence that CA raises crop yields under real farm conditions; rather, most of the evidence comes from experimental on-station or on-farm trials, which often involve higher levels of input use, weeding, and other crop management skills than is typical of smallholder farms in SSA (Giller *et al.*, 2009; Andersson and Giller, 2012). Moreover, some studies suggest that, to the extent that CA does offer yield benefits, those benefits may only be realized in the medium to long term (Giller *et al.*, 2009; Thierfelder *et al.*, 2013). This could further discourage CA use among African smallholders, many of whom are thought to have high discount rates and very short planning horizons due to poverty and other factors (Angelsen *et al.*, 1999; Holden and

Lunduka, 2014).[1] The emerging consensus is that CA may improve productivity under some conditions, but that these conditions may not obtain on the majority of African smallholders' farms (Andersson and Giller, 2012). Overall, the empirical evidence base for the productivity effects of CA under real smallholder farm conditions in SSA remains thin.

This paper seeks to bolster that evidence base and contribute to the debate over the suitability of CA for African smallholders by empirically analyzing the maize yield effects of some individual CA technologies using nationally representative survey data from smallholder farm households in Zambia. In particular, the paper examines the yield effects of planting basins and ripping, the two most important minimum tillage CA practices in Zambia.[2] Planting basins are a tillage system with minimal soil disturbance save for permanent planting stations (or basins) dug using manual labor.[3] Ripping is a tillage method where the soil is left undisturbed save for planting stations along rip lines made by animal draft or mechanical-drawn rippers. From this point forward, we refer to planting basins and ripping collectively as minimum tillage (MT). Our focus on ripping and planting basins is justified on the grounds that practicing MT is a necessary condition for any CA-based farming system, and MT is the most prevalent core CA principle in Zambia. The main objective of the paper is to econometrically estimate the *ceteris paribus* effects on maize yields of ripping and planting basins versus conventional tillage methods (especially plowing and hand-hoeing) under typical smallholder farm conditions. We focus on

[1] For further information regarding debates surrounding CA, see http://conservationag.wordpress.com/2009/12/01/ken-gillers-paper-on-conservation-agriculture/ (last accessed August 2014).

[2] Although zero tillage is another variant of minimum tillage CA practiced in Zambia, we focus only on ripping and planting basins in this study because our data do not distinguish between CA zero tillage and a similar traditional shifting cultivation system known as Chitemene. Chitemene is a slash-and-burn system where trees are cut in a large area and then piled on a smaller area and burnt. Crops are then grown in the ash for a few years, before moving on to the next site while leaving old sites in fallow (Holden, 1991). So as not to confound CA minimum tillage and Chitemene, we exclude from the analysis plots reportedly using 'zero tillage'.

[3] These basins are often dug using Chaka hoes into precise grids of 15,850 basins per hectare (Haggblade and Tembo, 2003). Chaka hoes are specifically designed to somewhat ease the digging of deep basins because they have wider blades and are heavier than regular hand hoes (Umar *et al.*, 2012). Some farmers use regular hand hoes to dig planting basins.

maize because it is the country's main staple food and arguably the most economically and politically important crop in Zambia.

Ours is not the first empirical study of the effects of CA tillage methods on maize yields in SSA or Zambia. We categorize the extant literature on this topic into three main categories: (i) those based on experimental plots; (ii) those based on case studies or seasonal snapshots; and (iii) those based on nationally representative observational data but that are not specifically focused on explaining the influence of tillage methods on yields. Fitting in the first category are cross country studies (Rockström *et al.*, 2009; Thierfelder and Wall, 2010) that compare maize yields between CA and conventional tillage plots in Zambia, Tanzania, Kenya and Zimbabwe, and in-country studies that do the same in Malawi (Ngwira *et al.*, 2012; Ngwira *et al.*, 2013) and Zambia (Thierfelder *et al.*, 2013). All of these studies find CA to offer maize yield advantages over conventional tillage based on experimental plots and based on bivariate mean comparisons. Such results are not unexpected given that experimental plots are typically managed by research institutions or CA advocates who supply all the requisite inputs and provide high-end crop management. The question is whether the results obtained on these experimental plots can be replicated under normal smallholder conditions.

In the second category of analysis are studies from Zambia that find that CA tillage systems offer maize yield advantages among a sub-segment of MT adopters (Haggblade and Tembo, 2003; Haggblade *et al.*, 2011; Umar *et al.*, 2011, 2012; Shitumbanuma, 2013; Kuntashula *et al.*, 2014). These studies typically use data drawn from case studies of selected areas where CA has been most promoted (Kuntashula *et al.*, 2014), and normally do not cover more than one agricultural season. Some of these studies also simply focus on MT yield effects, grouping together ripping and planting basins rather than allowing these two fundamentally different tillage methods to have different effects on yields. In the third category is an econometric analysis on nationwide panel data by Burke (2012) on the effect of inorganic fertilizer on maize yields but that also

includes tillage variables as controls. Burke finds no evidence of statistically significant MT effects on maize yields, but MT is not the focus of his study.

The analysis presented in the current paper differs from and compliments these previous studies in three main ways. First, unlike studies in category one whose results may not be a true reflection of on-farm conditions, our study uses farm household survey data that is representative of actual farmer situations. Second, unlike previous studies based on observational data, we attempt to test and control for the potential endogeneity of MT usage to maize yields and also go a step further to estimate the maize yield effects of the individual MT elements of ripping and planting basins as opposed to lumping them together and provide perspectives at national level and for agro-ecological zones 1 and 2a (the two zones most suitable for CA). Third, the current study compliments available case study or seasonal snapshot analyses in category two by using more recent "big" data of nearly 48,000 maize plots from 2008-2011. These data are statistically representative at both national and district levels and are from the Central Statistical Office/Ministry of Agriculture and Livestock - Crop Forecast Surveys. The data are a panel at the standard enumeration area (SEA) [4] level, and are the best data available to give the big picture of MT usage as main tillage at plot level by smallholder farmers in all districts and agro-ecological zones in Zambia. Use of these data rather than the data used in previous analyses is important because: (i) it allows us to analyze the effects of MT on maize yields over a longer time horizon and across the country and beyond CA promotional project sites; (ii) the large sample size allows our analysis to benefit from asymptotic properties thereby reducing many statistical and econometric problems common in small samples; and (iii) it also allows us to exploit the meso-panel data structure of the data and control for some time-constant unobserved factors that may confound the results. Exploiting the higher order panel structure of a national crop survey is also a methodological contribution, and an approach that could be replicated in other countries in SSA.

[4] SEAs typically contain 150-200 households or about 2-4 villages.

The remainder of the paper is organized as follows. Section 2 presents a brief background on CA in SSA with a focus on Zambia. The data and methods are described in sections 3 and 4, respectively. Results are presented in section 5, and conclusions and policy implications are drawn in section 6.

2. Development and productivity impact of conservation agriculture in sub-Saharan Africa

2.1. Development and promotion of CA in sub-Saharan Africa

Many SSA countries have fairly long histories of active CA promotion among small scale farmers (see Andersson and D'Souza (2014) for a readable account on the development of CA in SSA). Despite different initial motives for CA promotion across countries, for example food security-enhancing humanitarian motives in Zimbabwe, agricultural production intensification in Malawi, and addressing land degradation, water scarcity and productivity losses in Zambia (Haggblade and Tembo, 2003; Andersson and D'Souza, 2014), the objectives of increasing agricultural productivity and sustainably intensifying agricultural production are central components of all CA promotion efforts in the region.

In the Zambian context, CA promotional activities started around the 1980s when CA technologies were initially introduced as a package of potential solutions to declining soil fertility and water scarcity, especially in the drier agro-ecological zones (AEZs) 1 and 2a (Haggblade and Tembo, 2003).[5] CA in Zambia is based on the three core principles of no or minimum tillage, permanent soil cover or crop residue retention, and crop rotation or

[5] There are four AEZs in Zambia: AEZ 1 receives less than 800 mm rainfall per year; AEZ 2a has clay soils with 800-1000 mm rainfall per year; AEZ 2b has sandy soils with 800-1,000 mm rainfall per year; and AEZ 3 receives more than 1,000 mm of rainfall per year.

diversification. Planting basins and ripping are the two most commonly practiced forms of minimum tillage in Zambia (Ngoma *et al.*, 2014). The planting stations established under planting basin and ripping tillage systems are supposed to be placed in permanent positions so that farmers can use the same stations year after year, thereby reducing labor requirements after the first year (Haggblade and Tembo, 2003). The permanent planting stations are also thought to optimize input use, improve water retention, and help to build up soil organic matter.[6] CA farmers are encouraged to do the basin or rip tillage operations soon after harvest in the dry season when soils are still somewhat moist (as opposed to waiting until after the first rains to do tillage). Dry season land preparation facilitates early planting, and crops can potentially benefit from the initial nitrogen flush in the soil that comes with the first few rains; it also allows farmers to make use of the greater availability of labor during the dry season (Haggblade *et al.*, 2011). CA crop residue retention involves avoiding burning crop residues and leaving at least 30% of such residues in the fields. Recommended crop rotations involve cereal-legume crop rotations. Legumes are important to replenish soil nutrients, especially nitrogen. Agroforestry is another important aspect of CA and involves intercropping of cereals with nitrogen-fixing tree species such as *Sesbania sesban*.[7]

As in many other SSA countries, CA promotion in Zambia has mainly been donor-driven either through direct support to the government through the Ministry of Agriculture and Livestock (MAL) or through project financing. Longstanding CA advocates in Zambia include the Conservation Farming Unit (CFU) of the Zambia National Farmers Union (ZNFU), the Golden Valley Agricultural Research Trust (GART), World Vision, and Dunavant Cotton (now NWK

[6] See Haggblade and Tembo (2003), and Arslan et al. (2014) for further details on the development and diffusion of CA technologies in Zambia.

[7] The term conservation farming (CF) is also frequently used in the literature and especially in Zambia. Some groups use CF and CA interchangeably while others make a distinction between the two. In the latter case, CF involves minimum tillage practices in conjunction with crop residue retention and crop rotations with legumes, and CA is CF plus agroforestry. The differences are not important in the context of the current paper, and we use the terms CA and CF interchangeably.

Agri-Services Zambia). Other local and international NGOs across the country have also been actively involved in promoting CA through various projects. The Food Agriculture Organization of the United Nations (FAO), the European Union (EU), the Swedish International Development Cooperation Agency (Sida) and the Norwegian Agency for Development Coorperation (Norad) have been keenly involved in promoting CA in Zambia, as in many other parts of the world. Despite this long history of CA promotion in Zambia and much of SSA, evidence of its adoption and productivity impacts remains mixed. The next subsection reviews the evidence on the latter.

2.2. Productivity impacts of CA in sub-Saharan Africa

The emerging consensus in the existing literature is that CA-based farming systems have the *potential* to increase crop yields relative to conventional farming systems *under certain conditions* (Kassam *et al.*, 2009). However, there is less agreement in the literature about the magnitude of the yield impacts and how many years it takes from initial adoption of CA to the realization of yield benefits. For example, recent studies report that significant CA yield benefits accrue after two or more years (Thierfelder *et al.*, 2013; Brouder and Gomez-Macpherson, 2014; Corbeels *et al.*, 2014), with negative to neutral yield advantages in the short term. In Zambia, long-term CA trials by Thierfelder *et al.* (2013) in the southern and eastern parts of the country found that CA-based systems only conferred significant yield advantages after two seasons. In contrast, anecdotal evidence from CA proponents suggests that CA confers immediate yield benefits. The yield advantages conferred by CA are mainly attributed to improvements in water infiltration, soil moisture, soil porosity, soil organic matter, and crop management practices (Thierfelder *et al.*, 2013; Corbeels *et al.*, 2014).

In Zambia, analyses aimed at measuring the on-farm productivity impact of CA technologies have been plagued by challenges in defining CA adoption. For example, some studies on the productivity impact of CA do not mention how CA adoption is defined, for how long adopters

have used the practices, or what proportion of cultivated land is under CA among adopters, while other studies equate adoption of MT to adoption of CA, even if farmers do not practice other principles of CA (see Umar *et al.*, 2011). Such definitions may lead to overestimates of CA adoption by including farmers who are only experimenting with the technologies. While some studies isolate the individual elements of CA, others do not, making it difficult to determine which CA component(s) is (are) responsible for the yield effects.

Evidence on the yield effects of MT in Zambia is mixed. For example, use of basins was found to confer maize yield advantages in (Haggblade and Tembo, 2003; Haggblade *et al.*, 2011; Umar *et al.*, 2011), but not in Burke (2012), while use of MT (in general) was found to increase maize yields in Kuntashula *et al.* (2014). Additionally, "experienced CF adopters" were found to have as much as 2,000 kg/ha yield advantage over less experienced CF farmers and conventional farmers based on bivariate mean comparisons using data collected by taking physical measurements of plot sizes and harvest in Shitumbanuma (2013). Most of the aforementioned studies are based on small samples and seasonal snapshots, and draw their samples from within concentrated CF promotion areas. Others rely on experimental data, which has low external validity and can therefore offer only limited insights on the impacts of CA on real farmer conditions. This paper therefore approaches the productivity impact of CA from an empiricist's perspective while paying particular attention to definitional and estimation issues that may confound extant empirical results.

3. Data

This study uses data from annual Crop Forecast Surveys (CFS) conducted by the Ministry of Agriculture and Livestock (MAL) and the Central Statistical Office for the period 2008 to 2011 (i.e., the 2007/08 through 2010/11 agricultural years). During this period, the CFS was conducted in the same standard enumeration areas (SEAs) each year. The CFS data are the most current and

largest farm household survey data sets available in Zambia, allowing analysis of actual smallholder farm conditions across time and space.[8] The CFS is conducted between February and April each year and collects basic demographic information (household size, and gender, age, and marital status of household members) and detailed information on households' crop production activities (area planted, input use, tillage method, whether land preparation was done before or during the rainy season, etc.). Sampling for the CFSs is discussed below.

A limitation of the CFS data is that it is mainly a production-oriented survey, as opposed to an incomes- or livelihoods-oriented survey; as such, the CFS does not capture highly detailed socio-economic and demographic information. However, the CFS does capture data on the most important maize yield determinants in the Zambian context. We therefore do not anticipate major issues with omitted variable bias. A second limitation of the CFS data is that the survey is conducted before harvest but after maize plants have reached physiological maturity; production quantities are therefore based on farmers' estimates of how much they expect to harvest (as opposed to actual quantities harvested). Fortunately, comparisons of farmers' production estimates in the CFS to actual production quantities captured in post-harvest surveys suggest only small and non-systematic differences between expected and actual production (Zulu and Sitko, 2014)[9]. It has been argued that another potential limitation of large scale surveys like CFS relates to the survey design effects where the sampling protocols used do not take into account the clustering of agricultural technologies like CA (Grabowski *et al.*, 2014). We do not see this to be a problem with the CFS because these surveys are statistically representative at district level which allows analysis to be scaled down even to agro ecological zones (as done in this paper later on). Despite these limitations, we think that the CFS data are the best data available to

[8] Smallholder farm households are defined as those cultivating less than 20 ha of land.

[9] We use data from the CFS instead of from the Supplemental Survey (SS), a three-wave household-level longitudinal survey of smallholders, because those data are more dated (they cover the 1999/2000, 2002/03, and 2006/07 agricultural seasons) and are not representative at the district level. The CFS data are more recent and are representative at the district level. The CFS better captures changes over time and space in the use of CA in Zambia. The tradeoff is that while the SS data would allow us to control for time-constant unobserved effects at the household level, the CFS data only allow us to control for such effects at the SEA level.

address the core research question of this study (what are the *ceteris paribus* effects of ripping and planting basins on maize yields in Zambia) because the CFS data provide the most up-to-date, widest and statistically representative coverage of smallholder farmers at national, provincial, and district levels in Zambia.

In the econometric analysis, we supplement the CFS data with *dekadal* (10 day period) rainfall data from 36 rainfall stations throughout the country from the Zambia Meteorological Department. Descriptive results are from the CFS as well as from the 2008 Supplemental Survey (SS) and the 2012 Rural Agricultural Livelihoods Survey (RALS), both of which are nationally representative surveys of smallholder farm households. See Mason and Tembo (2014) for details on the SS and RALS. In the discussion of the results, we also draw on information collected during focus group discussions (FGDs) held with 57 farmers in Chipata, Choma and Chongwe districts in August 2014. Of these 57 farmers, 27 were consistent users of CA each year since 2009; the remaining 30 either never used CA or used it in only a subset of years. We held separate FGDs with each of the three farmer groups in all the districts visited. The three districts in which the FGDs were conducted had some of the highest variability in MT use rates in Zambia between 2008 and 2012 (Ngoma et al., 2014). Participants in the focus group discussions were selected with the help of camp extension officers in the districts.

3.1. Sampling

Sampling for the 2008-2011 CFSs was based on the 2000 Census of Housing and Population. The sampling frame mainly included rural SEAs, but urban SEAs with 70% or more of their households engaged in agricultural activities were also included. A two-stage cluster sampling scheme was used. In the first stage, 680 SEAs were selected out of a total of 12,789 SEAs nationwide using probability proportional to size, with the number of agricultural households serving as the measure of size. At the second stage, all households in selected SEAs were listed and agricultural households identified. Listed agricultural households were then stratified into three categories, A, B and C, on the basis of total area under crops; presence of some specified

special crops; numbers of cattle, goats and chickens raised; and sources of income. Systematic sampling was then used to select 20 households distributed across the three strata in each SEA. This resulted in a total national sample size of 13,600 households per year and a total of 51,156 maize plots between 2008 and 2011.

3.2. Data processing and caveats

We put the data through a series of filters to prepare it for use in the analysis. Starting with 51,156 maize plots owned by 37,169 households in panel SEAs between 2008 and 2011, we dropped 5% of the fields with seed rates exceeding 100 kg/ha; 0.08% which did not report any seed used; 0.7% with yields greater than 8000 kg/ha; 0.4% and 0.1% with basal and top dressing application rates, respectively, exceeding 400 kg/ha; and two fields that were larger than 20 ha. These cutoff points were determined on the basis of reasonable input use and yield rates in Zambia, and on the basis of recommendations by MAL. [10] Altogether, these changes resulted in the exclusion of 3,197 maize plots (or 6.2% of the original sample), bringing the analytical sample to 47,959 total maize plots. This data filtering is within acceptable levels; for example, Sheahan *et al.* (2013) excluded 9.7% of observations from their original sample after implementing similar cutoffs for a study of factors affecting maize yields in Kenya.

4. Methods

4.1. Conceptual Framework

The main objective of this paper is to estimate the *ceteris paribus* effects of planting basins and ripping on smallholder maize yields in Zambia. This is accomplished through econometric estimation of a maize production function following Xu *et al.*, (2009) and Burke (2012) for Zambia, and Sheahan *et al.*, (2013) for Kenya. The general production function is specified as

[10] The recommended maize seeding rate in Zambia is 20 kg/ha, and the recommended fertilizer application rates are 200 kg/ha each of basal and top dressing. Fields larger than 20 ha were excluded because these exceed the definition of a smallholder farmer (i.e., those cultivating less than 20 ha of land).

(1) $y = f(\boldsymbol{tillage}, \boldsymbol{X}, \boldsymbol{Z})$

where y is field-level maize yield in kg per ha; ***tillage*** is a vector of dummy variables capturing the tillage method used on the field (i.e., planting basins, ripping, and various conventional tillage methods), and capturing the timing of when tillage was done (i.e., before or during the rainy season); ***X*** is a vector of other yield determinants controlled by the farmer (e.g., use of hybrid seed, fertilizer application and seeding rates, labor quantity and quality, etc.); and ***Z*** is a vector of strictly exogenous yield determinants such as rainfall and other agro-ecological conditions (Burke, 2012). The specific variables included in ***tillage***, ***X***, and ***Z*** are discussed in detail in the next sub-section. A quadratic functional form is used for the production function in equation (1). As discussed in Sheahan *et al.*, (2013), the quadratic functional form is generally thought to be a good approximation of the underlying data generating process of crop yields and is frequently used in analyses of crop yield response in developing countries. See Burke (2012) and Xu *et al.* (2009) for other applications of the quadratic production functions in yield estimation in Zambia.

4.2. Empirical model

Bringing equation (1) to the data, we represent the empirical model as:

(2) $y_{sij} = \boldsymbol{tillage}_{sij}\boldsymbol{\beta}_1 + \boldsymbol{X}_{sij}\boldsymbol{\beta}_2 + \boldsymbol{Z}_{sij}\boldsymbol{\beta}_3 + \boldsymbol{year}\boldsymbol{\beta}_4 + c_s + u_{sij}$,

where y_{sij} is the maize yield in kg/ha in SEA s for household i on plot j, and we have excluded time-subscripts to indicate the fact that the data are a panel at the SEA-level and not at the household- or plot-level. ***tillage***, ***X***, and ***Z*** are defined as in equation (1) above; ***year*** is a vector of year dummies; c_s is unobserved time invariant SEA-level heterogeneity; u_{sij} is the idiosyncratic error term; and the $\boldsymbol{\beta}$'s are parameters to be estimated.[11]

[11] To keep the notation simple, we have also excluded the squared and interaction terms from equation (2) but they are included in the estimated models.

The specific explanatory variables included in the production functions estimated here were selected based on previous studies on the determinants of smallholder maize yields in eastern and southern Africa (Xu *et al.*, 2009; Burke, 2012; Sheahan *et al.*, 2013), agronomic principles of maize production in Zambia, and data availability. Table 1 presents summary statistics for the variables used in the regressions. The dependent variable, plot-level maize yield, averaged 1,796 kg/ha over the four-year study period.

[Table1]

Included in ***tillage***, the vector of tillage-related variables, are separate dummy variables equal to one if the plot was tilled using planting basins, ripping, plowing, bunding, or ridging. Conventional hand hoe tillage is the base tillage method and so its dummy variable is excluded from the regression models. As indicated in Table 1, the vast majority of maize plots were tilled using conventional tillage methods: 31%, 33%, and 28% were tilled by hand hoe, plowing, and ridging, respectively. About 2% of plots were tilled via bunding, and only 1% of plots each were tilled with ripping and planting basins. Also included in ***tillage*** is a dummy equal to one if the field was tilled before the onset of the rainy season, and equal to zero if the field was tilled during the rainy season. Overall 30% of the plots in the sample were tilled before the rains (Table 1) while 52%, 23%, 12% and 43% of all plots tilled with basins, ripping, plowing and hand hoeing , respectively, had tillage done before the rains. These average to about 25% for all tillage options in agro-ecological zones 1 and 2a. Recall that dry season land preparation is encouraged under CA to facilitate early planting and so that maize plants can benefit from the nitrogen flush associated with the first few rains of the season (Haggblade *et al.*, 2011). To capture potential differential effects of tillage method on yields depending on when tillage is done, we interact the tillage method dummies with the tillage-before-the-rains dummy.

Included in ***X***, the vector of other yield determinants under the control of the farmer, are basal and top dressing inorganic fertilizer application rates (kg/ha), whether hybrid maize seed was used (=1), and the seeding rate for all types of seed (kg/ha). On average, households used 61

kg/ha of basal dressing, 63 kg/ha of top dressing, and 21 kg/ha of maize seed. These fertilizer rates are lower than the recommended rates of 400 kg/ha but the seeding rates are close to the recommended seeding rate of 20 kg/ha (GRZ, Undated). Overall, less than half of the smallholder population used fertilizer and hybrid seed over the study period. *A priori*, increases in the fertilizer and seed application rates are expected to increase maize yields up to a point, beyond which decreasing marginal returns are likely to set in. The quadratic functional form allows for such effects. Our models also include interactions between basal and top dressing fertilizer to capture the effects of combined fertilizer application. We include interactions of hybrid seed use and fertilizer application rates to capture the combined effects of improved input use.

Also included in $\boldsymbol{X}$ are the area of the plot (ha), and proxies for household labor quantity and quality, namely: the number of adults age 15-65 in the household size (3.94 on average); the age of the household head (44 years on average) – older household heads may have more farming experience but may be less amenable to new management practices such as MT; a dummy equal to one if the household is male-headed (79% of the sample); and dummies for whether the household head is monogamously married (70%) or polygamously married (7%) – the remaining household heads are not married. We hypothesize that households with heads that are polygamously married might have more family labor available for maize production than households with monogamously married heads. Households with married households heads might have more family labor available than households with unmarried heads. The CFS data do not consistently capture information on labor input to maize production, so we use the marital status variables and number of adults as proxies.

Included in $\boldsymbol{Z}$, the vector of yield determinants that are strictly exogenous to the household, are growing season rainfall in millimeters (November to March) and a variable capturing rainfall stress periods measured as the number of 20-day periods during the growing season with less than 40 mm of rainfall. The former is expected to increase yields up to a point, while the latter is

expected to reduce yields. We also control for different soil and rainfall conditions by including dummies for AEZs 2a, 2b, and 3 (with AEZ 1 serving as the base). Year dummies (***year*** in equation 2) are included in the empirical model to control for year-specific yield effects.

Due to data limitations, we are not able to explicitly control for the number of times a plot is weeded, whether or not the plot is irrigated, or the use of herbicide, other crop protectants, or lime on the plot. To a certain extent, the labor quantity-related variables serve as proxies for the number of weedings. Very few smallholder plots in Zambia are irrigated, and use of herbicide, crop protectants, and/or lime is very rare among Zambian smallholders. There is also evidence suggesting that the majority of farmers using herbicides are under- and mis-applying it (Umar *et al.*, 2011).

We also do not observe in the CFS data the number of years in which a given plot has been under planting basins or ripping. Thus, our estimates of the *ceteris paribus* effects of these tillage methods on maize yields should be interpreted as average effects for plots currently under the tillage method.

4.3. Estimation strategy

The empirical model is linear in parameters and is estimated via pooled ordinary least squares with standard errors clustered at the SEA level. We estimate models using all observations (national-level model) as well as models using only observations from the two AEZs where CA has been most heavily promoted and is arguably most suitable (AEZs 1 and 2a).

The major econometric challenge in estimating the causal effects of planting basins and ripping on maize yields is the potential endogeneity of farmers' tillage method choices. Tillage methods are not randomly assigned to households or fields, and there may be systematic correlation between farmers' use of planting basins and ripping (and other tillage methods and inputs) and unobserved factors affecting maize yields. For example, farmers that are more motivated or progressive, or have greater farming skill or management ability, may be more likely to adopt planting basins or ripping, but would likely have higher yields than other farmers even if they used conventional tillage methods. (We use the age and gender of the household head to proxy for these factors.) As a second example, use of MT on a given plot could be correlated with unobserved plot-level factors such as soil quality that also affect yields. To address these concerns, we control for as many observed plot- and household-level maize yield determinants as possible given the available data. While we are somewhat constrained in what we can do to address the potential endogeneity of the observed explanatory variables in equation (2) given that we do not have plot- or household-level panel data, we do have SEA-level panel data. We take advantage of this data structure to control for time invariant SEA-level heterogeneity (c_s) using a correlated random effects (CRE) approach. We also use an instrumental variables/control function approach to test for remaining endogeneity of planting basins and ripping even after controlling for c_s. These two approaches are described in the next two sub-sections.

4.3.1. Controlling for SEA-level unobserved heterogeneity using correlated random effects (CRE)

We take advantage of the SEA-level panel structure of the CFS data to control for SEA-level time-invariant unobserved factors affecting maize yields that could be correlated with the observed yield determinants (e.g., average farming management ability, motivation, soil quality, and agro-ecological conditions in a household's SEA). We take a Mundlak-Chamberlain device/CRE approach to controlling for c_s (Mundlak, 1978; Chamberlain, 1984).[12] For simplicity, let $\boldsymbol{W}_{sij}$ represent all the time-varying covariates in equation (2), and recall that s indexes the SEA, i indexes the household, and j indexes the plot. Under the CRE approach, c_s is assumed to be a function of the SEA-level averages (across all time periods) of the time-varying covariates, i.e., $c_s = \psi + \bar{\boldsymbol{W}}_s \boldsymbol{\xi} + a_s$, where $c_s \mid \boldsymbol{W}_s \sim Normal(\psi + \bar{\boldsymbol{W}}_s \boldsymbol{\xi}, \sigma_a^2)$, σ_a^2 is the conditional variance of a_s, and γ and ξ are parameters. Under these assumptions and strict exogeneity, we can control for c_s by including the SEA-level time averages, $\bar{\boldsymbol{W}}_s$, as additional regressors in equation (2).[13] See Wooldridge (2010) for further details on the CRE approach to controlling for time invariant unobserved heterogeneity.

4.3.2. Testing for remaining endogeneity of minimum tillage choices

While the CRE approach described above allows us to control for correlation between the time-invariant SEA-level heterogeneity and plot- or household-level unobserved factors affecting

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[12] While a fixed effects (FE) approach would also have been possible, a CRE approach is generally preferred when using meso-panel data with time-varying sampling weights, as in the current application (personal communication, J. Wooldridge, June 2014). Nonetheless, as a robustness check, we estimated the models without sampling weights using both FE and CRE approaches and the results are very similar. Note that both the FE and CRE approaches allow the unobserved time invariant heterogeneity and the observed covariates to be correlated. This is a key difference between the CRE and 'regular' random effects approaches.

[13] As an example, the SEA-level time average of the planting basins dummy would be the proportion of maize plots in the SEA under planting basins over the 2008-2011 study period.

maize yields (c_s), there still may be correlation between the farmer's choice of tillage method and timing (***tillage***) and input use decisions (***X***), and the idiosyncratic error term (u_{sij}). This is a common challenge in estimating production functions because most right-hand-side variables are under the control of the farmer. While some authors acknowledge this potential endogeneity, possibly use CRE, and move on (e.g., Xu et *al.*, 2009, and Sheahan *et al.*, 2013), others try to go further and combine the CRE approach with instrumental variables or control function techniques to test and control for the endogeneity of the key covariate(s) of interest (e.g., Burke (2012) for inorganic fertilizer). In our study, the key covariates of interest are the planting basins and ripping dummy variables. We attempted to follow the latter approach by using a control function approach (Wooldridge, 2010) and instrumenting for a farmer's use of planting basins with a dummy variable equal to one if the household is in a district where the CFU has promoted CA and equal to zero otherwise; and by instrumenting for ripping using a dummy variable equal to one if the household is in a district where Dunavant Cotton/NWK Agri-Services Zambia has promoted CA and equal to zero otherwise.[14] The argument for these IVs is that CFU's and Dunavant's choice of where to promote CA should be exogenous to plot-level yields after controlling for observed input use levels (***X***), other observed factors (***Z***), and SEA-level time invariant unobserved heterogeneity. CFU and Dunavant promotion of CA is likely to affect a farmer's decision to use planting basins or ripping but is unlikely to be correlated with the idiosyncratic plot-level error term in the yield function. Unfortunately, these IVs were only weakly correlated with farmer's use of planting basins and ripping ($0.05 < p < 0.10$). Nonetheless, inclusion of the control function residuals in the yield functions suggested that ripping and planting basin decisions are exogenous to maize yields after controlling for the aforementioned observed and unobserved factors.[15] Given these indicative results that ripping

[14] Household- or plot-level IVs would have been better but no such IVs are available.
[15] These results are available from the authors upon request.

and planting basins are exogenous, and to avoid the bias and inconsistency created by weak IVs (Cameron and Trivedi, 2010), we did not pursue this approach further.

5. Results

5.1. Descriptive results

5.1.1. Are there systematic differences between minimum tillage plots and conventional tillage plots in maize yields and key determinants thereof?

As a prelude to the econometric results of the paper, the bivariate mean comparisons in Table 2 seek to answer the question of whether there are systematic differences between MT and non-MT plots in terms of maize yields and/or the main covariates used in the econometric analysis. Based on these bivariate comparisons, there is no statistically significant difference between yields on MT and non-MT plots.[16] Among the explanatory variables, the only statistically significant difference among MT and non-MT plots was in the gender of the household head (MT plots had a slightly higher percentage of male-headed households (83%) compared to non-MT plots (79%)).

[Table 2]

Although there are no statistically significant differences between mean yields on MT and non-MT plots in general, there may be differences between specific MT practices and their conventional tillage counterparts – i.e., between planting basins and hand-hoed plots, and/or between ripped and plowed plots. We explore these differences using first order stochastic dominance tests following Tatwangire (2011). Figure 1 shows the cumulative distribution functions (CDF) of maize yield under the different tillage options. The ripping CDF does not lie to the right of the plowing CDF at all yield levels, suggesting that ripping does not first-order stochastically dominates plowing.

[16] Throughout the paper and unless otherwise specified, we use $p<0.10$ as the cutoff of statistical significance.

While Figure 1 suggests that ripping might offer a yield advantage over plowing, the figure suggests that yields on planting basin plots (without controlling for other factors) are consistently below the yields on conventional hand-hoed plots. This is evident from the planting basins CDF consistently lying to the left of the hand-hoe CDF.

[Figure 1]

5.2. Econometric results

While the descriptive results in Figure 1 are interesting and suggest that there may be yield advantages associated with ripping and yield disadvantages associated with planting basins, we cannot infer causality from the descriptive results because other factors that affect yields may be changing along with the tillage methods. In contrast, the multivariate econometric analysis allows us to isolate the effects of planting basins and ripping by holding other factors constant. In the econometric analysis, we estimated three different specifications of the model in equation (2). The first specification (spec.1) excludes interaction and squared terms. The second specification (spec.2) includes interactions and squared terms for many of the variables but excludes interactions between the tillage method dummies and fertilizer application rate variables. The third specification (spec.3) is similar to spec.2 but includes tillage-fertilizer interactions. The results are robust to alternative model specifications, so we focus our discussion of the results mainly on spec.3, which is the most fully elaborated model. The estimated average partial effect (APE) of each covariate is reported in Table 4. Each table reports the results from the national and AEZs 1/2a models. Because of the large number of interactions and squared terms included in spec.2 and spec.3, caution must be exercised when interpreting individual coefficient estimates[17]. If one is interested in the overall effect of a given variable (e.g., the basal dressing fertilizer application rate), one should refer to the APE in Table 4 and not simply to the parameter estimate on that variable (e.g., the coefficient on *brate*).

[17] Not included here but coefficient estimates are available from the authors

[Table 4]

The APEs in Table 4 suggest that, overall, maize yields on plots using planting basins are not statistically different from the yields on plots using conventional hand hoe tillage, *ceteris paribus*. We therefore conclude that, compared to hand hoe tillage, use of basins *in and of itself* does not significantly increase maize yields in Zambia.[18] This result does not necessarily condemn use of basins but merely shows that after controlling for input use, labor availability, rainfall conditions, and various important agronomic interactions, improper use of planting basins – which results in late planting and additional weedpressure -- does not confer yield advantages over hand hoe tillage, on average. In contrast, the APEs for all specifications in Table 4 suggest statistically significant and positive ripping effects on maize yields, even after controlling for other factors. For example, at national level and in AEZs 1/2a, respectively, the maize yields on ripped plots are 234 kg/ha and 330 kg/ha higher than on conventional hand hoed plots. Moreover, compared to yields on plowed plots, yields on ripped plots are 238 kg/ha and 332 kg/ha higher at national level and in AEZs 1/2a, respectively (Table 4).

Although the overall effects of planting basins are not statistically significant, the positive and statistically significant interaction effect between planting basins and tillage before the rains suggest that planting basins have a more positive effect on yields when tillage is done *before* the rains. For example, in the national model (spec.3), the yield boost from planting basins over conventional hand-hoe tillage is 371 kg/ha larger when tillage is done before the rains than when tillage is done after the rains. A similar result holds for the AEZs 1/2a model (spec.3) . We used the spec.3 regression results to simulate the marginal effects of planting basins on maize yields (compared to conventional hand-hoeing) when tillage is done before versus after the rains. These

[18] Timing of basin tillage, how well basins are done, timely planting and input use are key. How long the planting basins have been in place could also affect the yield impacts thereof. However, as mentioned above, the data do not include information on the latter.

results are reported in panel A of Table 5 and suggest that when tillage is done *before* the rains, planting basins result in yield gains over conventional hand-hoeing of 191-194 kg/ha. This result is statistically significant at the 10% level in the national results but only weakly significant in AEZs 1/2a (p=0.17). When tillage is done *after* the rains, yields are 179 kg/ha and 168 kg/ha *lower* on planting basin plots than hand-hoed plots in the national-level and AEZs 1/2a models, respectively (Table 5, panel A). These results provide some evidence that when tillage is done early, planting basins can raise smallholders' yields relative to conventional hand-hoeing. This finding is consistent with the notion that dry season land preparation under CA facilitates early planting and allows maize plants to benefit from the nitrogen flush associated with early rains (Haggblade *et al.*, 2011).

There are at least three explanations for the finding that maize yields are lower under planting basins than conventional hand hoe when tillage is done during the rains. First, it may not be easy for farmers to dig basins to the required dimensions during the rainy season especially under water logged conditions and in clay loamy soils. This has implications on attainment of optimal plant populations and input use. Second, digging basins after the onset of the rainy season may lead to late planting which may negatively affect yields. And third, hand hoe farmers are likely to use conventional hand hoe tillage compared to basins (if tillage is done after the onset of the rains) because the former also helps clear all emerging weeds since it involves complete tillage of the entire soil surface (especially for farmers without access to herbicides).

Does the timing of tillage affect the impacts of ripping on maize yields, as it does for planting basins? Our results suggest that it does. The statistically significant, positive interaction effect between ripping and the timing of tillage variables provide evidence of such effects. More specifically, ripping yield gains over plowing are 481 kg/ha and 653 kg/ha larger when practiced before the rains compared to after the rains at the national and AEZ 1/2a levels, respectively . As was done for planting basins, we also used the results to simulate the marginal effects of ripping on maize yields (compared to conventional plowing) when tillage is done before versus after the

rains. These results are summarized in panel B of Table 5 and show that yields on ripped fields are 627-814 kg/ha higher than on plowed fields when tillage is done before the rains, *ceteris paribus*. This result is highly statistically significant ($p<0.01$) in both the national and AEZs 1/2a models. However, when tillage is done after the rains, there is no statistically significant difference between yields on ripped plots versus plowed plots. In other words, like planting basins, ripping only confers yield benefits over its conventional analogue when tillage is done before the rains.

[Insert Table 6]

Our findings that combining MT with early land preparation (early planting) boosts yields are consistent with the CA literature (Haggblade *et al.*, 2011) and are consistent with farmer experiences from the focus group discussions (FGDs). Our econometric results for ripping corroborate bivariate findings in (Umar *et al.*, 2011, 2012; Thierfelder *et al.*, 2013) that indicate ripping provides yield benefits over conventional plowing. Our results are contrary to econometric results in Burke (2012), who finds that use of basins and ripping had no statistically significant on yields. Our results are somewhat different from those of Hagglade and Tembo (2003), who find positive planting basin effects but no ripping effects on yields. Our econometric results for basin tillage are also in contrast to bivariate results for planting basin tillage in Umar *et al.* (2011) that indicate higher maize yields on basin tilled plots compared to hand hoe tilled plots. A plausible explanation for these differences in the results may be the omission of key interaction terms involving all tillage options, timing of tillage, and fertilizer application rates in Burke (2012) and Haggblade and Tembo (2003), and the failure to control for other yield determinants in the studies that rely on bivariate mean comparisons. Other potential reasons for the differential yield effects of ripping and basins depending on the timing of the tillage may be associated with differing knowledge requirements of the two MT tillage options. Planting basins have to be dug to specific dimensions using hand hoes and few farmers manage

to follow the specifications to the letter as was found in Umar *et al.* (2012) and Haggblade and Tembo (2003). This was also confirmed by farmers during the FGDs where it was mentioned that yield benefits are realized only if basins are dug to specifications and all field operations done on time.

If ripping confers higher yields than plowing on average (Table 4) and when tillage is done before the rains (Table 5), and planting basins confer higher yields than conventional hand-hoe when tillage is done before the rains, *ceteris paribus*, why are so few farmers practicing MT? Two major explanations are farmers' resource constraints and resistance to change. Adopting MT requires higher financial resources to address the higher weed pressure under MT. For example, farmers mentioned during the FGDs that they weed up to three times on MT plots compared to only once on plowed or hand-hoed plots per season. They added that MT plots had higher weed pressure because of reduced tillage at land preparation. The majority of the farmers resort to using family labor for weeding because they can neither afford to hire (that much) labor nor buy herbicides. And even among the few (ca. 2% according to RALS12) who buy herbicides, there are still knowledge gaps on appropriate application and handling. Similar results are reported in Umar *et al.* (2012).

Other potential impediments to increased adoption of MT relate to challenges of keeping residues on the fields. This is because these fields are open grazing land during the dry season under the prevalent communal land tenure systems. Another major problem especially when MT is done early in the dry season relates to basins and rip lines being trampled or buried by free-range livestock during the dry season. This necessitates redoing the basins and rip lines just before the rains, which adds to the high labor demands under MT. Moreover, dry season land preparation is very arduous on the dry, hard soils (especially when tillage is done just before the rains instead of shortly after harvest). This could further discourage use of planting basins and ripping, and, as our results in Table 5 show, if farmers wait to prepare planting basins or rip lines until after the rains, the yield benefits of MT evaporate.

Because of these challenges, few farmers have adopted MT and even among the adopters, the majority use MT on smaller portions of their total cropped land. Another major impediment that came out of the FGDs is the farmer's mindset: wealthy farmers see basin tillage as an ancient poor mans' technology, and other farmers have an entrenched belief in plow tillage. A participant during the FGDs summarized the latter thought by saying "*plow nipatali*" meaning plow tillage is the best. Because farmers cultivate larger areas (and hence have higher total production) with conventional hand-hoe or plow tillage compared to MT, they suggested that the per unit yield advantages from MT do not seem adequate to cover the costs of scaling up MT use to the farm level.

For ripping, another constraint to adoption could be limited availability of rippers or ripping services. As shown in Table 6, which presents descriptive results from the 2008 SS and 2012 RALS on receipt of extension information related to CA and on ripper ownership, as of 2012 less than 3% of smallholder households owned a ripper, even in the major MT agro-ecological zones, 1 and 2a. At the SEA level (typically 2-4 villages), ripper ownership increased from 2008 to 2012 but even in AEZs 1 and 2a, only 45% of SEAs contained at least one household that owned a ripper as of 2012. Further research is needed to understand the availability and affordability of ripping services.

Access to information on MT could also constrain its practice. As shown in Table 6, as of 2008, only 28% and 19% of Zambian smallholder farmers had ever received extension information on planting basins and ripping, respectively. These percentages were higher in AEZs 1 and 2a but the majority of farmers in these areas had not received information on MT as of 2008. By 2012, the percentage of farmers that had ever received extension advice on CF had risen to 50% nationally and 62% in AEZs 1 and 2a. So the word on CF is gradually getting out but as of yet, this has not translated into high MT use rates.

Moving beyond the tillage method effects on maize yields, the results for the other covariates in equation (2) are generally consistent with *a priori* expectations. Using hybrid maize seed

significantly increased average maize yield by 146 kg/ha and 135 kg/ha at national level and in AEZs 1/2a, respectively (Table 4). Similar positive effects of hybrid seed use on yield are reported in (Xu *et al.*, 2009; Burke, 2012) for Zambia, and in Sheahan *et al.* (2013) for Kenya. Additionally, results suggest that average maize yield increases by 3-4 kg and 5 kg per additional kg of basal and top dressing fertilizer, respectively (Table 4).

Results in Table 4 suggest the existence of a negative plot size-productivity relationship among smallholder farmers in Zambia. Increasing plot area by one hectare significantly reduces average maize yields by 40 kg/ha and 44 kg/ha at national level and in AEZs 1/2a, respectively. Additionally, all else constant, an increase in the number of rainfall stress periods significantly reduced maize yields by 40 kg/ha on average at national level. These results bring to light the need to adapt agricultural systems to cope with increasing rainfall variability in Zambia as highlighted in Chabala *et al.* (2013) and are also in line with findings in Lobell *et al.* (2008) that yields in SSA are projected to decline by 30% owing to climate variability.[19]

In summary, our overall results (Table 4) suggest that use of rip tillage confers statistically significant maize yield benefits over common conventional tillage options (especially plowing and hand hoe). Moreover, we found that both ripping and planting basins confer yield benefits over their conventional counterparts (plowing and hand-hoeing, respectively) when tillage is done before the rains, but not when tillage is done after the rains (Table 5).

6. Conclusions and Policy Implications

Raising agricultural productivity to meet growing food demands while increasing the resilience of rain-fed farm systems to climate variability is perhaps one of the most pressing contemporary development challenges in sub-Saharan Africa. Conservation agriculture (CA) technologies have been actively promoted over the last two decades as potential solutions to these problems in the

[19] We tested for interaction effects between minimum tillage methods and the rainfall stress variable but found no statistically significant effects.

region. Our results suggest that minimum tillage dimensions of CA practices offer viable options for improving smallholder cereal yields.

After controlling for time invariant unobserved heterogeneity at the enumeration area level by applying the correlated random effects-pooled ordinary least squares estimator to nationally-representative survey data from nearly 48,000 smallholder maize plots from 2008-2011, we find positive maize yield gains from minimum tillage over conventional tillage methods when tillage is done before the onset of the rains. Relative to tillage before versus after the onset of the rains, rip tillage conferred average maize yield gains of 577-821 kg/ha over conventional plow tillage, while basins tillage conferred average maize yield advantages of 191-194 kg/ha over conventional hand-hoe tillage. These results reinforce the importance of early land preparation and planting to maize productivity and highlight the overall potential significance of minimum tillage to improving smallholder productivity in Zambia and the region. Results also suggest that the realizable *ceteris paribus* yield gains of minimum tillage under smallholder farm conditions are only attainable if farmers do early land preparation and presumably plant early. While the results in this paper suggest that minimum tillage could help to raise maize yields in Zambia, further analysis is needed to establish whether these yield gains are large enough to offset the potentially higher costs associated with minimum tillage.

Given the main findings of the paper that minimum tillage can boost yields over conventional tillage methods if tillage is done before the onset of the rains, there is need to emphasize this critical factor in extension messaging about ripping and planting basins. Moreover, although extension messaging about CA had reached approximately 62% of Zambian smallholders in the drier agro-ecological zones 1 and 2a by 2012, additional extension efforts are needed to further spread information about CA and to demonstrate its potential benefits where the technologies are appropriate. Finally, given the larger yield benefits of ripping over conventional plowing (compared to the yield benefits of planting basins over conventional hand-hoeing), policies and

programs to improve the availability and accessibility of rippers and ripping services could play a key role in boosting smallholders' maize yields in Zambia.

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Tables and Figures

Table 1: Variables used in the econometric analysis

Variable	Description	Mean	Std. dev.	p10	p25	p50	p75	p90
yield	Maize yield (kg/ha)	1796.52	1460.26	283.95	690.00	1419.75	2555.56	3904.32
age_hh	Age of hh head (years)	43.84	14.45	27.00	32.00	41.00	53.00	65.00
sex_hh	Male hh head (=1)	0.79	0.41	0.00	1.00	1.00	1.00	1.00
p_married	Polygamously married (=1)	0.07	0.26	0.00	0.00	0.00	0.00	0.00
m_married	Monogamously married (=1)	0.70	0.46	0.00	0.00	1.00	1.00	1.00
adults	# adults 14 - 65 years	3.94	2.50	2.00	2.00	3.00	5.00	7.00
b_fert	Used basal fertilizer (=1)	0.43	0.50	0.00	0.00	0.00	1.00	1.00
tp_fert	Used top fertilizer (=1)	0.45	0.50	0.00	0.00	0.00	1.00	1.00
brate	Basal fertilizer rate (kg/ha)	60.50	87.38	0.00	0.00	0.00	100.00	200.00
tprate	Top fertilizer rate (kg/ha)	62.74	87.46	0.00	0.00	0.00	123.46	200.00
seedingrate	Seed rate (kg/ha)	21.06	17.16	4.68	10.00	17.40	25.00	46.40

hyb_seed	Used hybrid seed (=1)	0.45	0.50	0.00	0.00	0.00	1.00	1.00
aez3	AEZ 3 (=1)	0.34	0.21	0.00	0.00	0.00	1.00	1.00
aez2a	AEZ 2a (=1)	0.48	0.07	0.00	0.00	0.00	1.00	1.00
aez2b	AEZ 2b (=1)	0.07	0.50	0.00	0.00	0.00	0.00	0.00
aez1	AEZ 1 (=1)	0.11	0.47	0.00	0.00	0.00	0.00	1.00
rain	Season rainfall (mm)	1020.46	0.50	666.00	792.00	982.00	1172.00	1329.00
rain_stress	Rainfall season stress periods (#)	1.03	0.25	0.00	0.00	1.00	2.00	3.00
plot_size	Plot size (ha)	0.93	0.31	0.25	0.38	0.60	1.00	2.00
t_till	Tillage before rains (=1)	0.30	0.46	0.00	0.00	0.00	1.00	1.00
bund	Used bunding (=1)	0.02	0.14	0.00	0.00	0.00	0.00	0.00
ridge	Used ridging (=1)	0.28	0.45	0.00	0.00	0.00	1.00	1.00
pl_basins	Used planting basins (=1)	0.01	0.12	0.00	0.00	0.00	0.00	0.00
ripping	Used ripping(=1)	0.01	0.08	0.00	0.00	0.00	0.00	0.00
plow	Used plowing (=1)	0.33	0.47	0.00	0.00	0.00	1.00	1.00
hhoe	Used hand hoe (=1)	0.31	0.46	0.00	0.00	0.00	1.00	1.00

Source: Authors' computations from CFS 2008-2011

Table 2: Bivariate mean comparisons of key variables between minimum tillage plots and non-minimum tillage plots between 2008 and 2011

		Used minimum tillage on plot		t-stat. for diff.	
Variable	Description	**No**	**Yes**	(Yes-No)	p-value
yield	Maize yield (Kg/ha)	1796.99	1772.97	-0.38	0.701
plot_size	Plot size in ha	0.93	0.95	0.57	0.568
age_hh	Age of hh head	43.85	43.58	-0.40	0.685
sex_hh	Male hh = 1	0.79	0.83	2.44	0.015
adults	Number of adults per hh	3.95	3.81	-1.27	0.204
p_married	Polygamously married	0.07	0.08	0.81	0.416
m_married	Monogamously married	0.70	0.73	1.48	0.140
b_fert	Used basal mineral fertlizer	0.43	0.42	-0.24	0.810

tp_fert	Used top mineral fertilizer	0.45	0.46	0.30	0.762
brate	Basal fertilizer rate (kg/ha)	60.50	60.38	-0.03	0.976
tprate	Top fertilizer rate (kg/ha)	62.70	64.28	0.37	0.710
hyb_seed	Used hybrid maize seed	0.45	0.46	0.45	0.651
seedingrate	Seeding rate (kg/ha)	21.07	20.75	-0.46	0.648
rain	Growing season rainfall	1019.83	1052.00	1.60	0.110
rain_stress	# of 20 day periods with < 40mm	1.02	1.07	0.79	0.431

Source: Authors' computations from CFS 2008-2011

Table 3: Maize production function average partial effect (APE) estimates (dependent variable: maize yield in kg/ha)

		National			Agro-ecological zones 1 and 2a	
Variables	**Spec.1**	**Spec.2**	**Spec.3**	**Spec.1**	**Spec.2**	**Spec.3**
used pl_basins (= 1)	-41.417	-109.654	-112.264	-5.561	-83.107	-73.763
	(69.421)	(70.607)	(75.249)	(74.999)	(68.546)	(71.244)
used ripping (=1)	186.190*	187.298*	233.789**	276.028**	266.637**	329.941**
	(110.531)	(107.872)	(108.591)	(139.718)	(134.146)	(135.323)
used plow (=1)	-0.212	-6.720	-4.457	5.162	-6.893	-1.808
	(29.216)	(29.653)	(30.078)	(36.964)	(38.343)	(39.095)
used bunding (= 1)	178.598**	144.869	77.369	496.252***	463.384***	459.146***
	(85.104)	(91.881)	(92.889)	(148.980)	(149.626)	(140.091)
used ridging (=1)	114.475***	103.386***	98.295***	115.305***	98.279**	100.875**
	(27.539)	(27.959)	(27.862)	(37.262)	(38.744)	(39.837)
Tillage before rains (=1)	-22.486	-24.298	-24.450	36.195	19.623	20.203
	(21.171)	(22.812)	(22.732)	(29.686)	(33.435)	(33.374)
Used hybrid seed (=1)	180.629***	147.735***	146.055***	158.678***	137.000***	134.754***
	(22.693)	(23.034)	(22.985)	(29.072)	(29.854)	(29.824)
Seeding rate (kg/ha)	1.879***	0.691	0.749	1.946***	0.583	0.706
	(0.557)	(0.939)	(0.935)	(0.675)	(1.172)	(1.161)
basal fert use rate (kg/ha)	3.128***	4.072***	4.113***	3.180***	3.868***	3.922***

	(0.328)	(0.386)	(0.382)	(0.383)	(0.459)	(0.447)
top fert use rate (kg/ha)	4.832***	4.927***	4.822***	4.962***	5.162***	5.047***
	(0.320)	(0.389)	(0.387)	(0.369)	(0.478)	(0.470)
plot size in ha	-12.730	-39.094***	-39.636***	-13.270	-42.975***	-43.947***
	(9.187)	(13.037)	(12.998)	(11.390)	(16.551)	(16.526)
Growing season rainfall (mm)	0.001	-0.008	-0.009	0.014	0.017	0.011
	(0.106)	(0.108)	(0.108)	(0.145)	(0.147)	(0.148)
# of 20 day periods with < 40mm rainfall	-30.277*	-40.335**	-40.213**	9.666	0.146	-1.978
	(15.913)	(19.994)	(19.917)	(19.554)	(23.420)	(23.455)
Male head (=1)	37.179	45.866	44.331	17.066	22.335	19.409
	(29.562)	(29.683)	(29.664)	(40.368)	(40.383)	(40.330)
Age of hh head (years)	-0.290	0.993	0.970	-0.789	-0.080	-0.151
	(0.550)	(0.717)	(0.717)	(0.753)	(1.010)	(1.007)
Polygamously married (=1)	44.937	42.823	41.631	54.684	51.440	50.420
	(39.070)	(39.117)	(39.106)	(48.425)	(48.439)	(48.369)
Monogamously married (=1)	20.046	20.514	20.893	31.095	33.561	34.286
	(28.883)	(29.119)	(29.056)	(38.584)	(38.818)	(38.711)
Number of adults (15-65 years)	-0.733	-3.044	-2.933	-2.487	-3.984	-3.819
	(3.995)	(5.178)	(5.128)	(4.914)	(6.721)	(6.617)
2009.year	252.316***	237.026***	239.449***	377.950***	367.354***	370.649***
	(40.945)	(40.979)	(40.921)	(51.572)	(52.882)	(52.394)
2010.year	565.090***	541.306***	543.539***	792.754***	779.171***	776.082***
	(46.990)	(48.263)	(48.302)	(67.339)	(70.312)	(70.444)
2011.year	533.487***	519.053***	519.221***	576.920***	577.220***	581.136***
	(42.154)	(41.840)	(41.439)	(58.691)	(58.404)	(57.552)
AEZ 2a (=1)	17.997	45.055	59.577			
	(50.775)	(54.239)	(54.045)			
AEZ 2b (=1)	15.609	15.716	-21.610			
	(67.342)	(77.257)	(76.277)			
AEZ 3 (=1)	355.503***	345.079***	334.802***			
	(63.136)	(65.732)	(63.375)			
Observations	**47,838**	**47,838**	**47,838**	**25,808**	**25,808**	**25,808**

Notes: Standard errors clustered at the SEA level in parentheses; ***, **, * statistically significant at 1%, 5% and 10%, respectively; base tillage method, based year, and base agro ecological zone are conventional hand hoe, 2008, and AEZ 1, respectively.

Source: Authors' computations from CFS 2008-2011

Table 4: Marginal effects on yields of planting basins vs. hand hoe tillage, and ripping vs. plowing, by timing of tillage (based on specification 3)

Panel A: Simulated average yield differences (kg/ha) for planting basins (compared to hand hoe tillage) for tillage done before vs. during the rains[a]

	Tillage **before** the rains		Tillage **during** the rains	
	Marginal effect	t-stat.	Marginal effect	t-stat.
National results	191.45*	1.71	-179.25**	-2.21
AEZs 1 and 2a results	194.01	1.42	-168.41*	-1.88

Panel B: Simulated average yield differences (kg/ha) for ripping (compared to plowing) for tillage done before vs. during the rains, and with average inorganic fertilizer[b]

	Tillage **before** the rains		Tillage **during** the rains	
	Marginal effect	t-stat.	Marginal effect	t-stat.
National results	576.54***	2.96	95.79	0.77
AEZs 1 and 2a results	820.94***	3.30	167.77	1.11

Note: [a]The planting basins-fertilizer application rate interaction effects are *not* statistically significant in specification 3, and so are set to zero in these simulations. [b]The ripping-fertilizer application rate interaction effects *are* statistically significant in specification 3; the marginal effects of ripping vs. plowing in the table above are evaluated at the average basal and top dressing fertilizer rates in the sample (61 kg/ha basal and 63 kg/ha top dressing in the national model, and 56 and 59 kg/ha, respectively, in the AEZs 1 and 2a model). ***, **, * statistically significant at 1%, 5% and 10% respectively.

Source: Authors' computations from CFS 2008-2011

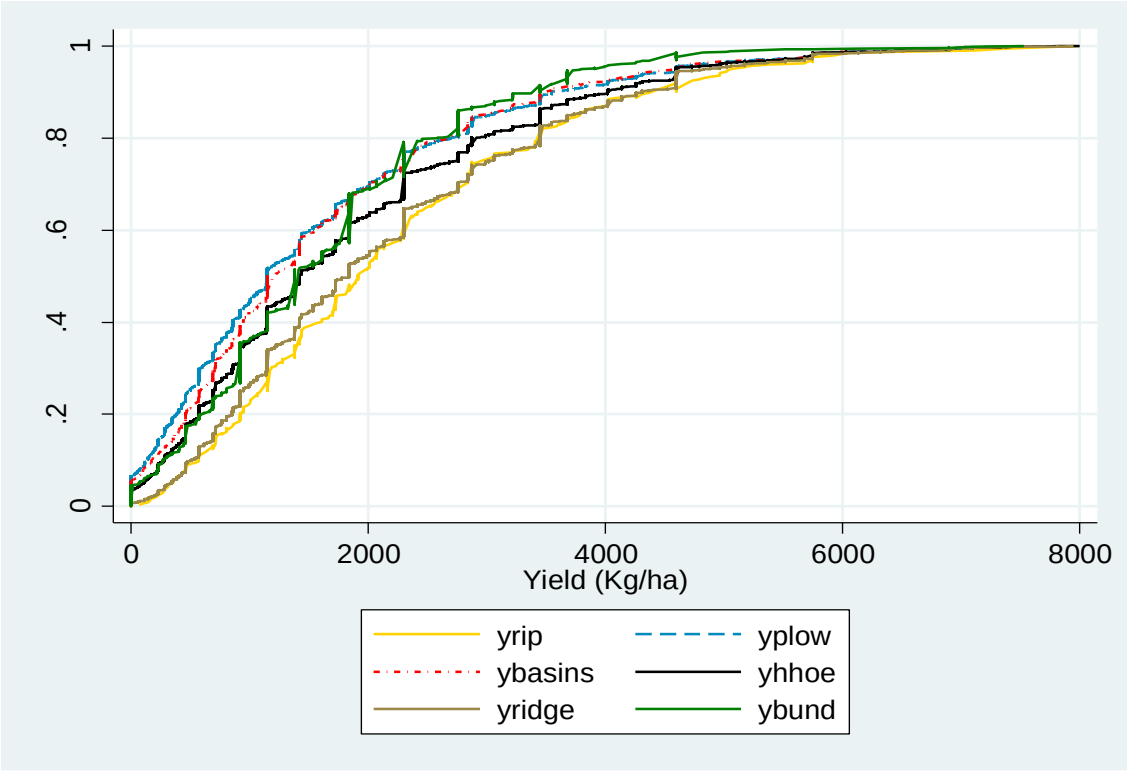

Figure 2: Cumulative distribution functions of smallholder farmer yields by all tillage options between 2008 and 2011 in Zambia

Source: Authors' computations from CFS 2008-2011