Conservation Farming Adoption and Impact Among First Year Adopters in Central Zambia

by
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The Indaba Agricultural Policy Research Institute is a non-profit company limited by guarantee and collaboratively works with public and private stakeholders. IAPRI exists to carry out agricultural policy research and outreach, serving the agricultural sector in Zambia so as to contribute to sustainable pro-poor agricultural development.

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Any views expressed or remaining errors are solely the responsibility of the authors.

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EXECUTIVE SUMMARY

In Zambia, as in most of Sub-Saharan Africa, rural poverty, food security, and farming are inextricably linked. While the livelihoods of nearly two thirds of Zambia's population depend directly on their agricultural productivity, average yields have historically been low and soil fertility has been diminishing. Conservation Farming (CF) has shown promise of being a solution to these challenges after several years of adoption, yet the short-term yield effects are more variable. A better understanding of the immediate yield effects and their profitability relative to other techniques is necessary to determine if CF adoption is an effective and feasible way to increase agricultural productivity while sustainably building soil fertility.

Our primary data were collected over the 2010/11 growing season in Mkushi, Zambia: 62 first year adopters of CF were interviewed and detailed labor, inputs, and yield data were obtained from their conservation and conventional maize plots. The data were analyzed to highlight actual differences in labor days used, inputs applied, and techniques employed across conservation plots and conventional plots. We estimated yield regressions to determine the yield effects and household level profitability of CF techniques in the first year of implementation. The analysis highlighted three main results.

First, CF maize plots had higher yields and were more profitable than conventional plots in most of the within household comparisons. CF basin plots produced two tons per hectare more maize than conventional hand hoe plots on average, but required 40 more labor days per hectare. While the increased labor requirement is substantial, most households observed a greater return for their inputs and labor on their CF plots. When all labor and inputs were carefully valued at the household level, the CF maize plots were more profitable than conventional plots in 71% of the comparisons. This is important for continued adoption as households likely make decisions based on observed results within their household.

Second, our yield regressions showed that fertilizer was highly effective in increasing yields on CF plots, but had no consistent impact on conventionally managed plots. This striking result stems from the improved moisture retention achieved with CF tillage techniques and from precision fertilizer application methods promoted in CF trainings. Although the farmers in our sample had used fertilizer for several years, this result alarms us to the fact that they were not achieving consistently increased yields in their conventional plots. Under certain rainfall distributions, like those experienced in the 2010/11 growing season, CF practices can show immediate improvements over conventional techniques.

Third, our discussions with farmers and our observations (obs.) over two growing seasons revealed that households showed a high willingness to adopt herbicides to control weeds. Our data showed that herbicides saved about 30 labor days per hectare and were more profitable than hand weeding. The increased usage of herbicides presents several benefits for farmers, but also brings several challenges. Most notably, improper use of herbicides may lead to large health and environmental costs.

CONTENTS

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

ACRONYMS

ADP	Animal Draft Power
CF	Conservation Farming
CFU	Conservation Farming Unit
cm	centimeters
FISP	Farmer Input Support Program
FRA	Food Reserve Agency
ha	hectares
HYV	High Yielding Variety maize seeds
IAPRI	Indaba Agricultural Policy Research Institute
kg	kilograms
km	kilometers
MACO	Ministry of Agriculture and Cooperatives
mm	millimeters
obs.	observations
ZMK	Zambian Kwacha
ZNFU	Zambia National Farmers Union

1. INTRODUCTION

Conservation Farming (CF) in Zambia has shown promise of achieving its objectives of increasing smallholder farm productivity while sustainably building soil fertility. The potential benefits of CF are well established in farm trial research (Verhulst et al. 2010 and Rockström et al. 2009), and studies of CF adopters have shown medium and long term advantages over conventional techniques (Haggblade and Tembo 2003; Marongwe et al. 2011). However, Giller et al. (2009) point out that adoption has been scattered and generally low while yield effects are more variable in the short-term as many of the benefits of CF practices are realized only after several years of continued implementation when the soil fertility is restored. Yet, CF technologies include management techniques that could immediately benefit farm productivity including increased soil water availability (Verhulst et al. 2010), more effective input usage (Nolin and von Essen 2004), and better weed control with herbicides among others.

While a body of research exists on the medium- and long-term effects of CF techniques, relatively little is known about the immediate impacts of CF methods on a household's yields and farm profits. The research that does exist is mixed and likely outdated. Giller et al. (2009) cite two articles from 1990 (Mbagwu; Gill and Aulakh) and one article from 1986 (Lal) in his discussion of the short-term yield effects of CF.

Furthermore, results of the first trial year of adoption are critically important to the continued adoption or dis-adoption of CF technologies. If households initially experience higher operating and management costs in their CF plots yet do not achieve a return comparable to that of their conventional plots, it would be hard to establish continued adoption no matter how heavily CF is promoted and no matter how large the eventual benefits may be. Conversely, if households improve yields and profits through CF techniques in their first year of adoption, then, in theory, their production and profits would improve in successive years as the medium to long term benefits of CF begin to take hold and as the labor requirement decreases.

This study aims to investigate the practices and results of first year CF adopters. We particularly focus on the differences in yield, profitability, and input effectiveness between CF and conventional plots.

In this paper, we will first outline the research approach and methods employed in this study. Then we will provide a brief introduction to Conservation Farming (CF) as practiced and promoted in Zambia followed by a detailed description of the specific region of study. Next, we will describe our data collection and analysis techniques. Then we will provide our results in two sections, the first of which will categorize our data on first year adopters and compare labor inputs and results for CF and conventional plots. The second section of our results will analyze the observed input effectiveness of CF and conventional application techniques. Lastly, we will summarize our results and observations in the conclusion.

2. METHODS

2.1. Approach

This study was conducted while the researcher was living and working in Mkushi, Zambia as an agricultural extension volunteer. In his time in Mkushi, CF was introduced to rural farmers by the Zambia National Farmers' Union's (ZNFU) Conservation Farming Unit (CFU) and there was an opportunity to analyze the results and experiences of the first year adopters.

This study is an improvement to the existing research because we do not compare CF adopters to non-adopters or even the national average for maize production; we compare them to themselves and, thus, are able to better control for variables like education, extension access, motivation, and access to inputs. Haggblade and Tembo (2003) used a similar technique by comparing control plots of CF adopting households. Consequently, we do not have results that are applicable to a broad population. This study details the experiences and results from CF first year adopters in a specific region of Zambia over a single growing season. The results we obtain and the conclusions we reach should be not be extrapolated beyond this context, yet this study is still a useful step in understanding the differences between conventional and CF technologies in the first year of adoption.

We will begin our analysis by characterizing the differences between CF and conventional plots in their techniques adopted, chemical inputs applied, labor expended, and yields achieved. We then value inputs, labor, and maize output to analyze the average profitability by plot type. Next, using our detailed household data, we compare CF and conventional plot profitability within each household to better characterize the results that smallholders actually observed. Then we estimate a yield regression to better understand what techniques impacted maize yields. We further our analysis with two additional variations of our base regression to directly analyze input effectiveness on yield. We then conclude our study with a qualitative discussion of herbicide usage.

2.2. Conservation Farming in Zambia

The CFU has been conducting trials, experimenting with alternative technology packages, and teaching CF technologies to smallholders in Zambia for almost 20 years and is the unmistakable leader in CF promotion. The three main principles of CF (minimum soil disturbance, maintaining soil cover, and crop rotation) form the basis of CFU's promoted technologies, but their extension programs also teach efficient input usage and timely plot management as important parts of CF. Altogether, the CF technologies as promoted by CFU amount to a shift away from culturally conventional farming methods which, unlike CF, involve full soil inversion.

Conventionally, Zambian smallholder farmers prepare their fields for planting by turning the soil's entire surface area after the rains have arrived. Farmers with animal draft power (ADP) till the soil with a moldboard plow and farmers without ADP (and without money to hire in ADP) till with a hoe either by forming ridges or simply turning the soil in place (we will call these tillage techniques plowing, ridging, and conventional hand hoe respectively). CFU promotes minimum soil disturbance in land preparation. Hand hoe farmers are encouraged to dig a grid of *basins* at 90 centimeters (cm) by 70cm spacing and farmers with ADP are taught to *rip* lines through the soil at 90cm spacing. CFU also emphasizes depth in land preparation; basins and rip lines should achieve a depth of 20cm while conventional tillage may not even reach 10cm depth. By achieving a greater depth in land preparation than has been historically achieved on the plot, farmers break through existing plow and hoe pans and facilitate water percolation and root development below the otherwise impenetrable pans. Most of the farmers in our study were hand hoe farmers, so we will focus our discussion on basins, but both of these tillage techniques, if done properly, disturb less than 10% of the soil's surface area.

In the first season of implementation, basins can facilitate better root development, enable precise fertilizer application in the maize rooting zone, and, perhaps most importantly, improve water infiltration and water holding capacity (Rumley and Ong 2007). Over time, the minimum soil disturbance builds soil organic matter and restores soil fertility.

Soil cover and crop rotation, the other two CF principles, are also promoted by CFU. Farmers are instructed to maintain soil cover throughout the year. In Zambia, this means not burning field residues during the dry season. CFU also suggests that farmers using labor-intensive techniques may plant a cover crop between rows to suppress weeds. While retaining crop residues in the field may help reduce runoff and improve moisture retention, it can also have the negative effect of reducing nitrogen immediately available to crops as nitrogen is bound up in decomposition (Verhulst et al. 2010).

For crop rotation, CFU instructs farmers to devote one third of their cultivated area to a legume. While many farmers are aware of the benefits of rotating crops, implementation rates are often low and monoculture maize is the common practice in many parts of the country. Farmers cited the limited markets for legumes as a major deterrent to crop rotation as the opportunity cost of not growing maize was quite high.

CF adopters have been shown to rarely adopt all three of these principles at the same time. Kabamba and Muimba-Kankolongo (2009) found that 10% of their sample employed what CFU terms *conservation farming* (all three principles in the same plot). The same study found that 40% of farmers adopted *improved reduced tillage* (minimum soil disturbance only) and another 40% implemented *conservation tillage* (minimum soil disturbance coupled with crop rotation).

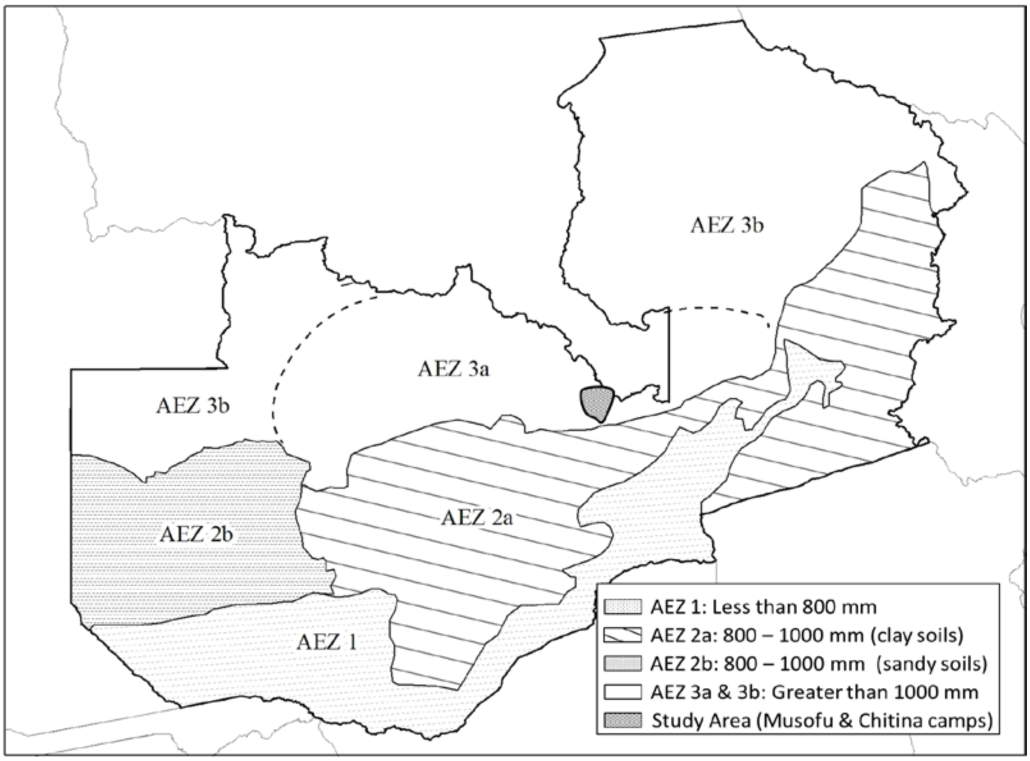
In addition to these three principals of CF, CFU also teaches precise input application as an important part of their package of technologies. And, to smallholder farmers, the most important input is inorganic fertilizer, which has been promoted and subsidized heavily for more than 15 years in Zambia (Haggblade and Tembo 2003). Smallholders use two types of fertilizer: basal or D compound, composed of 10% nitrogen, 20% phosphorus, and 10% potassium, and top dressing, or urea, composed of 46% nitrogen. Conventionally, farmers apply fertilizer by either broadcasting or dropping it as they walk between the rows. Smallholders often wait until their maize has germinated and apply basal fertilizer on top of the soil. CFU promotes applying consistent, measured volumes of fertilizer directly to the maize rooting zone. Farmers are instructed to apply two #8 gram cups of basal fertilizer within each basin prior to planting and an additional two cups of top dressing per basin 5cm from the maize after the maize has reached the five leaf stage of growth. CFU also recommends the application of lime, which is not conventionally used, to help neutralize acidic soils. This more accurate application technique is intended to improve yields through improved fertilizer efficacy.

While fertilizer is a regularly used input, CFU also promotes the use of herbicides, which are less common and relatively new to most smallholders. Herbicides, if used properly, can provide an effective and timely weed kill, and CFU believes them to be time saving and even profitable for smallholder farmers (CFU 2010). Because they use minimum tillage practices, CF farmers experience higher weed development in early years of CF adoption. Most conventional farmers use their initial land preparation as a first weeding. Because conventional farmers wait until the rains are well established to begin their land preparation, when they completely turn the soil they also kill and bury initial weeds. Without soil inversion, CF farmers must rely on additional weeding labor or, alternatively, herbicides to cope with initially heavier weed banks. Over time, CFU believes that the weed banks will diminish as weeds are well controlled and prevented from seeding. However, in the first year of adoption, weed pressure remains an additional plot management challenge for CF adopters. CFU helps address this challenge by being a leader in herbicide extension. CFU teaches proper handling, storing, mixing and application procedures for herbicides, and supply training to farmers who would not likely receive it through government extension channels.

2.3. Area of Study

Zambia is composed of 10 provinces, each of which is divided into districts, which are further subdivided into camps by the district level governments. This study was conducted during the 2010/11 growing season in the Chitina and Musofu camps of Mkushi district, Central Province, Zambia. These two camps cover more than 50,000 hectares and straddle the border between Zambia's agro-ecological zones 2a and 3a as shown in Figure 1. Rainfall typically exceeds 800 millimeters (mm) annually and the region has easily leached, acidic soils, although there are patches of heavier, clay soils. Arable land is not a constraint for most households as the area is not densely populated and the majority of the land is uncultivated miombo woodland.

Figure 1. Study Area and Zambia's Agro-ecological Zones



Source: Adapted from Nielson 2009.

Unsurprisingly, the primary economic activity for most households is agriculture. While many smallholders maintain gardens, all households grow field crops and many produce enough to sell. Maize accounts for the clear majority of cultivated land, as it is both the staple crop for consumption and the primary cash crop. Traditionally, smallholders grow maize with a form of slash and burn agriculture called the chitemene system. With the rise of fertilizer use in recent years, the chitemene system has been adapted and farmers now cultivate the same plot of land for longer periods (often as monoculture maize) before shifting to more fertile soil leaving their other plots fallow.

Farmers in the two camps benefit from strong market access with both government and private input and output markets within reach. The Zambian government improves smallholder market access for maize through two support programs: the Farmer Input Support Program (FISP) and the Food Reserve Agency (FRA). FISP allocates subsidized hybrid maize seed and fertilizer to smallholders registered with a farmer group or cooperative. The FRA purchases maize from smallholders at a subsidized price in rural depots or buying sheds. Both camps had a centrally located FRA depot in the 2010/11 growing season that also served as the distribution point for FISP inputs. No household was more than 15 kilometers (km) away from a depot implying that all households had good access to a market for their harvested maize and, if they had cash available to buy in to FISP, a portion of subsidized inputs. Additional seed, fertilizer, and herbicides could be obtained at retail prices in the town of Mkushi, which is an average of 40km from the two camps.

Chitina is uniquely located less than 10km north of a commercial farm block which provides an available market for those looking to sell their labor and work for a cash wage of about two dollars a day. It is also common for households to purchase inputs stolen from the commercial farms on the black market at well below retail prices.

Each camp has a Ministry of Agriculture and Cooperatives (MACO) camp officer stationed near its FRA depot. While these camp officers are employed to provide extension services to farmers, their primary work is facilitating the FISP distribution and the FRA maize purchases. Social networks play an important role in working with the MACO officers and not everyone has direct access to their services. As a result, most farmers receive no formal training or extension advice.

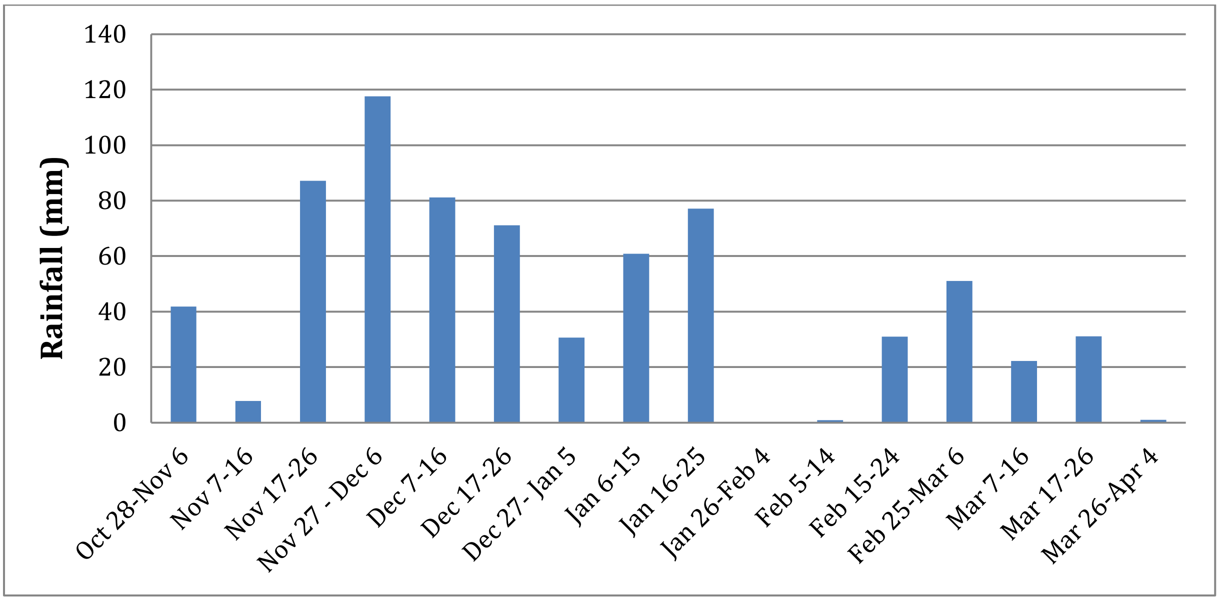
2.4. Rainfall for the 2010/11 Growing Season

Farmers in Chitina and Musofu claimed to have noticed changing and less reliable rain patterns in the area. A few of the commercial farmers located just south of Chitina also believed that rains were becoming heavier but more erratic with more uneven distributions throughout the rainy season. Irregular and less predictable rain patterns adversely affect rainfed crops and are yet another challenge smallholder agricultural success.

Improved minimum tillage techniques that increase water infiltration and moisture retention can mitigate the effects of irregular rain patterns and climate change (CFU 2009). Figure 2 shows the rainfall distribution for the 2010/11 growing season recorded at the nearest reliable research station in Kabwe. This rainfall pattern closely follows what we observed in Musofu and Chitina over the course of the growing season.

The rains started strong and there was a long window of planting dates from mid-November to late December that facilitated good maize germination and healthy early growth.

Figure 2. Rainfall Distribution in Study Area for 2010/11 Growing Season



Source: Zambia Meteorological Department. Note: There was no recorded rainfall prior to October 28, 2010 or after April 4, 2011.

The rains were more or less consistent until about February when there was a three week time period with no rainfall. Figure 2 shows less than 1mm of rainfall for the 20 day period of January 26 through February 14. This was problematic for farmers as the gap in rains occurred when many maize crops were tasseling.

The distribution of rainfall allowed basins to demonstrate their improved water harvesting and moisture retention abilities. In February, towards the end of the rain gap, the researchers observed a few basin crops that held strong and green that were directly adjacent to conventional plots that began to lose their dark color and wilt slightly.

2.5. Data

To compare and contrast conventional and CF maize plots we interviewed sixty two households from the Musofu and Chitina camps. All of the households planted a portion of their maize under conservation tillage as promoted by CFU. The 2010/11 season was CFU's first year promoting CF in the area, so all interviewed households were first year adopters of the technology as explained in section 2.1.

We used two interviews to obtain our detailed data. The first interview, conducted at the end of the growing season before the maize was dry, acquired detailed recall labor data on 136 plots, covering each household's CF and conventional maize plots. Additionally, we obtained comprehensive input data and recorded each farmer's perception of CF technologies in this first interview. We implemented the second interview immediately after maize harvest and used it primarily to record the maize harvested from each plot and to measure the area of each plot using Global Positioning System.

We did not obtain harvest or post-harvest labor data. However, we have no reason to believe that the labor required to harvest, shell, and bag maize depends on anything other than the amount of maize produced. Therefore, we assume that harvest and post-harvest labor is proportional to the harvested volume and that the proportion is the same for both conventional and CF plots within the household.

Although we do not have data on labor used after the maize reached maturity, the depth of the data we have allows us to be precise in valuing labor used during the growing season and accurate in valuing the inputs applied by each household. These valuations are crucial to our analysis of plot profitability. Each input used is valued at the cost to the household including transportation costs. A few households obtained the same input from two different sources at two different prices. An example is households that received subsidized fertilizer through FISP, but also purchased additional fertilizer in Mkushi. Because we do not know the source of the fertilizer used on each plot, we applied a weighted average cost of the input and applied it to each plot. We value household labor at 10,000 Zambian Kwacha (ZMK); the wage rate for a day's labor on the commercial farms which are walking distance away for some households in our sample. Our data also show that the average wage for hired labor was very close (within 500 ZMK) to the commercial farm wage. However, we do not consider the timing of labor in our valuations and the 10,000 ZMK blanket price is likely an overestimate for labor activities performed in off-peak times of year. For example, preparing basins before the onset of rainy season, as promoted by CFU, likely has a lower opportunity cost to the household as there are few on farm activities happening before the rains. The uniform price used for household labor will have a larger effect on CF plots because labor on conventional plots is used almost exclusively during rainy or peak season.

3. RESULTS

3.1. Adopted Practices

As we previously explained in the methods section of this paper, CF is a package of farming technologies consisting of several changes to what is conventionally and culturally implemented by smallholder farmers. Adoption of the technologies is not a binary adopt or not adopt result. There is a spectrum of technology adoption, especially in the first year CF is implemented. We begin our analysis by characterizing what farmers actually adopted out of the CFU package of technologies.

Table 1 splits the 136 maize plots in our sample into conventional tillage and minimum tillage plots and shows the percentages of plots where each CFU technology was adopted. We include four maize plots identified as zero-tillage together with our CF plots as they are technically minimum tillage. About one-fourth of CF plots were improved minimum tillage meaning, of the three principle technologies, only minimum tillage was implemented. About 40% of the minimum tillage plots employed conservation tillage or residue retention paired with minimum soil disturbance. About 56% of the minimum tillage maize plots were planted following a non-maize crop or fallow period. Finally, only 22% of the minimum tillage plots were conservation farming plots employing all three of the CF principle technologies.

Interestingly, the principle technology adoption rates for CF and conventional plots were quite similar. Yet, from our field observations we believe that the rates of residue retention and crop rotation were higher for CF adopters than they would have been for a random sample of all households. The vast majority of maize plots in the area were burned prior to planting and monoculture maize is ubiquitous. So why did we observe higher rates of crop rotation and residue retention for CF adopters and why are those rates so similar on CF and conventional plots?

Table 1. CFU Technology Adoption Rates by Conventional and CF Tillage

	Conventional Tillage Plots (65 plots)	CF Tillage Plots (71 plots)
CFU Principle Technologies	% of plots	% of plots
Improved Reduced Tillage (only)	0.0%	25.4%
Residue Retention	44.6%	40.8%
Crop Rotation (in prior year)	46.2%	56.3%
Residue Retention + Crop Rotation	20.0%	22.5%
Additional CFU Technologies		
Basal Fertilizer Applied Beneath Seed	6.2%	19.7%
Lime Applied	6.2%	70.4%
Herbicides Applied	18.5%	39.4%
Timely Planting	27.7%	53.5%
High Yielding Variety (HYV) Seed	92.3%	94.4%

Source: Author.

The answer has to do with how farmers viewed the technologies. CFU promoted these three principal technologies heavily in their trainings, but the ideas of crop rotation and residue retention were not new, as farmers likely had some exposure to them and many had likely implemented them in the past. The CFU trainings may have confirmed their previous training or experience and led farmers to implement crop rotation and residue retention at higher rates on all of their plots. The minimum tillage technology, however, would have been totally new to most farmers and they may have been more cautious in their adoption and only implemented minimum tillage on CF plots. In fact, households identified their maize plots as either conventional or CF solely based on the tillage technique. For instance a plot cultivated with basins, but otherwise farmed completely conventionally would be identified as CF by the farmer. Alternatively, a plot that was plowed with oxen, but otherwise complied with CF technologies would be identified as conventional.

3.2. Input Usage

The additional CF technologies shown in the bottom half of Table 1 were also new technologies that farmers had likely had limited exposure to prior to CF trainings with the exception of HYV seeds which were commonplace. These technologies have to do with input application and they were adopted in CF plots more readily than in conventional plots. We would expect farmers to try the new input or application technique in their CF plots before adopting them more widely.

Table 2 explores input application a step further. First, it is worth noting the small number of observations for ridges, ripping, and zero-till tillage techniques. We will continue to report all tillage methods, but we will focus our discussion on basins, conventional hand hoe, and plow plots which together account for almost 90% of our sample.

Sixty of the sixty-two households obtained at least a portion of subsidized seed and fertilizer from the FISP, but herbicides were unsubsidized and the households that purchased them paid market prices in cash.

Table 2. Inputs Used by Tillage Method

Tillage Method		Plot Area (ha)		HYV Seed	Fertilizer Applied[a] (kg/ha)		Herbicides	
	# of plots	mean	median	% plots	mean	median	% plots applied	mean applied (L/ha)
Basins (CF)	62	0.36	0.26	98.4%	436	397	37.1%	4.5
Conventional hand hoe	22	0.40	0.27	81.0%	388	288	9.1%	3.5
Ridges	6	0.33	0.30	100.0%	247	241	16.7%	1.5
Ripping (CF)	7	1.63	0.80	85.7%	352	406	57.1%	4.3
Plow	35	0.84	0.44	100.0%	415	375	22.9%	2.5
Zero-till	4	0.16	0.15	50.0%	253	179	0.0%	.
All	136	0.55	0.33	94.0%	405	376	27.9%	3.9

Source: Author. a. All plots had some fertilizer applied.

The more established inputs (HYV seeds and fertilizer) were applied at higher rates on basins plots than conventional hand hoe plots: HYV seeds were planted in 98% of basin plots but in only about 80% of conventional hand hoe plots. Farmers applied an average of 48 kg more fertilizer per hectare to basin plots than conventional hand hoe plots.

Interestingly, HYV seed usage and fertilizer application rates for basins were very similar to those for conventional plow plots. Almost all of those plots used HYV seed and the mean and median fertilizer kgs per hectare application rates were close to the CFU recommendation of 400 kgs per hectare.

There is a more marked difference in usage and application rates for herbicides that most farmers had limited exposure to prior to the 2010/11 season. Almost 40% of basin plots had herbicides applied compared to about 23% of plow plots and about 9% of conventional hand hoe plots. This is undoubtedly because CFU directly promoted herbicides for weed control on CF plots and it was a new technology that farmers wanted to try before widely adopting.

Table 3 continues our comparison of CF and conventional plots by exploring labor expenditures across farm activities. First, we notice that basin plots required 40 more labor days per hectare than any other farming method during the first year of adoption. Digging basins is hard work: the majority of the increased labor expenditure came in land preparation where basins required 36 more labor days per hectare than conventional hand hoe techniques. If three family members were working together, on average, it would have taken them almost two extra weeks to dig a hectare of basins than it would have taken them to turn the entire surface of the field with a hoe. This might sound surprising, and CFU suggests that basins should reduce land preparation labor requirements because by digging basins only 10% of the soil surface is disturbed, whereas 100% of the soil surface is turned in conventional hand hoe. However, Haggblade and Tembo (2003) found that labor demands fell roughly in half after three years of digging the same planting basins. Yet there are three reasons to believe this result of high labor requirements in the first year of adoption.

Table 3. Mean Labor Days per Hectare by Activity and Tillage Method

Tillage Method	Total Labor	Land Cultivation	Planting	Hand-weeding	Applying Fertilizer[a]	Applying Lime	Applying Herbicide
Basins (CF)	154	78.3	13	44.2	10	5.2	0.6
Conventional hand hoe	113.3	42.6	16.3	42.8	9	0	0.1
Ridges	79.5	42.4	8.3	21.2	6.1	0	0.1
Ripping (CF)	55.1	3.6	7.1	32	6.5	3	1
Plow	51	6	6.1	30.4	8.2	0.1	0.3
Zero-till	49.1	0	19	25.3	4.7	0	0
All	109.4	46.2	11.4	38.2	8.9	2.6	0.4

Source: Author. a. Includes basal fertilizer, top dressing, and manure applications.

3.3. Labor

The first is the depth of the basins. CFU promotes digging the soil to a depth of 20cm to break the hard pan and ultimately improve root penetration and water infiltration. In conventional hand hoe land preparation, depth is not the objective, turning the soil surface quickly is. Digging down can require much more effort than skimming the soil surface. The second reason is the timing of land preparation. CFU promotes early (before the rains) land preparation to ensure timely planting when the rains come. Most households were unable to complete their land preparation prior to the onset of the rains, and those farmers that did prepare land in October found the ground hard and the digging difficult. When the rains soften the soil, cultivation becomes much easier. The third reason is that these were first year adopters of CF technologies who had never dug basins before. Farmers were learning as they were digging and were probably very deliberate in the placement of their ropes for spacing and precise in the dimensions of their basins at the cost of efficiency. For these three reasons, basins required substantially more labor in land preparation than conventional hand hoe.

In all other activities, basins had a similar average labor requirement to conventional hand hoe plots. Plow plots required much less labor than basins and hand hoe plots and, unsurprisingly, the majority of the difference came in land preparation where plowing only required six labor days on average to prepare a hectare.

The substantial increased labor expenditure on CF basin plots makes the immediate effects of the techniques even more important. Farmers are unlikely to continue CF practices if they require a substantial increase in labor and produce less maize. Moreover, for some households, the increased labor requirement might be enough to dis-adopt basins regardless of the results. One household we interviewed suggested that no added amount of maize would be worth the heavy labor of digging basins and vowed not to continue with CF even without quantifying the harvest differences between his CF and conventional plots.

3.4. Yield and Profit Results Comparisons

Table 4 shows that, on average, basins produced more maize per hectare than any other tillage technique. The average yield margin of basins over conventional hand hoe and conventional plow techniques was 2 tons and 1.5 tons per hectare respectively.

Table 4. Plot Size, Yield, and Profitability by Tillage Method

Tillage Method	# of plots	Plot Area (ha)		Yield (kg/ha)[a]		Profitability (ZMK/ha)	
		mean	median	mean	median	mean	median
Basins (CF)	62	0.36	0.26	4,659	4,187	2,843,000	2,634,000
Conventional hand hoe	22	0.40	0.27	2,605	1,917	872,000	575,000
Ridges	6	0.33	0.30	2,125	1,758	843,000	580,000
Ripping (CF)	7	1.63	0.80	2,691	1,811	1,490,000	723,000
Plow	35	0.84	0.44	3,165	2,359	2,094,000	1,562,000
Zero-till	4	0.16	0.15	3,838	3,753	3,418,000	3,487,000
All	136	0.55	0.33	3,717	3,108	2,192,000	1,718,000

Source: Author. a. Observed yield (reported maize kg harvested divided by measured field area).

It appears that the farmers that worked through the initial land preparation were ultimately rewarded with more maize. Furthermore, basin plots were more profitable on average than conventional hand hoe and conventional plow plots. Profits were calculated at the plot level by taking the value of maize produced at the FRA subsidized price and subtracting the costs of inputs and labor (in our sample all households sold their maize to the FRA). Inputs were carefully valued for each household and for each plot and our input valuations include transportation costs when applicable. Hired labor was valued at the cost paid in each instance and in-kind payments (any compensation other than cash) were estimated into a cash value and included in the cost. Household labor was valued at 10,000 ZMK per day for reasons discussed in section 2.5. Our profit valuations show that basins returned almost 2,000,000 ZMK per hectare above conventional hand hoe returns despite the increased labor in land preparation.

However, Tables 1 and 2 suggest that more inputs were applied to CF plots on average. Did basins show a significant yield advantage over other plots when we control for input usage and plot characteristics?

In Table 5 we see that fertilizer had a significant, but relatively low impact on yields. One kg of fertilizer corresponded to less than 4 kgs of maize on average. More importantly, the negative and significant effects of hand hoe, ridges, and AT plow cultivation techniques on yield suggest that basin plots did show significantly higher yields than conventional plots when controlling for input usage. Basins produced 2 tons and 1.6 tons more maize than hand hoe and plow plots respectively. This solidly confirms that basins achieved more maize on average in our sample.

This result likely has a lot to do with the rainfall pattern that we outlined in section 2.4. Basins help retain moisture longer than conventional land preparation techniques and this proved vitally important as there were three weeks without rain when the maize was tasseling. While this result shows that, under certain conditions, basin plots, in their first year of implementation, can outperform conventional plots; this analysis does not have much value for a farmer deciding whether or not to continue his adoption of CF.

Table 5. Yield Regression

Dependent Variable = maize yield in kg/ha

Inputs	Coefficient	P-value	Significance
Fertilizer (kg)	3.79	0.000	***
HYV	457.19	0.641	
Herbicide (liters)	49.14	0.594	
Labor Days Weeding	-3.67	0.615	
Tillage Techniques			
Conventional Hand hoe	-2052	0.006	***
Ridges	-2414	0.030	**
Plow	-1601	0.012	**
Ripping	-1104	0.272	

Source: Author. *** Statistically significant at the 99% confidence level. ** Statistically significant at the 95% confidence level.

Table 6. Head-to-Head Profitability Comparisons at the Household Level

	# of obs.	# of obs. where CF was more profitable	share of obs. where CF was more profitable	mean profit difference (CF plot – Conventional plot)	median profit difference
Basins vs. Conventional Hand hoe	23	18	78%	2,053,000	1,931,000
Basins vs. Plow	35	23	66%	181,000	578,000
Basins vs. Ridges	6	4	67%	1,897,000	2,379,000
Ripping vs. Plow	2	2	100%	2,803,000	2,803,000
TOTALS	66	47	71%	1,068,818	1,280,652

Source: Author.

A rural farmer does not base his decisions on data from sixty-two nearby households, but rather decides how to farm based on the information he has, which is most often only the plot comparisons within his household. Thus, how CF plots perform relative to conventional plots at the household level will be much more important to adoption of CF.

Table 6 tries to capture the information available to the household decision makers by comparing the profitability of maize plots at the household level. Profits were calculated in the same manner as Table 4 and profit differences were computed by subtracting the conventional plot's profit from the CF plot's profit within each household. When we frame the question in a way that is more representative of the information available to smallholders, we see that basins were more profitable than conventional hand hoe plots in 78% of the comparisons. In other words, when households had both a basin plot and a conventional hand hoe plot, the basin plot was more profitable 78% of the time and by an average margin of more than 2,000,000 ZMK per hectare. Basins even outperformed plow plots in two-thirds of the observations although the mean profit difference was less than 200,000 ZMK per hectare.

To summarize, the average first year basin adopter in our study used slightly more fertilizer and substantially more labor on his basin plot than his conventional plot (about 50 kg more fertilizer and about 40 labor days per hectare more than conventional hand hoe plots and about 20 kgs more fertilizer and about 103 labor days per hectare more than plow plots). However, he was rewarded for his efforts with substantial and significant yield gains from his CF plot. Moreover, accounting for the higher expenditures on inputs and labor, his CF plot was more profitable than his conventional plot. These average results from Tables 1 and 2 suggest that there can be immediate benefits from CF adoption, while Table 6 suggests that farmers realized these benefits in the majority of their within household plot comparisons, which would likely help the continued adoption and expansion of CF. We did indeed observe that many of the interviewed households continued with CF techniques in the 2011/12 season and CF adoption grew to more than 150 households in our study area.

3.5. Input Use Efficiency

In the previous section, we learned that households were more cautious in their adoption of new technologies promoted by CFU (Table 1). Many of these new technologies involve new inputs or new input application techniques. Next, we explore whether or not these CF techniques showed improved effectiveness over conventional techniques. We will focus our analysis on the two major purchased inputs, fertilizer, and herbicides.

3.5.1. Fertilizer Effectiveness

Table 5 suggests that fertilizer had a positive and significant effect on yield as a 1 kg increase in fertilizer used corresponded to a 3.8 kg increase in maize yield. This is not a large impact and while it suggests a profitable return to fertilizer of about 3,000 ZMK per kg at the subsidized prices for maize and fertilizer[1], the return is negative at market prices, about -1,340 ZMK per kg. Table 5 does not attempt to identify fertilizer effectiveness directly, so, to learn more about when fertilizer works more and less effectively, we ran two variations of the same regression, one with fertilizer and seed interaction terms, and one with fertilizer and tillage technique interaction terms.

Table 7 includes fertilizer and seed interaction terms and suggests that fertilizer used with hybrid seed had a positive and significant effect on yield while fertilizer used with local seed did not significantly impact yields. The size of the effect increased slightly to 3.9 kgs of maize per kg of fertilizer from 3.8 in Table 5 because we isolated out fertilizer used ineffectively with local seed varieties. It is not surprising that HYV seeds responded better than local seeds to fertilizer, as HYV are propagated to achieve high yields with fertilizer, but the fact that fertilizer used with local seeds had no significant effect on yield is unexpected.

Table 7. Yield Regression with Fertilizer and Seed Interaction Terms

Dependent Variable = maize yield in kg/ha			
	Coefficient	P-value	Significance
Interaction Terms			
Fertilizer and HYV	3.9	0.000	***
Fertilizer and local seed	5.6	0.190	
Weeding			
Herbicide (liters)	49.87	0.589	
Labor Days Weeding	-3.63	0.620	
Tillage Techniques			
Conventional Hand Hoe	-2232	0.003	***
Ridges	-2410	0.030	**
Plow	-1609	0.012	**
Ripping	-1218	0.227	

Source: Author. *** Statistically significant at the 99% confidence level. ** Statistically significant at the 95% confidence level.

[1] The FRA price of maize was 1,083 ZMK per kg while the market price was about 700 ZMK per kg, and the FISP price of fertilizer was 1,000 ZMK per kg while the market price was 4,000 ZMK per kg.

This result shows that fertilizer certainly does not increase yields across all farming techniques and also strongly corroborates the promotion of fertilizer and hybrid seeds together through FISP.

Table 8 clarifies fertilizer effectiveness further. The interaction terms for fertilizer and tillage techniques suggest that fertilizer used on conservation tillage plots had a significant effect on yield while fertilizer used on conventional plots had no significant impact. The fertilizer used on basin plots showed a much larger significant effect than our previous regressions: our results suggest that a 1 kg increase in fertilizer used on basins corresponded to a 7 kg increase in maize yield while 1 kg of fertilizer used on conventional plots did not have any consistent influence.

This meaningful result is partly attributable to the water harvesting ability of basins. Fertilizer requires water and basin plots would have had more moisture on average than conventional plots, so we would expect and, indeed, did observe fertilizer to be more effective in basin plots.

The fertilizer effectiveness is also partly explained by the application technique used on CF plots explained in section 2.2. Most farmers interviewed tried but did not use the recommended cups to apply fertilizer throughout their plots because they felt they took too long. However, they did take greater care when applying their fertilizer and, at least, attempted to be more precise in where and when they applied it. While this is very real improvement on the haphazard conventional application of fertilizer, there is still plenty of room for progress.

Table 8. Yield Regression with Fertilizer and Tillage Interaction Terms

Dependent Variable = maize yield in kg/ha

	Coefficient	P-value	Significance
Interaction Terms			
Fertilizer and basins	7.04	0.000	***
Fertilizer and Conventional hand hoe	0.41	0.804	
Fertilizer and ridges	4.06	0.656	
Fertilizer and plow	1.85	0.357	
Fertilizer and ripping	18.63	0.014	**
Weeding			
Herbicide (liters)	34.21	0.711	
Labor Days Weeding	-5.5	0.477	
Tillage Techniques			
Conventional Hand hoe	-2560	0.000	***
Ridges	-2770	0.129	**
Plow	-1726	0.005	**
Ripping	-371	0.718	

Source: Author. *** Statistically significant at the 99% confidence level. ** Statistically significant at the 95% confidence level.

Table 1 shows that only 20% of CF plots had basal fertilizer properly, beneath the seed as compared to only 6% of conventional plots. Late fertilizer delivery through FISP contributed to the low percentage of plots that properly applied basal. However, several households had their fertilizer prior to planting and still chose to apply it on top of the soil after the maize had germinated. One of the MACO camp officers promoted applying D compound in this fashion, likely to ease complaints about late fertilizer delivery. With such low quality extension advice, very few farmers really understand how their fertilizer works which certainly contributes to its ineffective conventional application techniques.

Our fertilizer analysis shows, somewhat alarmingly, that conventional tillage and conventional fertilizer application techniques were ineffective on average and that fertilizer used with local maize also had no significant effect on yields. Keep in mind that we believe our sample of CF adopters had above average access to extension and inputs and most households had used fertilizer for several years, yet our data show that they conventionally used it in wasteful and ineffective ways. Conversely, fertilizer used on basin plots and applied more judiciously was effective and profitable, likely due to the moisture retention of basins and the application techniques promoted by CFU.

3.5.2. Herbicide Usage

While fertilizer was an established technology at the time of our study, herbicides were a new technology and farmers were just beginning to use them. In the two growing seasons we spent working closely with smallholders, no technology was more readily adopted than herbicides. Twenty eight of the sixty two households interviewed applied herbicides to their maize plots in the 2010/11 growing season (Table 2). This was a large share of households considering how new herbicides were to the area: of all the households interviewed only one reportedly obtained herbicides the previous year (2009/10 growing season). In the 2011/12 season, however, we observed herbicides to be much more widely adopted by farmers using CF and conventional techniques alike. This observed rate of adoption suggests that farmers saw value in herbicides over hand weeding, a suggestion that was confirmed by our numerous conversations with CF adopters and conventional farmers. Yet our regressions consistently show a positive, but insignificant effect of herbicides on yields.

We would expect herbicides, if used properly, to positively impact yields by doing a better, timelier job of weed control than weeding with a hoe. In fact, we observed this to be to true in several maize plots in the area. However, the assumption that herbicides were generally used properly may be too strong. Mixing and applying herbicides is a technical process that, despite the CFU trainings on herbicides, few farmers understood completely. We visited at least one plot with damaged maize from an incorrect application of chemicals. Imprecise mixing and application of herbicides may have contributed to the insignificance of herbicides in our regressions.

Other possible causes of herbicides' insignificant effect are the infrequent weed control observed in our sample and possibly ill-timed herbicide applications. Our detailed labor data show that there were a total of 201 complete weed controls (herbicide applications and hand weedings) over 133 maize plots: an average of 1.5 weed controls per plot in the 2010/11 growing season. It is likely that most plots had high weed pressure and herbicide applications may have been too late. Timing is also important in weed control and it is possible that herbicides were applied after weeds were established and damage was already done to their maize. Alternatively, farmers may have applied herbicides early and then left the plot and waited too long to perform another weed kill allowing weeds to flourish and use valuable nutrients. Perhaps the infrequent weed control, possible ill-timed herbicide applications, and potential misuse of herbicides contributed to herbicides' insignificant effect. This does not, however, help explain why an increasing number of smallholders were willing to spend their scarce cash on an input that did not show a consistent effect on yields across households.

To clarify the rapid adoption of herbicides we first turn to our regressions in Tables 5, 7, and 8 where we see that our variable for hand weeding was also insignificant in all three regressions. Further, the effect of herbicides was at least consistently positive across all three regressions while the effect of our hand weeding variable was consistently negative. These results suggest that, while herbicides did not significantly impact yields, they did not, observably, do a poorer job of weed control than hand weeding.

Turning our attention to Table 9, we see that herbicides achieved a full weed kill in an average of 30 fewer labor days per hectare than hand weeding. Weeding is physically demanding work often done at a busy time of year for farm labor and, to most households, saving 30 weeding days of labor would be quite valuable. It is easy to see that herbicides would be an attractive option if a household had cash available even if they do not improve yields.

If we make the safe, and arguably generous, assumption that hand weeding and herbicides offered the same quality of weed control (or had the same effect on output) then Table 9 shows that herbicides were also more profitable than hand weeding. If a household could choose between hiring in labor to weed their maize plot at a cost of about 300,000 ZMK per hectare or purchasing three bottles of herbicide at around 50,000 ZMK per bottle and spraying their field using only one and a half days of labor per hectare, herbicides would be the faster and cheaper option.

From this analysis and from our conversations with these farmers, it seems very likely that herbicide adoption and use will continue to rise. This is an exciting prospect for rural households as our data suggest herbicides can save money, provide a more timely weed kill, and free household labor for other uses. We believe that, as farmers become more familiar with herbicides, they will use them more effectively and more consistently, and, ultimately, herbicides usage will result in better weed kills and higher maize yields.

However, these benefits come with the risk of misuse. From our fertilizer analysis we learned that, despite the fact that most households have been using fertilizer for several years, it is often used improperly.

Table 9. Herbicide and Hand Weeding Labor and Costs ('000 ZMK)

	# of obs.	Labor days per ha		Labor cost per ha		herbicide cost per ha (mean)	Cost for 1 ha of weed control	
		mean	median	mean	median		mean	median
Herbicide application	38	1.5	1.1	15	11	166	181	177
Hand-weeding	163	31.9	26.6	319	242	0	319	242

Source: Author.

Herbicides are less familiar, more technical to apply, and potentially much more dangerous if misused. While we did not observe any severe adverse effects, misunderstanding a chemical can result in total crop loss or physical harm.

We conclude that herbicides are attractive to farmers because they achieve an adequate weed kill using 30 fewer labor days per hectare than conventional hand weeding. We observed that herbicide use grew tremendously from the 2009/10 growing season to the 2011/12 growing season, and the growth will likely continue. While this new technology has exciting prospects for smallholder productivity and crop management, more research is needed to better understand the potential benefits and possible risks of more widespread herbicide use.

4. CONCLUSIONS

We reach three direct conclusions based on our data and our observations from time spent in the field. First, this research shows that CF techniques can be highly effective even in the first year of adoption. Basin plots showed higher yields and profits than conventional tillage plots both on average and, more importantly for continued adoption of CF, in 71% of the within household comparisons (Tables 4 and 6). While much of the increased production was likely attributable to the distribution of rainfall for our study area (shown in Figure 2), which was perhaps an ideal pattern to demonstrate the water harvesting ability of basins, CF techniques outperformed conventional techniques by a wide margin.

Input application techniques also contributed to the higher yields obtained in CF plots. Our second conclusion is that fertilizer was highly effective in CF plots, and, perhaps more alarmingly, fertilizer use had no significant impact on conventional plot yields. Fertilizer used with local maize seed varieties also had no significant impact on yields.

The group of CF adopting households was among the better farmers in our study area with good access to extension agents and, yet, they still applied fertilizer ineffectively on their conventional plots. Despite the fact that chemical fertilizers are an established and commonly used technology, many smallholders demonstrated that they do not know how to use them properly. The fertilizer application techniques promoted by CFU together with CF tillage proved to be a substantial and significant improvement to how fertilizer was commonly applied.

Our third conclusion is that herbicide adoption will likely continue to rise and more research is needed to better understand the benefits and costs of widespread herbicide use. Despite the fact that herbicides showed no significant yield effects on maize, farmers readily adopted the new technology because they saved household labor and were likely more profitable than hand weeding. While herbicides have the potential to save labor and increase yields and smallholder incomes, they also have serious risks of misuse.

APPENDIX

Full list of variables included in regressions.

Variable	Regression 1	Regression 2	Regression 3
Independent Var.			
Yield (kg/ha)	X	X	X
Dependent Variables			
Planting date	X	X	X
HYV dummy	X	X	X
Conventional hand hoe dummy	X	X	X
Ridges dummy	X	X	X
Plow dummy	X	X	X
Ripping dummy	X	X	X
Zero-tillage dummy	X	X	X
Plot size (ha)	X	X	X
Lime applied (kg)	X	X	X
Manure applied (kg)	X	X	X
Fertilizer applied (kg/ha)	X	X	X
Crop rotation dummy	X	X	X
Virgin land dummy	X	X	X
Female headed household dummy	X	X	X
Herbicides used (L/ha)	X	X	X
Weeding labor (days/ha)	X	X	X
Residues burned dummy	X	X	X
Fertilizer and HYV seed interaction term		X	
Fertilizer and local seed interaction term		X	
Fertilizer and basins interaction term			X
Fertilizer and Conventional hand hoe interaction term			X
Fertilizer and ridges interaction term			X
Fertilizer and plow interaction term			X
Fertilizer and ripping interaction term			X
Fertilizer and zero till interaction term			X

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