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PRODUCTIVITY IMPACT OF CONSERVATION FARMING ON SMALLHOLDER COTTON FARMERS IN ZAMBIA

by

Steven Haggblade and Christina Plerhoples

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The views expressed in this document are exclusively those of the authors.

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EXECUTIVE SUMMARY

Increasing agricultural productivity offers a potentially powerful tool for reducing poverty in Africa. But some skeptics question the feasibility of smallholder-based agricultural growth, particularly at the low end of the asset distribution where shortages of land, skilled labor, animal traction and financial assets mire the poorest farm households in a low-productivity treadmill.

This paper examines conservation farming (CF) as a possible tool for incrementally raising productivity and incomes among resource-poor farm households in Africa. Discussion focuses on asset-poor households in Zambia's cotton zone, where a majority of farm families till with a hand hoe but where CF is most well established and best suited agronomically. Using plot-level data and a linear programming optimization model, the paper quantifies the yield, area and income gains possible under CF for these resource-poor households.

The results suggest that CF can increase crop income by roughly 85% among the poorest category of smallholder cotton farmers, those without access to any cash inputs. Because CF reallocates heavy land preparation labor to the dry season, it relieves the peak-season labor bottlenecks that typically constrain area cultivated under rainfed hand hoe agriculture. While the typical smallholder farm household can manage only about 1.1 hectares under conventional hand hoe tillage, these same households can cultivate about 1.5 hectares under hand hoe CF.

A second category of farm households, using purchased input packages costing $60 per season, can double crop income under hand hoe CF using only household labor. Roughly two-thirds of the income gain stems from increased land productivity (higher yield), while the remaining one-third comes from area expansion made possible under CF. A third, highest cost option involves the use of herbicides to cut peak season labor requirements. This high-input package requires input purchases of fertilizer, hybrid seeds, and herbicides costing roughly $150 per season, but it enables farm households to triple crop income compared to low-input conventional tillage. By adding herbicides to the mix, hand hoe CF farmers can potentially cultivate as much as 2.7 hectares using only family labor.

Because cotton companies typically finance cotton input packages, and because cotton production and CF require disciplined, precise management, Zambia's smallholder cotton farmers constitute a self-selected group of small farmers well able to benefit from the productivity gains made possible under CF. Given the large potential income and output gains under herbicides, these merit careful testing for possible inclusion in cotton input packs.

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ACRONYMS

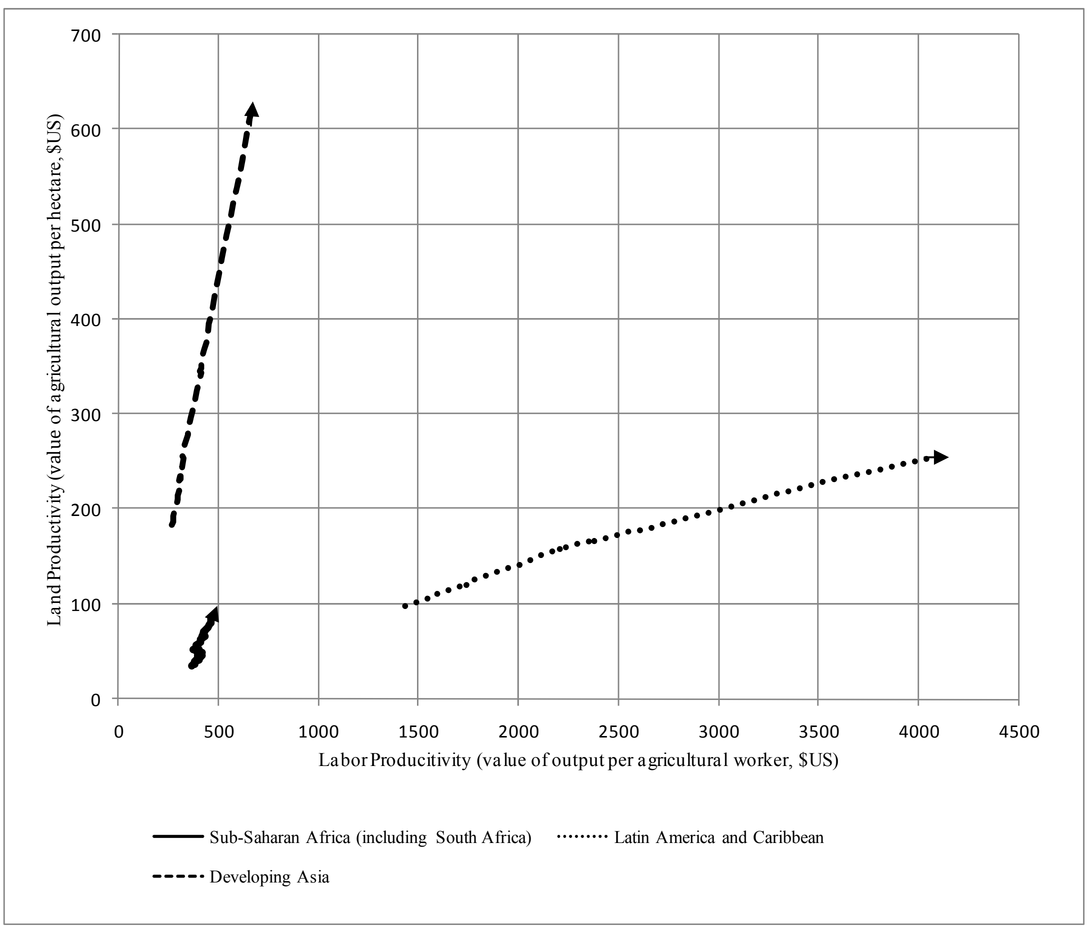
AEZ	Agro-Ecological Zone
AMIC	Agricultural Market Information Centre
CF	Conservation Farming
CFU	Conservation Farming Unit
CSO	Central Statistical Office
FAOSTAT	Food and Agricultural Organization Online Statistical Database
FSRP	Food Security Research Project
ICRSAT	International Center for Research in the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IMAG	Institute of Agricultural and Environmental Engineering
INESOR	Institute of Economic and Social Research
MACO	Ministry of Agriculture and Cooperatives
MSU	Michigan State University
ZNFU	Zambia National Farmers Union

1. OBJECTIVES

Low agricultural productivity lies at the heart of continued widespread hunger and poverty in Africa. Roughly two-thirds of Africa's poor work primarily in agriculture (IFPRI 2004). Yet their land and labor productivity remain the lowest in the world (Figure 1). As a result, African farmers produce output per worker valued at only half the level achieved in developing Asia, while land productivity in Africa, as measured by cereal yields, remains at one third of the level prevailing in developing Asia and Latin America (FAOSTAT 2010). Among all developing regions, only in Africa has agricultural productivity growth failed to keep pace with population over the past five decades (Figure 2).

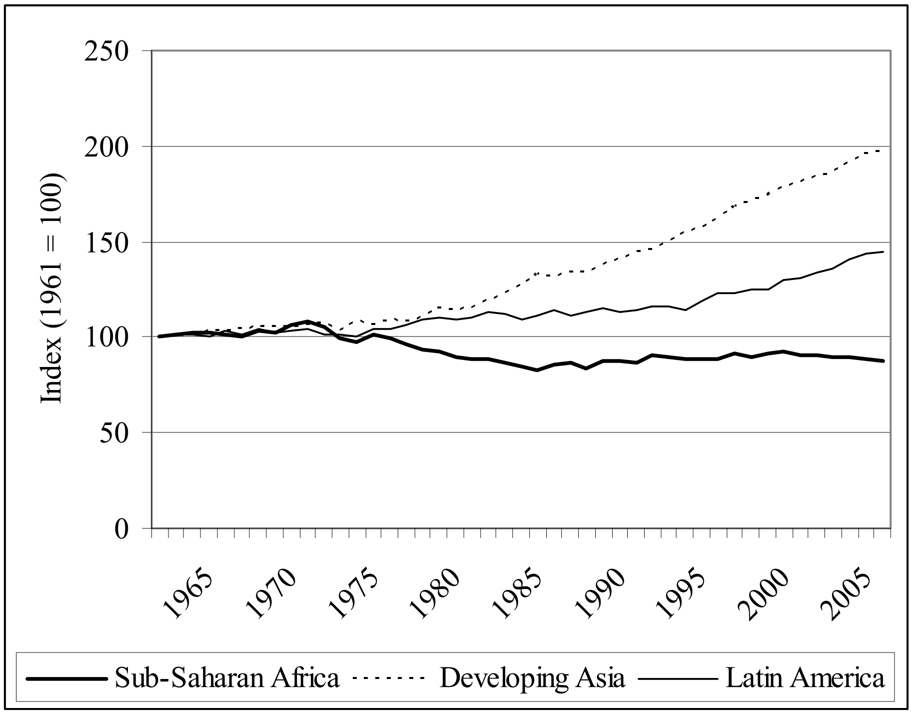
Increasing agricultural productivity, therefore, offers a potentially powerful tool for reducing poverty in Africa (World Bank 2007; Diao et al. 2007). Indeed, increased onfarm productivity attacks poverty from three different directions (Diao, Headey, and Johnson 2008). It increases the productivity and incomes of the majority of Africa's poor, who work primarily in agriculture. It reduces food prices, which govern real incomes and poverty in urban areas. And it stimulates important growth linkages with the rest of the economy Delgado, Hopkins, and Kelly 1998; Haggblade, Hazell, and Dorosh 2007). As a result, most empirical

Figure 1. Trends in Agricultural Factor Productivity, 1961 to 2003*



Source: FAOSTAT 2010. *The arrows at the tip of each time series indicate the value in 2003.

Figure 2. Trends in the Value of Agricultural Production Per Capita



Source: FAOSTAT 2010.

studies document strong poverty reduction from agricultural income growth (Thirtle, Lin, and Piesse 2003; Christiaensen, Demery, and Kuhl 2006; Bezemer and Headey 2008; World Bank 2008). Available estimates of poverty elasticities suggest that every 1 percent increase in agricultural income per capita reduces the number of dollar-a-day poor by between 0.6 and 1.8 percent, roughly 50% more than from comparable income gains in manufacturing or services (Thirtle, Lin, and Piesse 2003; Diao et al. 2007; Diao, Headey, and Johnson 2008).

Despite this potential, some skeptics question the feasibility of smallholder-based agricultural growth in Africa.[1] Particularly at the low end of the asset distribution, meager endowments of land, skilled labor, animal traction livestock, and financial assets combine with low-productivity agricultural technology to mire the poorest farm households in a low-productivity treadmill. Skeptics question the efficacy of an escape route via agriculture.

This paper examines conservation farming (CF) as a possible tool for incrementally raising the productivity and incomes of resource-poor farm households in Africa. Discussion focuses on asset-poor households in Zambia's cotton zone, where a majority of farm families till with a hand hoe, where livestock disease and household financial constraints severely limit animal traction, and where household labor constraints limit cultivated area to roughly 1 hectare per household.

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[1] Skeptics of smallholder agricultural growth include Bryceson and Jamal (1997); Maxwell (2005); Ellis (2005); and Collier (2008 and 2009). For more optimistic perspectives on the prospects for smallholder agriculture see Lipton (2005); Hazell et al. (2007); Bezemer and Headey (2008); Byerlee and de Janvry (2009); World Bank (2008); Haggblade (2009); and Headey, Bezemer, and Hazell (2010).

CF offers a package of agronomic practices for raising agricultural productivity on farms of varying resource levels. The hand hoe and animal traction CF packages developed by Zambia's Conservation Farming Unit (CFU) raise crop yields in several ways. Minimum tillage, crop residue retention and fixed planting stations build up soil organic matter, soil structure and water retention capacity. Leguminous crop rotations build up soil fertility through biological nitrogen fixation. Water harvesting, in fixed planting basins and rip lines, enable crops to withstand dry spells and simultaneously improve responsiveness to small but targeted doses of mineral fertilizer. Dry season minimum tillage likewise boosts yields by enabling farmers to plant with the first rains. Early planting, in turn, favors good crop establishment as well as benefits from the biological nitrogen flush that occurs after the first rains. CF, thus, increases land productivity and crop yields through a variety of improved agronomic practices.

A second important but much-less-discussed benefit involves area expansion made possible by reducing peak season labor bottlenecks. Under rainfed agricultural production, common throughout most of Africa, labor bottlenecks at planting and weeding times often critically constrain farm output (Cleave 1974; Ruthenberg 1980; Collinson 1983; INESOR 1999; Lee, Barrett, and McPeak 2006). During the four to six week period following the first rains, farmers must prepare their soil, plant and conduct the critical first weeding. Under CF, dry-season land preparation using minimum tillage methods enables farmers to reallocate heavy land preparation to the slack agricultural season. So during the peak agricultural season, right after the first rains, they are able to concentrate household labor on early planting and weeding of expanded areas. This increases labor productivity by allowing farm households to cultivate greater areas with available household labor.

This paper aims to quantify these two productivity-enhancing dimensions of CF. Using micro-economic evidence from Zambia's cotton belt, the paper applies a linear programming model to measure the magnitude of yield, area and income gains under different conventional and CF packages. The analysis examines households with varying sets of resource constraints and evaluates prospects for moving them up the economic ladder towards higher productivity, more commercially oriented agriculture.

2. A PRIMER ON CONSERVATION FARMING

2.1. Agronomics

2.1.1. Key Agronomic Practices

Conservation farming (CF), as practiced in Zambia, involves a package of several key practices: dry-season land preparation using minimum tillage systems; crop residue retention; seeding and input application in fixed planting stations; and nitrogen-fixing crop rotations (CFU 2007a and 2007b). For hand hoe farmers, CF revolves around dry-season preparation of a precise grid of 15,850 permanent planting basins per hectare, with each basin 20 cm deep, 30 cm long and the width of a hoe blade. Unlike the conventional hand-hoe and plowing technologies they replace, CF requires moving only about 15% of the soil where crops will be planted. For farmers with access to animal traction, CF technology involves dry-season ripping, normally with the locally developed Magoye Ripper. For large-scale commercial farmers, mechanized minimum tillage with leguminous crop rotations such as soybeans, green gram, and sunhemp completes the ladder of CF technologies.

CF in Zambia represents a local variant of minimum tillage technologies adopted in many parts of Africa. Similar hand hoe planting basin systems have emerged across much of the Sahel as well as in Cameroon, Nigeria, Uganda, Tanzania, and Zimbabwe (Critchley, Reij, and Willcocks 1994; Reij and Waters-Bayer 2001; Goddard et al. 2007). Ox-drawn rippers have expanded recently in Tanzania, Kenya, and Namibia, while early work with tractor-drawn minimum till systems in Zimbabwe and South Africa provided much of the inspiration for subsequent transfer of reduced tillage practices to ox and hand-hoe cultivation systems (Oldrieve 1993; IMAG 2001). The CF packages currently promoted in Zambia emerged in the mid 1990's, building explicitly on early minimum tillage work among commercial and smallholder farmers in Zimbabwe (Oldrieve 1993; CFU 1997).

2.1.2. Yield Gains

CF practices improve soil fertility in a variety of ways. By concentrating organic matter and fertilizer in fixed planting stations, CF focuses on improving soil structure and fertility in zones of immediate proximity to the planted crops – in basins or along rip lines – where they will provide the greatest benefit. By breaking through pre-existing hoe pan or plow pan layers, the CF technologies aim to improve water infiltration and root development while also harvesting water in years of sporadic rainfall. By reallocating land preparation to the dry season, in advance of the rains, CF redistributes heavy labor and draft power requirements outside the peak agricultural season. Early land preparation likewise enables farmers to sow with the first rains when the plants will benefit from the initial nitrogen flush in the soil. Over time, CF systems aim to improve soil structure, soil organic matter, and soil fertility in the fixed planting stations.

As a result, most studies of CF document substantially higher yields on CF plots – often double those achieved under conventional tillage (Arulussa 1997; INESOR 1999; Langmead 2001 and 2002; Stevens et al. 2002; Haggblade and Tembo 2003; Twomlow and Hove 2006). Though gains vary across locations and over time, evidence from central Zambia suggests that about 25% of observed gains under CF stem from higher input use, another 25% from early planting, and about 50% of the yield difference stems from CF cultural practices themselves – the retention of crop residue, the build-up of soil organic material and concentration of nutrients in the basins, and the water harvesting effects of the basins during the sporadic rainfall common in the semi-arid zones of Africa (Haggblade and Tembo 2003).

2.1.3. Energy Savings

Unlike conventional tillage, which involves complete soil inversion, CF adopts minimum tillage practices under which farmers move only a small fraction of their topsoil – about 15% in hand-hoe CF and even less under animal traction and tractor-pulled rippers. Moving less soil requires less energy. Indeed, high fuel costs and the potential for significant fuel savings motivated the early investigation of minimum tillage technologies by commercial farmers in Zambia and Zimbabwe (Vowles 1989). Zambian commercial farmers discovered that low-till cultivation enabled them to reduce fuel consumption by 75%, from 120 to 30 liters per hectare, dramatically improving the profitability of mechanized maize production. Parallel benefits of reduced soil compaction and improved soil structure became apparent later to the early adopters (Hudson 1995; The Farmer 1995).

2.1.4. Area Expansion

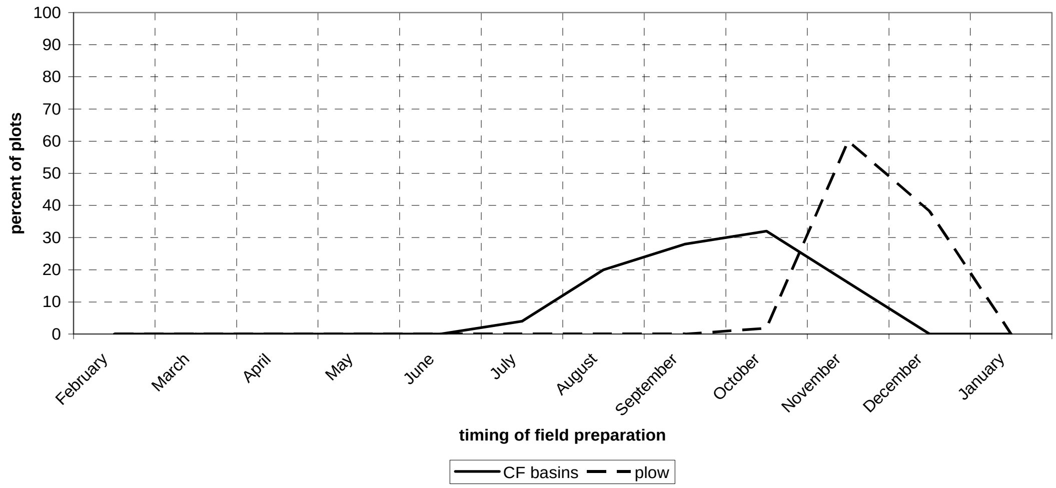
Under conventional tillage, which involves complete soil inversion, farmers must wait for the first rains to prepare their fields. As a result, they must complete their heavy land preparation as well as their first weeding during the first month after the planting rains. Under these circumstances, early season labor constraints, particularly during the first weeding, set an upper bound on the cropped area a family can manage using only household labor. For the average farm household in central Zambia, with five family members, peak-season labor bottlenecks limit the area they can cultivate under conventional hand hoe tillage to about 1 hectare.

In contrast, CF households can prepare their fields during the dry season, because they move only a small fraction of their topsoil. As a result, CF farmers prepare their fields two to three months earlier than farmers practicing conventional tillage (Figure 3). Veteran CF farmers prefer land preparation at the very beginning of the dry season, when residual moisture makes basin preparation easiest. Moreover, the labor required to dig CF basins diminishes over time as soil structure improves in the fixed planting stations (Figure 4). Given dry season land preparation, CF farmers are able to manage larger areas than they could under conventional tillage by planting early, with the first rains and then concentrating available household labor on weeding of their expanded plots. Labor productivity increases under CF because it enables farm families to cultivate greater areas with available household labor.

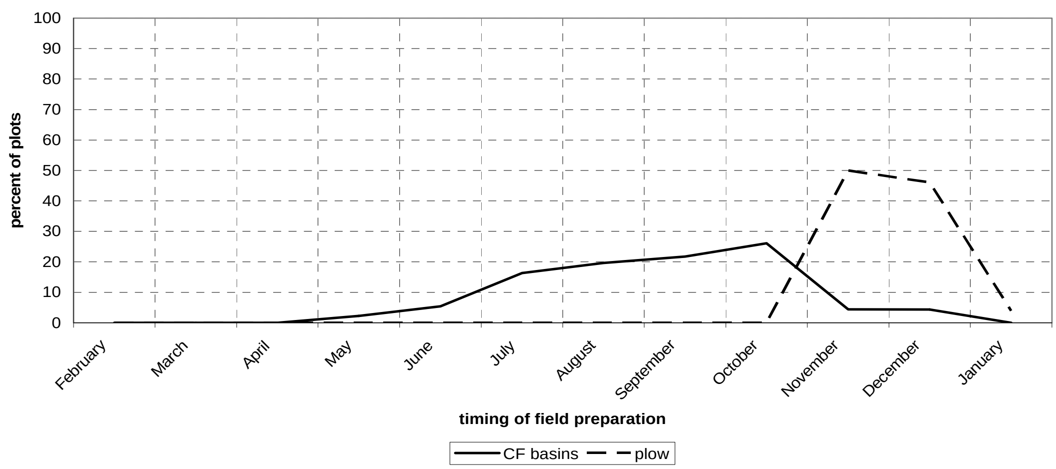
2.2. Agro-Ecological Zones

CF technology development and extension efforts in Zambia have focused on the arid and semi-arid central and southern sections of Zambia, in Agro-Ecological Zones

Figure 3. Timing of Land Preparation, by Tillage Method, Zambia 2001



a. cotton plots

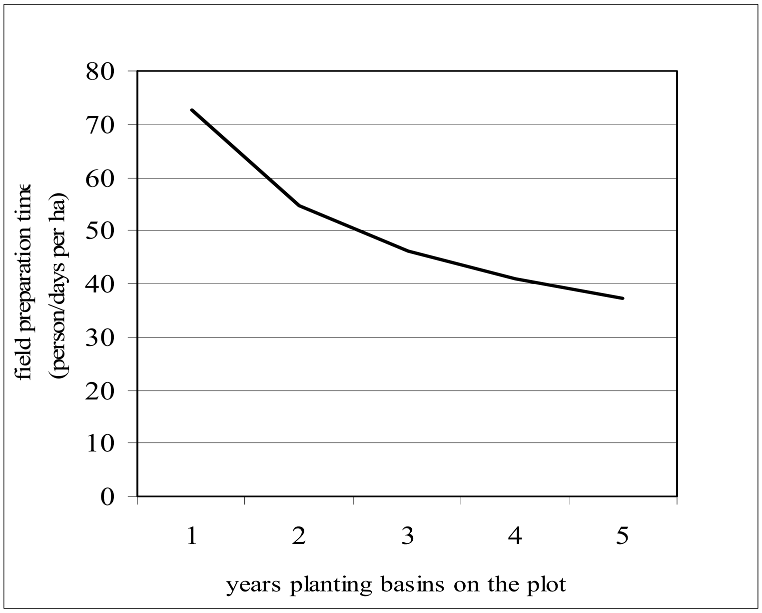


b. maize plots

Source: Haggblade and Tembo (2003).

(AEZ) 1 and 2a (Langmead 2002; CFU 2002). Zambia's most arid farming zone, AEZ 1, receives less than 800 mm of rainfall in most years and lies mostly in the southern and eastern parts of the country (Figure 5). Given low rainfall, it remains sparsely populated. Semi-arid AEZ2a occupies the more populous middle section of Zambia. Forty percent of Zambian farm households, and over 95% of cotton farmers, operate in AEZ2a, where rainfall lies between 800 and 1,000 mm per year and where generally good access to markets makes commercial farming attractive (Table 1). From its inception, in 1996, Zambia's Conservation Farming Unit (CFU) began working in AEZ1 and 2a, because of their amenability to water-conserving dry-season tillage and because of their proximity to major commercial markets.

Figure 4. Declining Labor Requirements over Time for Digging Conservation Farming Basins



Source: Haggblade and Tembo (2003).

Figure 5. Zambia's Agro-Ecological Zones

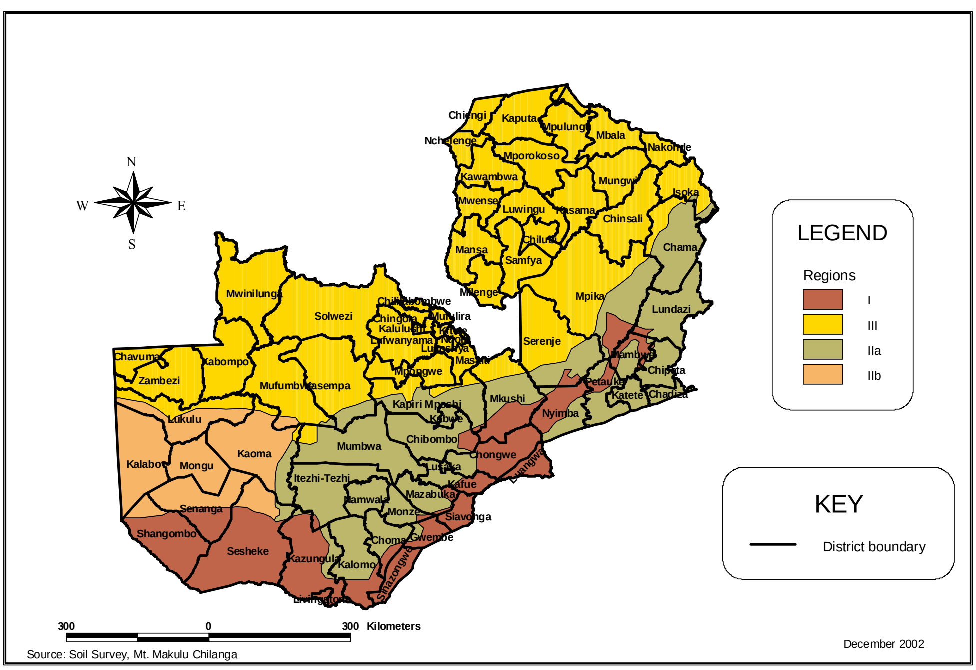


Table 1. Number of Farming Households in Zambia, by Agro-Ecological Zone

	Agro-Ecological Zone					
	1	2a	2b	3a	3b	Total
Total farm households						
number	73,313	513,218	105,543	433,751	141,319	1,267,145
percent	6%	41%	8%	34%	11%	100%
Cotton growing households						
number	5,008	126,096	0	127	0	131,230
percent	4%	96%	0%	0%	0%	100%

Source: Supplemental Post-Harvest Survey of 2002/03.

Zambia's Ministry of Agriculture partitions the country's middle rainfall belt into two parts, based on differences in soil type. The western portion of AEZ2 , referred to as AEZ2b, falls within the same 800 to 1,000 mm rainfall bounds as AEZ2a. However, unlike AEZ2a, the western zone (AEZ2b) is endowed with very sandy soils. These make permanent planting stations and water harvesting difficult. Long distances to the line of rail and to major export markets result in a distinct pattern of crop and livestock farming. These characteristics result in lower potential for both CF and commercial agriculture in general.

Both rainfall and temperature increase in northern and northwest Zambia, in AEZ 3. Rainfall exceeds 1,000 mm per year, and as a result, the region enjoys a growing season roughly one month longer than in AEZ2a. Because moisture rarely constrains farm output in Zone 3, water-harvesting technologies such as CF basins are not appropriate there.[2] For this reason, Zambia's Conservation Farming Unit focused its early technology development and extension efforts predominantly in AEZ2a, in the heart of Zambia's cotton belt.

2.3. Cotton and Conservation Farming

Cotton farmers rank among the earliest and most loyal adopters of CF, in large part because the CF practices of early land preparation, early planting, early weeding, precise field layout and careful input application coincide with best-practice management for cotton farming. Zambian farmers grow cotton, a 160-day crop, under roughly 130 days of rainfall. To do this successfully requires early planting and good soil moisture retention, both key outcomes of CF agronomic practices. Because cotton is long-cycle crop, early planting is critical to achieving good yields. Cotton extension specialists estimate that, on average, cotton yields fall by 100 kg for each week late the crop is planted (Birgess 2009).[3] This makes CF dry season land preparation particularly valuable to cotton farmers and to the ginners whose viability depends on high levels of capacity utilization, which in turn, depends on the productivity of the smallholder cotton farmers who supply them with cotton lint.

[2] Although Zambia's Conservation Farming Unit has developed a separate CF technical package for the high-rainfall Agro-Ecological Zones III, extension efforts have focused on the semi-arid regions (Langmead 2002; CFU 2002)

[3] Econometric estimates during one season place the gains at about 30-60 kg per week (Haggblade and Tembo 2003).

Because of these complementarities between cotton production and CF, Zambia's largest cotton company, Dunavant,[4] actively engaged the CFU, at its launch in the mid-1990s, to help in their extension program (Arulussa 1997; CFU 2006). Many of Dunavant's distributor farmers – the lead farmers through whom the company distributed inputs, credit and information on key management practices to their cotton farmers – served as CF demonstration farmers. As a result, cotton farmers constitute the single largest group of CF adopters in Zambia (Haggblade and Tembo 2003).

The discipline required for successful cotton production meshes well with the disciplined management required by CF. Because cotton production demands careful attention to planting date, regular weeding, constant spraying, and insect monitoring, as well as repeated careful hand harvesting, cotton farmers constitute a self-selected group of diligent, hard-working, professional small farmers. Not surprisingly, given these complementarities, Zambia's CFU focused its first decade of field trials, demonstrations and extension efforts in the cotton belt of Central Province, attracted by the discipline of the cotton farmers, the keen interest of the Dunavant cotton company and Dunavant's willingness to financially support CF extension for its lead cotton farmers. Reciprocal benefits generated a mutual attraction between cotton farmers and Zambia's CFU. Since the beginning of CF extension efforts in Zambia, during the mid 1990's, CF and cotton production have grown together.

This paper focuses on smallholder cotton farmers in AEZ2a of Zambia, for several reasons. First, cotton farmers constitute the single largest group of commercial smallholder farmers in Zambia, over 100,000 strong (Table 1). Because of cotton's demanding agronomics, they are among the most disciplined smallholder farmers in Zambia. Secondly, cotton production takes place in the agro-ecological and commercial zone where CF has been promoted the longest and has advanced furthest. Therefore, CF technology packages are generally available to this group of small farmers. Third, Zambia's cotton farmers are generally resource-poor smallholders. As the following evidence will reveal, they hold lower stocks of key assets than other smallholder farmers hold and have less access to nonfarm cash earnings. Cotton farmers in AEZ2a, thus, offer an ideal test group for evaluating the impact of improved CF technology on productivity among resource-poor smallholder farmers.

[4] Dunavant became the largest cotton ginner in Zambia in 1997 when the company bought assets of the defunct government parastatal, Lintco, from Lonrho cotton. Dunavant operated in Zambia until 2009 when they sold their gins and other assets to Allenberg Cotton, a division of Louis Dreyfus.

3. DATA AND METHODS

3.1. Optimization Methods

To quantify the potential productivity gains available from the adoption of alternate technology packages, the following analysis applies standard linear programming methods. The basic model maximizes crop income, given standard input-output coefficients and subject to a set of household asset constraints, including farm labor, land and cash. Equation (1) formulates the optimization problem formally, as follows:

(1) Maximize crop income = $\Sigma_i P_i Q_i - \Sigma_n P_n I_n,$

where the subscript "i" refers to the three outputs (maize, groundnuts, and cotton) and "n" refers to the purchased inputs used in production of these three crops:

a) Subject to household labor constraints:

Labor use (early rains) $\leq$ Labor available (early rains)
Labor use (mid-season) $\leq$ Labor available (mid-season)
Labor use (harvest season) $\leq$ Labor available (harvest season)
Labor use (dry season) $\leq$ Labor available (dry season)

b) Subject to land constraints

Land farmed $\leq$ Land owned

c) Subject to cash constraints

Input costs $\leq$ available household cash earnings.

Given wide swings in marketed food supplies and prices from one year to the next, particularly for maize, many farm households seek to produce a minimum basket of staple foods to ensure household food security. Under this "security first" scenario, households add the following additional constraint:

d) Subject to minimum staple food production

Staple food production (Q_i) $\geq$ minimum household security requirements.

3.2. Data

The baseline data for these optimization simulations draw from a nationally representative farm household survey conducted in Zambia in 2004. Conducted by Zambia's Central Statistical Office, the survey was designed as an in-depth supplement to the annual Post-Harvest Survey. With a sample size of 5,100 farms and 16,600 individual cultivated plots, these data provide household-level information on asset holdings, land allocation, and labor availability. The survey data likewise provide plot-level information on purchased input use, outputs produced, tillage methods, crop rotations and other agronomic practices (see Central Statistical Office 2004).

Standard labor input requirements under conventional farming technologies draw on prior work by Siegel and Alwang (2005). We have supplemented these with detailed input from the CFU about the labor requirements and timing of land preparation, weeding, insect monitoring, spraying, harvesting, and post-harvest operations under both conventional and CF packages as well as with herbicides (Annex Table A.1).

Baseline budgets value all inputs and outputs using 2009/10 prices obtained from Zambia's Agricultural Market Information Centre (AMIC), input suppliers, and cotton companies (Annex Table A.2). The following section uses these data to provide an empirical profile of smallholder cotton farmers in Agro-Ecological Zone 2a of Zambia.

4. A PROFILE OF SMALLHOLDER COTTON FARMERS IN AGRO-ECOLOGICAL ZONE 2A

4.1. Cropping Patterns

Cropping patterns in Agro-Ecological Zone 2a focus heavily on three major crops: maize, cotton, and groundnuts. Virtually all households grow maize, while roughly half plant groundnuts and one quarter also produce cotton (Table 2). To a lesser extent, farm families also cultivate sweet potatoes, sunflower, cassava, an assortment of different beans and secondary cereals. Given the dominance of maize, cotton and groundnuts – across the zone and among cotton farmers – the optimization scenarios in this paper focus on land and labor allocation among these three principal crops.

4.2. Farm Size Distribution

Zambian farms range in size from dozen or so large corporate estates managing thousands of hectares to over one million smallholder farms managing less than five hectares each (Siegel and Alwang, 2005). The largest farms dominate production of wheat and soybeans, while the small and medium scale farms dominate the production of coarse cereals and cotton. Among cotton producers, farms less than five hectares account for 98% of national production.

To differentiate among this wide dispersion of farm types, Zambia's Ministry of Agriculture and Cooperatives (MACO) classifies small and medium scale farms into three size categories. Category A farmers manage less than 2.5 hectares, while Category B farmers operate between 2.5 and 5 hectares, and Category C farms have between 5 and 20 hectares under cultivation or managed fallow.

Table 2. Crop Cultivation in Agro-Ecological Zone 2a of Zambia

	All Households in AEZ2a			Cotton Farmers in AEZ2a		
Crop	% hh	ha/hh	total hectares	% hh	ha/hh	total hectares
maize	98%	1.09	558,261	99%	1.06	135,367
cotton	25%	0.23	118,890	100%	0.93	118,890
groundnuts	48%	0.20	100,167	56%	0.22	27,756
sweet potatoes	16%	0.05	26,503	7%	0.02	2,397
sunflower	11%	0.07	34,771	15%	0.09	11,739
beans	7%	0.02	11,441	4%	0.01	1,607
cassava	7%	0.03	15,468	3%	0.01	1,289
sorghum	6%	0.03	14,499	2%	0.01	881
soya beans	5%	0.02	12,063	3%	0.02	2,558
cowpeas	5%	0.01	7,158	2%	0.01	1,137
tobacco	3%	0.02	10,468	3%	0.01	1,775
millet	3%	0.01	5,063	1%	0.00	321
rice	2%	0.01	2,833	3%	0.01	894
other crops	3%	0.01	4,751	2%	0.01	852

Source: CSO 2004.

Table 3. Farm Size Distribution in Agro-Ecological Zones 2a of Zambia, 2003

Farm Size	Households		Cultivated Area	
	%	number	total hectares	mean ha per family
All farming households in AEZ2a				
A1. 1.5 ha or less	46%	237,608	198,454	0.8
A2. 1.51 to 2.5 ha	26%	133,824	237,394	1.8
B. 2.51 to 5 ha	21%	107,359	297,887	2.8
C. 5 to 20ha	7%	34,427	225,720	6.6
Total	100%	513,218	959,455	1.9
Cotton farming households in AEZ2a				
A1. 1.5 ha or less	29%	36,967	39,599	1.1
A2. 1.51 to 2.5 ha	31%	38,788	71,958	1.9
B. 2.51 to 5 ha	30%	38,113	116,002	3.0
C. 5 to 20ha	10%	12,228	79,296	6.5
Total	100%	126,096	306,854	2.4

Source: CSO 2004.

Using the MACO classification, Table 3 describes the size distribution of the small and medium-scale holdings (those under 20 hectares) in AEZ2a. Three-fourths of all farms in this zone, and 60% of cotton farmers, operate less than 2.5 hectares of land. Indeed, nearly half of all farms, and 30% of cotton farmers, operate 1.5 hectares or less.

These data on farm size distribution reveal that cotton farmers differ in some ways from non-cotton farmers. In terms of cropped area, cotton farmers cultivate 25% to 50% greater area than non-cotton farmers in AEZ2a. Among the smallest of these farms, the A1 group, farmers till roughly 1.1 hectares of land by hand hoe, roughly 25% more than the 0.8 hectares cultivated by non-cotton farmers (Table 4). Though both cotton and non-cotton farmers cultivate about half a hectare of maize and 0.1 ha of groundnuts, the cotton farmers add 0.4 ha of cotton to the mix, leading to larger overall cropped area.

4.3. Tillage Systems

Hand hoe tillage predominates among farms with less than 2.5 hectares, while animal traction dominates among farms over 2.5 hectares. For this reason, labor availability generally sets the upper limit on area cultivated by the smallest (Category A) farm households.

Cotton farmers in these smallest size classes (the Category A1 and A2 farmers) prepare land primarily using a hand hoe. Farmers in Category A1, who cultivate less than 1.5 hectares, till roughly three-fourths of their land with a hand hoe while using oxen on the remaining one quarter (Table 5). Because of the prevalence of hand hoe agriculture among small farmers in Zambia, CF technology development and extension efforts have devoted considerable attention to the hand-hoe variant of CF, using a precise grid of hand-dug basins.

Table 4. Cropping Pattern, by Farm Size in AEZ2a

Farm Size	Average Area Cultivated per Household (ha)				
	maize	cotton	groudnuts	other	total
Households not growing any cotton					
A1. 1.5 ha or less	0.58	0.00	0.09	0.12	0.79
A2. 1.51 to 2.5 ha	1.16	0.00	0.23	0.35	1.74
B. 2.51 to 5 ha	1.81	0.00	0.29	0.53	2.63
C. 5 to 20ha	4.89	0.00	0.47	1.23	6.60
Total	1.19	0.00	0.18	0.31	1.69
Cotton farming households in AEZ2a					
A1. 1.5 ha or less	0.50	0.42	0.09	0.06	1.07
A2. 1.51 to 2.5 ha	0.79	0.71	0.23	0.12	1.86
B. 2.51 to 5 ha	1.39	1.16	0.27	0.22	3.04
C. 5 to 20ha	2.87	2.51	0.42	0.70	6.48
Total	1.09	0.94	0.22	0.19	2.43

Source: CSO 2004.

Table 5. Share of Cropped Area, by Tillage Method, among Cotton Famers in AEZ2a

Farm Size	Tillage Method			Total
	hand hoe	oxen	tractor	Cultivated
A1. 1.5 ha or less	73%	26%	1%	100%
A2. 1.51 to 2.5 ha	63%	36%	1%	100%
B. 2.51 to 5 ha	33%	65%	2%	100%
C. 5 to 20 ha	29%	69%	3%	100%
Total	44%	54%	2%	100%

Source: CSO 2004.

4.4. Asset Holdings

In terms of asset holdings, cotton farmers manage slightly more land with similar amounts of family labor but with fewer cattle, fewer tractors and less cash income than non-cotton farmers (Table 6). Indeed, the difference in cash income earnings is striking. Cotton farmers earn half as much wage and business income as non-cotton farmers. This holds true for annual cash earnings as well as those accruing during the fourth quarter of the calendar year, when the bulk of agricultural input purchases take place.

These data suggest that may cotton attract farm households with few alternative means of earning cash income. Certainly one major attraction of cotton farming is that Zambia's cotton companies provide inputs on credit. Moreover, they do so on a large scale; cotton is the largest out-grower crop in Zambia. Cotton farmers receive inputs on credit from the cotton companies, who then deduct these input loans at harvest time when marketing the farmers' cotton. Given the dearth of agricultural input credit financing available through Zambia's rural financial system, contract crops such as cotton enable cash-constrained rural households a feasible pathway to participating in high-input commercial crop production.

Table 6. Asset Holdings by Farm Size, Agro-Ecological Zone 2a

Farm Size	Land (ha/hh) total*	Land (ha/hh) cultivated	Labor hh size	Labor FTE**/hh	Cattle (per hh) total	Cattle (per hh) trained oxen	Tractors (per hh)	Cash Income (M K/hh) annual	Cash Income (M K/hh) Oct-Dec
All farming households in AEZ2a									
A1. 1.5 ha or less	0.9	0.8	5.3	1.7	2.3	0.3	0.1	3.3	0.7
A2. 1.51 to 2.5 ha	2.0	1.8	6.0	1.9	2.5	0.6	0.1	4.4	1.0
B. 2.51 to 5 ha	3.2	2.8	6.6	2.1	4.0	1.0	0.0	4.4	1.0
C. 5 to 20ha	9.6	6.6	8.0	2.6	10.2	1.8	0.0	9.9	2.3
Total	2.3	1.9	5.9	1.9	3.2	0.6	0.1	4.4	1.0
Farming households not growing any cotton									
A1. 1.5 ha or less	0.9	0.8	5.3	1.6	2.6	0.4	0.1	3.5	0.8
A2. 1.51 to 2.5 ha	2.0	1.7	6.0	2.0	2.9	0.7	0.1	5.0	1.1
B. 2.51 to 5 ha	3.4	2.6	6.6	2.1	4.5	1.0	0.0	5.0	1.2
C. 5 to 20ha	10.6	6.6	7.8	2.6	11.2	1.6	0.1	12.2	2.9
Total	2.1	1.7	5.8	1.9	3.5	0.6	0.1	4.8	1.1
Cotton farming households in AEZ2a									
A1. 1.5 ha or less	1.1	1.1	5.2	1.8	0.7	0.2	0.0	1.6	0.4
A2. 1.51 to 2.5 ha	2.0	1.9	6.0	1.9	1.6	0.4	0.0	2.0	0.4
B. 2.51 to 5 ha	3.4	3.0	6.5	2.1	0.9	0.0	0.0	2.9	0.7
C. 5 to 20ha	7.8	6.5	8.3	2.7	2.0	0.1	0.1	5.0	1.0
Total	2.7	2.4	6.1	2.0	0.7	0.0	0.0	2.5	0.5

Source: CSO 2004.
* total land = cultivated land plus fallow land.
** FTE = full-time adult male labor equivalent. See Table A.1 for details.

The following discussion evaluates prospects for increasing productivity among the smallest category of smallholder cotton farms, the A1 farms that currently cultivating roughly 1 hectare per household using conventional technology. The analysis assesses the extent to which CF technology packages can improve household productivity and incomes among this resource-constrained group of smallholder cotton farmers.

5. ALTERNATE TECHNOLOGY PACKAGES

5.1. Conventional Hand Hoe Packages

Smallholder farmers can choose from among a range of input packages and management practices for all three of their major crops (Table 7). For maize cultivation, farmers can select either low- or high-input conventional hand hoe packages. The low-input package (M1) relies on recycled local varieties of maize seed and no fertilizer. It requires no cash inputs and results in low yields of about 1 ton per hectare.

In contrast, the high-input maize package (M2) involves purchase of hybrid seeds and fertilizer costing about 1.2 million Kwacha ($250) per hectare. Under officially recommended fertilizer doses, which most farmers do *not* follow, input costs would rise an additional $190 per hectare. Despite official MACO recommendations of 400 kg of fertilizer per hectare (200 kg of basal and 200 kg of top dressing), farmers planting high-input maize packages use an average of 250 kg of fertilizer per hectare, according to our analysis of the 2003 Central Statistical Office (CSO) crop survey data (CSO 2004). Mize yields more than double, from 1 ton per hectare to 2.2 tons, when farmers move from M1 to M2. However, input costs rise faster. Given the fertilizer price of 3,600 Kwacha per kilogram ($750 per ton) prevailing in 2009, returns to both labor and land fall for the high-input (M2) package.[5] In these circumstances, low-input conventional maize packages (M1) prove more profitable than the high-input technologies (M2) (Table 8).

Groundnuts, similarly, come in low- and high-input packages. The low-input package using recycled seeds (GR1) requires no purchased inputs and yields about 340 kg/hectare. With purchased inputs of improved seeds and lime (GR2), costing about 365,000 Kwacha ($80) per hectare, farmers increase their groundnut yields by 66%.

Smallholder cotton farmers receive a standard input package, on credit, from the cotton companies for whom they grow. Zambia's cotton companies generally do not provide fertilizer on credit to their contract farmers because of its low profitability on cotton and because their early experience with fertilizer distribution resulted in farmers diverting the bulk of the fertilizer to their maize plots. As a result, smallholder cotton farmers all use the same input package of improved seeds and sprays, but no fertilizer. Under both conventional and conservation tillage, the standard one-hectare cotton pack costs about 140,000 Kwacha ($30) per hectare. Cotton yield under conventional hand hoe tillage (COT1) rarely exceeds 800 kilograms per hectare (Tschirley and Kabwe 2007).

5.2. Hand Hoe Conservation Farming

5.2.1. Hand Weeding

CF technologies for maize (M3, M4, and M5) enable farmers to redeploy land preparation from the peak season, following the initial rains, to the dry season. This raises dry-season labor requirements by about 20 person-days per hectare. But in doing so,

[5] Note that this represents a decrease from the 4,400 Kwacha per kilogram ($880 per ton) price prevailing in 2008.

Table 7. Cropping Technologies Available to Hand Hoe Cotton Farmers in AEZ2a

Crop Technologies							Labor Requirements, by Season (persondays/ha)					Purchased Inputs (quantity per hectare)*							
Code	Crop	Tillage	Variety	Fertilizer	Herbicides	Yield (kg/ha)	Early rains	Mid Season	Harvest Season	Dry Season	Total	Basal Fertilizer	Top Dressing	Pesticides (1 ha pack)	Seeds	Lime	Herbicide (liters)	Ripper Rental	Plow Rental
M1	Maize	Hoe	Local			1,000	37	18	21	11	87								
M2	Maize	Hoe	Hybrid	Yes		2,200	47	27	25	15	113	125	125		25				
M3	Maize	CF Basins	Local			1,400	31	25	37	34	127								
M4	Maize	CF Basins	Hybrid	Yes		3,000	35	29	50	34	148	125	125		25				
M4h-lite	Maize	CF Basins	Hybrid	Yes	1 round	3,000	17	11	50	34	112	125	125		25		3		
M4h-full	Maize	CF Basins	Hybrid	Yes	3 rounds	3,000	15	9	50	34	108	125	125		25		7		
M5	Maize	CF Ripper - rental	Hybrid	Yes		3,000	35	29	50	3	117	125	125		25			1	
M6	Maize	Ox - rental	Local			600	20	13	16	6	55								1
M7	Maize	Ox - rental	Hybrid	Yes		1,800	28	20	25	15	88	125	125		25				1
M8	Maize	Ox - owned	Hybrid	Yes		2,400	28	20	27	16	91	125	125		25				
GR1	Groundnuts	Hoe	Local			340	46	23	32	48	148								
GR2	Groundnuts	Hoe	Improved			565	49	25	46	68	187				25	200			
COT1	Cotton	Hoe	Hybrid			800	38	32	40	3	112			1					
COT2	Cotton	CF Basins	Hybrid			1,150	27	25	66	34	152			1					
COT2h-lite	Cotton	CF Basins	Hybrid		1 round	1,150	9	7	66	34	116			1			3		
COT2h-full	Cotton	CF Basins	Hybrid		3 rounds	1,150	7	5	66	34	112			1			7		
COT3	Cotton	CF Ripper - rental	Hybrid			1,150	27	25	66	3	121			1				1	
COT4	Cotton	Ox - rental	Hybrid			800	21	25	40	3	89			1					1
COT5	Cotton	Ox - owned	Hybrid			950	21	25	45	3	94			1					

Source: Siegel and Alwang 2005; CSO 2004; Conservation Farming Unit 2008.
* Kilograms per hectare unless otherwise indicated.
** Shading indicates conservation farming technologies.

Table 8. Returns to Labor and Land among Hand Hoe Farmers in AEZ2a

Technology Code	Crop	Tillage	Yield (kg/ha)	Costs and Returns ('000 Kwacha) Revenue	Input Cost Cash	Input Cost Credit	ANTRAC Rental	Gross Margin	Labor (days) Peak	Labor (days) Total	Returns to Labor (Kwacha/day) Peak	Returns to Labor (Kwacha/day) Total
M1	Maize	Hoe	1,000	720	0	0	0	720	37	87	20	8
M2	Maize	Hoe	2,200	1,584	1,153	0	0	432	47	113	9	4
M3	Maize	CF Basins	1,400	1,008	0	0	0	1,008	31	127	33	8
M4	Maize	CF Basins	3,000	2,160	1,153	0	0	1,008	35	148	29	7
M4h-lite	Maize	CF Basins	3,000	2,160	1,333	0	0	828	17	112	49	7
M4h-full	Maize	CF Basins	3,000	2,160	1,573	0	0	588	15	108	39	5
M5	Maize	CF Ripper - rental	3,000	2,160	1,153	0	125	883	35	117	25	8
M6	Maize	Ox - rental	600	432	0	0	300	132	20	55	7	2
M7	Maize	Ox - rental	1,800	1,296	1,153	0	300	-157	28	88	-6	-2
M8	Maize	Ox - owned	2,400	1,728	1,153	0	0	576	28	91	21	6
GR1	Groundnuts	Hoe	340	884	0	0	0	884	46	148	19	6
GR2	Groundnuts	Hoe	565	1,469	365	0	0	1,104	49	187	23	6
COT1	Cotton	Hoe	800	976	0	140	0	836	38	112	22	7
COT2	Cotton	CF Basins	1,150	1,403	0	140	0	1,263	27	152	47	8
COT2h-lite	Cotton	CF Basins	1,150	1,403	180	140	0	1,083	9	116	120	9
COT2h-full	Cotton	CF Basins	1,150	1,403	420	140	0	843	7	112	120	8
COT3	Cotton	CF Ripper - rental	1,150	1,403	0	140	125	1,138	27	121	42	9
COT4	Cotton	Ox - rental	800	976	0	140	300	536	21	89	26	6
COT5	Cotton	Ox - owned	950	1,159	0	140	0	1,019	21	94	49	11

Source: Table 7, Annex Tables A3, A4, A5.

CF lowers early season labor demands by 12 days per hectare (from 47 to 35 days) under high-input maize production (Table 7, compare M4 and M2). This enables farmers to plant early, with the first rains, and to begin weeding early as well.

Together, these changes raise yields by about 800 kilograms per hectare under high-input maize production (Table 7). Even under low-input CF (M3), maize yields rise roughly 400 kg per hectare above low-input conventional tillage (M1) because of early planting made possible under CF (Table 7).[6] This increases returns to land and to peak season by about 40% (Table 8). Under high-input CF (M4), farmers easily achieve maize yields in the range of 3 tons per hectare, resulting in a doubling of returns to land and a tripling of returns to peak season labor and total labor when compared to conventional (M2) tillage. Purchased input costs remain comparable, at 1.2 million Kwacha ($250) for both CF and conventional high-input maize packages (Table 8).

Cotton farmers also see productivity gains under CF. Because of the low profitability of fertilizer use on cotton, input packages remain the same under both conventional (COT1) and CF (COT2). Whether used under conventional tillage or CF, the cotton input pack costs 140,000 Kwacha (about $30) per hectare. In addition, most cotton farmers receive inputs on credit from their sponsoring cotton company, which then deducts the input loan during cotton purchasing at harvest time. Returns to land increase by roughly 50% under CF, while returns to peak season labor roughly double (Table 8).

5.2.2. Herbicides

Weeding labor constrains cotton output in many parts of Africa. For this reason, cotton companies in West Africa and in northern Mozambique are actively experimenting with herbicides (Tschirley, Poulton, and Labaste 2009). In Mozambique, as in Zambia, herbicides cost less than hiring weeding labor (Pitoro, Govene, and Boughton 2008). The use of pre-emergent herbicide likewise enables better crop establishment, in the absence of weed competition.

In Zambia, herbicide application, instead of weeding with a hand hoe, cuts peak season labor requirements in half (Table 7).[7] Under a low-input herbicide regime (COT2h-lite and M4h-lite) involving a single application of a selective herbicide (such as Blazine), or a pre-emergent spray (such as Roundup) followed by a ten days of follow-up hand weeding, herbicide costs come to about 180,000 Kwacha ($40) per hectare. Under maize production, returns to peak season labor increase by 70%, from 29,000 Kwacha ($6) per day under standard high-input CF (M4) to 49,000 Kwacha ($10) per day under high-input hand hoe CF plus a single round of herbicide application (M4h-lite). Herbicide use proves even more attractive under cotton farming, raising peak season labor productivity by 150%, from 47,000 Kwacha ($10 per day) under standard hand hoe CF (COT2) to 120,000 Kwacha ($26 per day) under hand hoe CF with a single herbicide application (COT2h-lite) (see Table 8).

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[6] These budgets estimate the gains from early planting at 400 kg/ha. Regression estimates by Haggblade and Tembo (2003) suggest a 400 kg gain in maize yielder under CF, 27 kg per day times 15 days earlier planting. This result is consistent with long-term agronomic data suggesting maize yield losses of 1% to 2% per day for each day a farmer delays planting after the first planting rains (Howard 1994; Nyagumbo 2008).

[7] Cotton producers in Mozambique underscore the importance of weeding labor. When asked the key to higher productivity on some cotton farms, they indicated that the most productive cotton farmers were those with cash to hire weeding labor (Pitoro, Govene and Boughton 2008).

A heavier herbicide application regime involves three rounds of herbicide use: first, a pre-emergent application of glyphosate, second, post-emergence spot spraying with glyphosate using a spray hood or Zamwipe to kill off late-emerging perennial weeds, and a final overall spray of glyphosate after maize and cotton stalks have lignified at the base to kill late-emerging weeds. Input costs increase by 420,000 Kwacha (about $80) compared to hand hoe weeding (M4). Under a full three-cycle herbicide regime, returns to land and labor exceed conventional tillage by a wide margin, for both cotton and maize. Nevertheless, they remain lower than the single herbicide application (COT2h-lite and M4h-lite). For that reason, the single herbicide applications (COT2h-lite and M4h-lite) emerge as the more profitable of the two herbicide packages.

5.3. Conventional Animal Traction: Plowing

Households with access to trained oxen can break peak season labor bottlenecks by substituting animal power for human muscle. By dramatically reducing land preparation labor, plowing enables households to expand cropped area.[8] However, this area expansion comes at a cost. Plowing requires complete soil inversion, and this demands at least four times as much energy as minimum tillage cultivation. Given the heavy workload, farmers are unable to plow fields during the dry season. Instead, they must await the first rains. As a result, animal traction owners plant about one week later than hand hoe CF farmers do, incurring roughly a 200-kilogram yield loss in maize output and 100 in lost cotton production. Moreover, soil inversion causes large-scale loss of soil organic matter, through oxidation, further diminishing long-term soil productivity. Over time, repeated plowing seals the wet soil in the same way a trowel does, leading to the development of an impermeable plow pan through which roots and water cannot penetrate. For this reason, regularly plowed land requires periodic deep ripping to ensure proper plant root development.

Under owner-operated animal traction, plowing increases returns to land and labor by about 33% compared to conventional hand hoe tillage (Table 8, compare M8 with M2 and COT5 with COT1).[9] But returns to both land and labor remain well below those achieved under hand hoe CF (compare M8 with M2 and COT5 with COT2). Household income could still increase, however, if area expansion under conventional animal traction can compensate for the lower land and labor productivity compared to hand hoe CF. Given the high cost of asset ownership (about $1,200 for a team of working oxen), this option lies beyond the financial capacity of most smallholder (A1 category) farmers.

Rental or borrowing of plowing teams may be financially feasible for poor households, but it is much less profitable than either owner plowing or hand hoe CF. Plow rental costs 300,000 Kwacha (about $60) per hectare. However, because owners plow their own fields first, farmers who rent or borrow inevitably begin land preparation much later than owners of full draft teams. Given delayed land preparation and planting, cotton yields fall 15% while maize yields fall 25% compared to owner-operated plowing (compare M8 with M7 and COT5 with

[8] Under animal traction plowing, weeding labor becomes the binding input constraint limiting area cultivated. As section 6 reveals, a farmer who must rely on household labor can weed and manage about 3 hectares of land. See Table 11.

[9] Note that this analysis overstates the profitability of plowing with own oxen by imputing zero cost of owning and managing cattle. Because asset-poor households do not own cattle or possess the financial resources to procure veterinary services and manage them, the owner oxen technologies (M8 and COT5) are not feasible options for the resource-poor farmers that constitute the focus of this paper.

COT4). Cotton production with rented plowing teams reduces returns to land and labor by roughly 50%. With maize production, plow rental generates negative returns (Table 8).

5.4. Conservation Farming Animal Traction: Ripper Rental

Using minimum tillage animal traction, CF with animal-drawn rippers aims to capture the benefits of area expansion while at the same time avoiding plow-induced damage to soil structure and soil organic matter. Rather than completely inverting the soil, rippers chisel only a small crack in the soil. As a result, ripping requires less energy than plowing, and so ripping becomes possible during the dry season.

For resource-poor farmers, dry season rental offers several major benefits: on-time planting, soil organic matter retention, and area expansion made possible through animal traction. Whether they prepare land with a ripper or dig basins with a hand hoe, households practicing CF plant with the first rains and allocate agricultural season labor according to identical cropping calendars (compare M5 with M4 and COT3 with COT2). Under rented ripper services, as with hand hoe CF, weeding labor limits area planted. Returns to peak season labor are, therefore, equal under ripper rental (M5 and COT3) and hand hoe CF basins (M4 and COT2) (Table 8). Rental services for dry season ripping cost 125,000 Kwacha ($25) per hectare.

As this overview suggests, farm households face an array of technological choices. Moreover, they must make their input selections at planting time, well before they know what rainfall patterns, crops yields and output prices will prevail at the end of the season. Therefore, technology selection involves elements of risk and uncertainty. The ensuing analysis uses prices and yields from a normal harvest year in order to assess the tradeoffs involved in selecting among these various technical packages. Given acute cash constraints among the poorest farm households, analysis evaluates options with varying levels of cash requirements, from zero to about $400 per season.

6. INCOME GAINS UNDER CONSERVATION FARMING

6.1. Baseline Farm Profitability

Cropping data from smallholder cotton farmers in AEZ2a indicate that the smallest 30% of cotton farmers (the A1 group farming up to 1.5 hectares in total) cultivate a total of roughly 1 hectare each divided, as follows, among their three main crops: 0.5 hectares of maize, 0.1 hectares of groundnuts, and 0.4 of cotton hectares of cotton (Table 4). Baseline optimization runs suggest that pure income maximization would result in complete household specialization in the single most profitable crop: cotton or maize, depending on the technology, location, rainfall, management skills, and relative prices faced by each specific farmer. In the case of hand hoe farmers in AEZ2a, under 2009/10 prices for inputs and outputs, households would specialize in cotton production, planting 1.15 hectares and nothing in maize or groundnuts (Table 9, Simulation 1b).

Yet very few households specialize completely. In part, they plant a portfolio of different crops in order to spread yield and price risks. In addition, in locations where food markets are thin, or where prices swing widely from one year to the next, many households prefer to invest some land and labor in producing their own food staples in order to provide a minimum expected food security basket for the household. This “safety first” decision rule appears to prevail among most of Zambia’s smallholder cotton farmers. Over 95% produce maize as well as cotton, and over half grow groundnuts as well (Table 2).

The “safety first” decision rule that best fits observed farmer behavior specifies minimum food production of 625 kilograms of maize per household (125 kilograms per capita) and 50 kilograms of groundnuts (10 kg per capita). Imposing these safety first rules under conventional hand hoe farming technology, the baseline linear programming optimization solution allocates 0.63 hectares of maize (M1), 0.15 hectares of groundnuts (GR1) and 0.36 hectares of cotton (COT1), thus tracking observed planting behavior closely (Table 9, Simulation 1a). Comparison with unconstrained land allocation (Simulation 1b) suggests an income penalty of about 9% under this safety first rule. Given wide historic swings in maize yields and prices, and given Zambia’s reliance on rainfed maize production, most smallholder cotton farmers in AEZ2a prefer to ensure at least part of their food security by devoting a portion of their cropped area to maize and groundnuts. For this reason, the optimizations below all impose the safety first decision rule.

6.2. Gains from Hand Hoe Conservation Farming Technology

6.2.1. Cash Constraints

Cash constraints limit the choices available to many smallholder cotton farmers. Compared with non-cotton growing households in AEZ2a, cotton farmers earn only about half as much nonfarm wage and business income as comparably sized non-cotton growing households in their area (Table 6). This suggests that the widespread availability of cotton input financing, through contract growing arrangements with the ginneries, may attract the more cash-constrained farmers to cotton production. Given an absence of input credit for food crop inputs, households without ready cash during the October to December planting season are unable to purchase improved seeds and fertilizer for high-input maize and groundnut technology packages. This limits their options to low-input maize (M1, M3) and groundnut

Table 9. Gains from Hand Hoe Conservation Farming among Cash-Constrained Smallholder Cotton Farmers in AEZ2a

	Conventional Tillage		CF Basins	
	1a	1b	2a	(2a-1a)/1a
Simulations				
Safety first*	yes	no	yes	
Input credit (or cash) available	no	no	no	
Land constraint (ha)	2	2	2	
Crop Allocation				
Maize				
Technology	M1	M1	M3	
Land (ha)	0.63	0.00	0.45	-29%
Production (kg)	625	0	625	0%
Groundnuts				
Technology	GR1	GR1	GR1	
Land (ha)	0.15	0.00	0.15	0%
Production (kg)	50	0	50	0%
Cotton				
Technology	COT1	COT1	COT2	
Land (ha)	0.36	1.15	0.84	133%
Production (kg)	289	922	966	234%
Asset Allocation (3 major crops)				
Land (ha)	1.13	1.15	1.43	26%
Labor (person days)				
total	117	129	206	77%
peak season	43	43	43	0%
Cash requirements (Kwacha)	0	0	0	0%
Crop Income ('000 Kwacha)				
Cash income	302	963	1,060	251%
Total crop income	882	963	1,640	86%
Returns to Assets				
Land ('000 Kwacha/ha)	778	836	1,145	47%
Labor ('000 Kwacha/person day)				
total	8	7	8	5%
peak season	20	22	38	86%

Source: Linear Programming Optimizations.
* Safety first indicates that households aim to produce a minimum food bundle for household consumption: 625 kg of maize per household (125 kg/capita) and 50kg of groundnuts per households (10 kg/capita).

(GR1) technologies. However, because most cotton farmers produce on contract under outgrower schemes run by the major ginneries, even highly cash-constrained smallholder farmers can obtain full cotton input packs on credit. In 2009/10, the standard pack of improved seeds and insecticides costs K 140,000 ($30) per hectare. The cotton companies deduct these input loans at harvest time when they purchase the seed cotton from the farmers.

For cash-constrained farm households, the comparison in Table 9 summarizes the gains to CF (Table 9, Columns 1a and 2a). Even under low-input CF (M3), maize yields rise by an average of 40% due to early planting[10]. This enables households to reduce land area devoted to maize production by about 0.2 hectares and still meet their expected food security needs. Under CF with hand dug basins, cotton yields increase by roughly the same percentage as for maize.

In addition to these productivity gains, CF enables a substantial area expansion by allowing farmers to redeploy their roughly 30 days per hectare of heavy land preparation labor out of the peak season into the dry season. This enables smallholder households to increase planted area by about 25%, from 1.1 to 1.4 hectares, using only household labor.[11] Under these conditions, total crop income increases by over 80% (Table 9). About two thirds of this gain stems from increased yield, while one third comes from expansion of land area made possible by dry season land preparation under CF.

6.2.2. No Cash Constraints

Among households with ready access to nonfarm income (or, more rarely, with access to input credit for fertilizer, maize and groundnut seeds), high-input technologies become feasible for both maize (M2,M4) and for groundnuts (GR2). In Table 10, columns 2c and 1c compare outcomes among smallholder farmers with sufficient cash for purchasing the high-input maize and groundnut input packages. Among farmers practicing conventional tillage, high-input maize production sometimes proves unprofitable, as under the high fertilizer prices prevailing in 2009.[12] For this reason, income maximization leads households to adopt low-input (M1) conventional technology even under unconstrained access to cash (Table 10, Simulation 1c).

However, under CF, even in the face of high fertilizer prices, high-input maize production (M4) proves more profitable that low-input maize production (M3), doubling maize yields to about 3 tons per hectare, and enabling households to meet food security requirements with only 0.2 hectares planted to maize. Improved groundnut seeds (GR2) increase yields by more than 60% compared to local varieties. With cotton, as before, CF households (COT2) achieve higher yields due to early planting, water harvesting, and improved soil structure in the planting basins. Using area-weighted yield gains, the high-input CF technologies provide an overall 60% yield gain to smallholder farmers.

Available hand hoe CF technology enables small farm households to expand total planted area by roughly 30%, from 1.13 to 1.47 hectares, by redeploying land preparation labor to the dry season and applying family labor to planting and weeding during the first month of the rainy season (Table 10, Simulations 1c and 2c). Overall, the CF packages double household crop income, from 882,000 Kwacha ($190) under conventional hand hoe production, to 1.8 million Kwacha ($380) under hand hoe CF. About two-thirds of this gain comes from yield increases under CF and one-third comes from area expansion.

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[10] As noted earlier, yield gains under CF will be far higher than 40% during intermittent rainfall years because of the water harvesting properties of the CF basins and because of improved moisture retention due to higher soil organic content in the basins. These results, however, consider only the gains to early planting.

[11] This means that, even if larger land allocations could be made available to these households, availability of household labor would limit cultivated area to about 1.4 hectares.

[12] Fertilizer prices were even higher in 2008, at about $880 per ton.

Table 10. Gains from Conservation Farming Rippers among Smallholder Cotton Farmers in AEZ2a

	Hand Hoe Only		Animal Traction Rental		Herbicides plus CF Hand Hoe			
	Conventional	CF basins	Plow	Ripper	Y max	maize max	cotton herbicides only	
	1c	2c	1e	2e	2i	2k	2l	2m
Simulations								
Safety first*	yes	yes	yes	yes	yes	yes	yes	yes
Input credit (or cash) available	yes	yes	yes	yes	yes	yes	yes	yes
Herbicide financing	n.a.	n.a.	n.a.	n.a.	farmer	farmer	farmer	cotton co.
Land constraint (ha)	2	2	5	5	5	5	5	5
Crop Allocation								
Maize								
Technology	M1	M4	M1	M5	M3	M4h-lite	M4	M4
Land (ha)	0.63	0.21	0.63	0.21	0.61	2.29	0.21	0.21
Production (kg)	625	625	625	625	853	6870	625	624.99
Groundnuts								
Technology	GR1	GR2	GR2	GR2	GR2	GR2	GR2	GR2
Land (ha)	0.15	0.09	0.09	0.09	0.09	0.0885	0.09	0.09
Production (kg)	50	50	50	50	50	50	50	50
Cotton								
Technology	COT1	COT2	COT4	COT3	COT2h-li	COT2h-li	COT2h-li	COT2h-lite
Land (ha)	0.36	1.17	0.77	1.17	2.23	0	2.41	2.41
Production (kg)	289	1,347	615	1,347	2,559	0	2,772	2,772
Asset Allocation (3 major crops)								
Land (ha)	1.13	1.47	1.48	1.47	2.92	2.38	2.71	2.71
Labor (person days)								
total	117	225	139	182	351	273	326	326
peak season	43	43	43	43	43	43	33	33
Cash ('000 Kwacha)	0	272	263	445	433	3,084	706	272
Crop Income ('000 Kwacha)								
Cash income	302	1,479	412	1,333	2,574	1,723	2,610	2,545
Total crop income	882	1,787	959	1,614	3,122	1,993	2,918	2,853
Returns to Assets								
Land ('000 Kwacha/ha)	778	1,217	648	1,100	1,068	838	1,078	1,054
Labor ('000 Kwacha/person day)								
total	8	8	7	9	9	7	9	9
peak season	20	41	22	37	72	46	88	86
Cash (Kwacha/Kwacha)	n.a.	7	4	4	7	1	4	10

Source: Linear Programming Optimizations.
* Safety first indicates that households aim to produce a minimum food bundle for household consumption: 625 kg of maize per household (125 kg/capita) and 50kg of groundnuts per households (10 kg/capita).

6.3. Animal Traction Conservation Farming through Ripper Rental

Hand hoe farmers who rely on manual tillage do so because they do not own enough cattle to plow with their own oxen (see Table 6). Plow rental, though possible for households with access to cash, involves planting late, usually 4 to 8 weeks later than large cattle owners who prepare their own fields first and then rent out oxen afterwards, late in the season after they have finished preparing their own plots (Haggblade and Tembo 2003). Although plow rental increases cropped area to about 1.5 hectares, yields remain low under late-planted conventional plowing. As a result, household income rises only about 9%, to 959,000 thousand Kwacha ($200), compared to high-input conventional hand hoe cultivation (compare 1c and 1e in Table 10). Note that because weeding labor limits area cultivated, even under animal traction land preparation households that rely on family weeding labor can cultivate only 1.5 hectares, about the same area they can manage under hand hoe CF.

Animal drawn rippers, the animal traction technology recommended under CF, circumvent the problem of late planting with rented plowing teams. Because CF, in all its variants, involves dry season land preparation, households who do not own large herds can rent rippers and ox teams during the dry season to prepare their fields. Unlike plow rental, ripper rental enables timely planting, with the first rains.

Ripper rental increases household cropping income to 1.6 million Kwacha ($340), about 80% higher than conventional hand hoe tillage (Table 10, compare simulations 2e and 1c) but about 10% below earnings attainable under hand hoe CF. Although households are able to increase cropped area to about 1.5 hectares under CF with a rented ripper (Table 10, column 2e), this results in lower income than farming 1.5 hectares under CF basins (Table 10, column 2c). This is because yields, and therefore revenue, remain comparable while the 125,000 Kwacha cost of renting the oxen and ripper reduces household cash income. Nevertheless, even in this case, ripper rental may make sense, if households have significant nonfarm employment opportunities during the dry season. Notice that total labor required under ripper rental (Column 2e) falls 20% below that required for hand digging CF basins. Households with off-season nonfarm income earning opportunities that will earn them in excess of 8,000 Kwacha per day will be better off renting a ripper and redeploying skilled household labor in nonfarm pursuits.

Both hand hoe and animal traction CF enable adopting households to expand cultivated area from about 1 hectare under conventional hand hoe tillage to about 1.5 hectares under either CF technology. Because households plant and weed by hand, under either hand hoe or animal traction CF, dry-season land preparation enables comparable area expansion. Above 1.5 hectares, peak-season household labor constraints during planting and weeding become binding, regardless of the CF tillage method used.

6.4. Herbicides

Access to herbicides radically reduces peak season weeding labor requirements. The single-pass herbicide regime (M4h-lite and COT2h-lite) reduces weeding labor from 50 to 14 days per hectare (Annex Table A.1). When combined with dry season land preparation, this reduction in peak season labor requirements enables farm households to crop 2.7 hectares of land under hand hoe cultivation using only household labor (Table 10, Simulation 2l). As a result, hand hoe farmers can increase their income from these three crops to 2.9 million Kwacha ($620) per year, triple what they can earn under conventional hand hoe agriculture (1c) and 60% higher than under CF basins without herbicides (Simulation 2c). Because herbicides so drastically reduce labor requirements, peak season labor usage falls to 33 person-days, below the 43 available from typical household labor pool (Simulations 2l and 2m). In these scenarios, harvest-time labor constraints become binding, instead of peak season labor, because of the heavy demands of multiple rounds of hand picking of cotton.

However, herbicides also raise cash input requirements considerably. Under a maize-based cash cropping scheme, use of herbicides and fertilizer would raise cash input costs to 3.1

million Kwacha ($660) per season (Simulation 2k). However, herbicide application on maize proves less profitable than on cotton, because maize is a lower-value crop. Returns to peak season labor increase by 70% with maize-based herbicides and by 150% with cotton-based herbicides (Table 8). Therefore, a low-herbicide input regime would involve using herbicides on cotton but not on maize. Under minimum safety-first maize production using standard CF basins and limiting herbicide application to cotton plots only, farmer-financed input costs (for maize and groundnut seeds, maize fertilizer and cotton herbicides) increase from 272,000 Kwacha ($60) under CF basins (Simulation 2c) to 706,000 Kwacha ($150) under a light cotton herbicide regime (Simulation 2l).

For resource-poor households, the most financially feasible herbicide package would involve cotton company financing of herbicides along with their standard cotton input pack. Assuming a 15% interest charge on herbicides supplied on credit (30% per year over six months), resource-poor households could cultivate 2.4 hectares of cotton, 0.2 hectares of maize and 0.1 hectares of groundnuts (Simulation 2m). They would require cash sufficient to self-finance their 0.2 hectares of maize inputs, about 272,000 Kwacha ($60), and rely on cotton company financing for the cotton seed, sprays and herbicides for their 2.4 hectares of cotton. Under this scenario, households earn 2.9 million Kwacha ($610) in income from these three crops; nearly triple what they can under conventional tillage.

This suggests that cotton company inclusion and financing of one round of herbicides in their cotton packs could potentially raise cotton production and household income considerably. Cotton companies with excess ginning capacity could considerably ramp up cotton production from their existing farmers. Under the more profitable, light herbicide regime (COT2h-lite), the typical resource-poor household could more than double cotton output compared to standard CF (2,772 tons under 2m compared to 1,347 tons under 2c) and increase output by nearly an order of magnitude compared to conventional tillage (289 tons under simulation 1c). This would only work, however, if farmers apply the herbicides to their cotton crop and not to their maize. Given past experience with the diversion of cotton-financed fertilizer onto maize plots, cotton companies will need to identify an herbicide package that will work well under cotton but not under maize. If they can find such a formulation, it offers the most significant available opportunity for raising income of asset-poor smallholder farmers in central Zambia. Indeed, cotton companies in northern Mozambique are currently experimenting with herbicides in their input packs, in order to raise productivity and output of their smallholder contract farmers, thereby increasing ginning throughput and profitability (Tschirley, Poulton, and Labaste 2009; Pitoro, Govene, and Boughton 2008).

6.5. Nonfarm Income Interactions

Returns to peak season farm labor increase dramatically under CF, roughly doubling under standard CF packages, from about 20,000 Kwacha ($4) per day under conventional tillage (1a and 1c) to about 40,000 Kwacha ($9) per day under CF (2a and 2c). Use of herbicides pushes returns to peak season labor to over 80,000 Kwacha ($18) per day (Table 10, columns 2l and 2m).

Yet overall returns to farm labor increase only slightly from about 8,000 Kwacha ($1.60) per day to about 9,000 Kwacha ($1.70) under hand hoe CF to $1.90 under CF with herbicides (Table 10). How, then, does farm income double under CF and triple under CF plus herbicides? The key lies in area expansion enabled by CF. This, in turn, requires additional family labor during the middle and harvest season, to handle increased mid-season weeding, spraying, harvesting, and post-harvest processing of large areas and outputs. As a result of the area and output increases under CF, total labor use increases from 117 person days under low-input conventional farming (1c) and 139 under high-input conventional hand hoe agriculture (1c) to 225 person days under high-input CF (2c) and 326 under herbicide-based CF production (2m). Thus, the 320% increase in cropping income under herbicide-based CF (Table 10, column 2m compared to 1c) requires 280% increase in total family labor time. Essentially, CF enables families to activate under-employed seasonal labor during the non-peak seasons.

Because of the cyclical agricultural calendar, seasonal unemployment is common, making area expansion under CF attractive for large numbers of rural households. However, the increase in non-peak season labor inputs also means that families with significant nonfarm income-earning opportunities during the agricultural season may prefer not to expand area cultivated as fully as CF allows.

In general, nonfarm earnings interact with agriculture in two key ways. They provide cash income necessary for financing agricultural inputs. They also offer an alternate outlet for deploying household labor. Households without significant mid and late-season nonfarm employment prospects are the most likely to benefit from CF. Recall, too, that a shortage of nonfarm cash income also promotes interest in cotton farming, because cotton production requires no cash inputs other than those provided on loan by the cotton ginners. For this reason, households with the lowest nonfarm cash earnings are most likely to become cotton farmers.

This makes cotton farmers a doubly attractive group for CF. Their low level of nonfarm earnings (see Table 6) makes them likely to have surplus low-season household labor with low opportunity costs. Likewise, the discipline and management skills required by cotton farming likewise make them well suited to the discipline of CF. Thus, Zambia’s cotton farmers constitute a self-selected group of disciplined, cash-poor farmers with low opportunity cost of low-season agricultural labor. All of these attributes dispose them to favor area expansion under CF.

7. CONCLUSIONS

Conservation farming enables even the smallest Zambian farms to achieve yield gains of 40% to 60% over conventional tillage. Area gains of 0.3 to 0.4 hectares (about 25%) compound the income benefits achievable under standard hand hoe CF. Adding herbicides to the mix, along with standard CF hand hoe packages, enables smallholder farmers to increase cultivated area much further, by over 140%, from 1.1 to 2.7 hectares. As a result, smallholder cropping income increases by 85% to 325%, depending on the CF package adopted (Table 11).

With zero cash inputs, resource-poor cotton farming households can increase their crop income by 85%, from 882,000 to 1.6 million Kwacha ($190 to $350) by adopting CF hand hoe packages for cotton as well as for low-input maize and groundnuts. A second category of farmers, with access to cash inputs of about 272,000 Kwacha ($60) per season, are able to adopt high-input CF maize and groundnut packages along with the standard company-financed CF cotton packs, thus raising crop income further, to 1.8 million Kwacha ($380) per season. The addition of herbicides to hand hoe CF packages offers a third, more expensive but more lucrative, set of options. A maize-maximizing, herbicide-based CF package requires 3.1 million Kwacha ($660) in cash inputs and generates cropping income of 2 million

Table 11. Summary Results

		Hectares Cultivated	Crop Income (000 Kw)	Input cost ('000 Kw)	Labor inputs (days) peak	total
Cash-constrained households						
Hand hoe						
conventional	1a	1.13	882	0	43	117
CF basins	2a	1.43	1,640	0	43	206
Cash available						
Conventional tillage						
hand hoe	1c	1.13	882	0	43	117
plow rental	1e	1.48	959	263	43	139
own cattle*	1g	1.88	1,803	332	43	184
Conservation farming						
CF basins	2c	1.47	1,787	272	43	225
CF ripper rental	2e	1.47	1,614	445	43	182
CF basins + herbicides						
maximum income	2i	2.92	3,122	433	43	351
maximum maize	2k	2.38	1,993	3,084	43	273
cotton herbicides	2l	2.71	2,918	706	33	326
herbicides financed	2m	2.71	2,853	272	33	326

Source: Linear Programming Optimizations. See Annex Tables A.4 and A.5.
* Note that these budgets do not impute any capital or recurrent costs of cattle ownership.

Kwacha ($420) per season. Households can lower cash input costs by reducing maize area to the minimum required for household food security requirements. This option reduces cash input costs to 706,000 Kwacha ($150) per season and generates household income of 2.9 million Kwacha ($620) per season. Herbicide financing through cotton companies, and restriction of herbicide use to cotton plots, offers the greatest potential for resource-poor households to increase incomes. If cotton companies were to agree to finance herbicides on CF cotton plots, farmer-financed inputs costs (for maize and groundnuts) would remain at 272,000 Kwacha ($60) while cropping income reaches 2.9 million Kwacha ($610) per season (Table 11).

Smallholder cotton farmers combine the discipline and the interest required to succeed under CF. Under existing input packages, the sequence of CF packages reviewed in this paper offer a feasible means of doubling household crop income among resource-poor smallholder cotton farmers in central Zambia. Adding herbicides to the input mix, together with hand hoe CF, roughly triples smallholder crop income. This suggests that the inclusion of herbicides in cotton input packs merits serious investigation and field-testing in Zambia.

ANNEX

Annex Table A.1. Labor Requirements by Crop and Technology

		Technology Packages					Labor Requirements by Activity (person days per hectare)							
Code	Crop	Tillage	Variety	Fert	Herbicid	Yield Kg/Ha	Prep	Plant	Weed	Fert	Guard/Sp	Harvest	P-Harvest	Total
M1	Maize	Hoe	Local			1,000	30	7	18	0	10	11	11	87
M2	Maize	Hoe	Hybrid	Yes		2,200	34	6	25	8	11	14	15	113
M3	Maize	CF Basins	Local			1,400	34	6	50	0	11	13	13	127
M4	Maize	CF Basins	Hybrid	Yes		3,000	34	6	50	8	11	19	20	148
M4h-lite	Maize	CF Basins	Hybrid	Yes	1 round	3,000	34	6	14	8	11	19	20	112
M4h-full	Maize	CF Basins	Hybrid	Yes	3 rounds	3,000	34	6	10	8	11	19	20	108
M5	Maize	CF Ripper - rental	Hybrid	Yes		3,000	3	6	50	8	11	19	20	117
M6	Maize	Ox - rental	Local			600	9	6	18	0	10	6	6	55
M7	Maize	Ox - rental	Hybrid	Yes		1,800	9	6	25	8	11	14	15	88
M8	Maize	Ox - owned	Hybrid	Yes		2,400	9	6	25	8	11	16	16	91
GR1	Groundnuts	Hoe	Local			340	38	8	22	0	10	22	48	148
GR2	Groundnuts	Hoe	Improved			565	40	8	25	0	10	36	68	187
COT1	Cotton	Hoe	Hybrid			800	30	2	27	0	20	30	3	112
COT2	Cotton	CF Basins	Hybrid			1,150	34	2	50	0	20	43	3	152
COT2h-lite	Cotton	CF Basins	Hybrid		1 round	1,150	34	2	14	0	20	43	3	116
COT2h-full	Cotton	CF Basins	Hybrid		3 rounds	1,150	34	2	10	0	20	43	3	112
COT3	Cotton	CF Ripper - rental	Hybrid			1,150	3	2	50	0	20	43	3	121
COT4	Cotton	Ox - rental	Hybrid			800	9	2	25	0	20	30	3	89
COT5	Cotton	Ox - owned	Hybrid			950	9	2	25	0	20	35	3	94

Source: Siegel and Alwang 2005; Conservation Farming Unit 2008.

Annex Table A.2. Baseline Input and Commodity Prices, 2009/10

Item	Unit	Price (Kw/unit)
Outputs		
maize	kg	720
groundnuts	kg	2,600
cotton	kg	1,220
Inputs		
maize seed	kg	10,100
groundnut seed	kg	13,000
cotton pack	1 ha pack	140,000
basal fertilizer	kg	3,600
urea	kg	3,500
lime	kg	200
herbicide	liter	60,000
antrac rental	ha	300,000
ripper rental	ha	125,000

Sources: Agricultural Market Information Centre (AMIC); National Farmers Union commodity price postings.

Annex Table A.3. Conventional Tillage Optimization Simulations

	Actual	Optimization Scenarios						
	0	1a	1b	1c	1d	1e	1f	1g
Simulations								
Safety first*	---	yes	no	yes	no	yes	no	yes
Input credit (or cash) available	---	no	no	yes	yes	yes	yes	yes
Technology availability	---------- conventional hand hoe only ----------					-- ANTRAC rental --		own cattle
Land constraint (ha)	---	2	2	2	2	5	5	5
Crop Allocation								
Maize								
Technology	M1	M1	M1	M1	M1	M1	M7	M8
Land (ha)	0.50	0.63	0.00	0.63	0.00	0.625	0.00	0.26
Production (kg)	500	625	0	625	0	625	0	625
Groundnuts								
Technology	GR1	GR1	GR1	GR1	GR2	GR2	GR2	GR2
Land (ha)	0.10	0.15	0.00	0.15	0.00	0.09	0.00	0.09
Production (kg)	34	50	0	50	0	50	0.00	50
Cotton								
Technology	COT1	COT1	COT1	COT1	COT1	COT4	COT4	COT5
Land (ha)	0.40	0.36	1.15	0.36	1.15	0.77	2.08	1.53
Production (kg)	320	289	922	289	922	615	1,666	1,450
Asset Allocation (3 major crops)								
Land (ha)	1.00	1.13	1.15	1.13	1.15	1.48	2.08	1.88
Labor (person days)								
total	103	117	129	117	129	139	186	184
peak season	38	43	43	43	43	43	43	43
Cash requirements (Kwacha)	0	0	0	0	0	263	625	332
Crop Income (Kwacha)								
Cash earnings	334	302	963	302	963	412	1,116	1,556
Total sales and in-kind	783	882	963	882	963	959	1,116	1,803

Source: Linear Programming Optimizations.

* Safety first indicates that households aim to produce a minimum food bundle for household consumption: 625 kg of maize per household (125 kg/capita) and 50kg of groundnuts per households (10 kg/capita).

Annex Table A.4. Conservation Farming Optimization Simulations

	Actual	Optimization Scenarios												
	0	2a	2b	2c	2d	2e	2f	2g	2h	2i	2j	2k	2l	2m
Simulations														
Technology availability	conventional	hand hoe conservation farming (basins)				ANTRAC rental		own cattle		------- herbicides plus hand hoe CF -------				
Land constraint (ha)	---	2	2	2	2	5	5	5	5	5	5	5	5	5
Income maximization?	no	yes	yes	yes	yes	no	yes	no	yes	yes	no	no	no	no
Other requirements	---	---	---	---	---	ripper rental	---	own cattle	---	---	herbicides	max maize	cotton herbicides only	
Safety first*	---	yes	no	yes	no	yes	yes	yes	yes	yes	yes	yes	yes	yes
Input credit (or cash) available	---	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Herbicide financing	---	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	farmer	farmer	farmer	farmer	cotton co.
Crop Allocation														
Maize														
Technology	M1	M3		M4		M5	M4	M8	M4	M3	M4h-lite	M4h-lite	M4	M4
Land (ha)	0.50	0.45	0.00	0.21	0.00	0.21	0.21	0.26	0.21	0.61	0.21	2.29	0.21	0.21
Production (kg)	500	625	0	625	0	625	625	625	625	853	625	6870.00	624.99	625
Groundnuts														
Technology	GR1	GR1		GR2		GR2	GR2	GR2	GR2	GR2	GR2	GR2	GR2	GR2
Land (ha)	0.10	0.15	0.00	0.09	0.00	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.088496
Production (kg)	34	50	0	50	0	50	50	50	50	50	50	50.00	50	50
Cotton														
Technology	COT1	COT2	COT2	COT2	COT2	COT3	COT2	COT5	COT5	COT2h-lite	COT2h-lite	COT2h-lite	COT2h-lite	COT2h-lite
Land (ha)	0.40	0.84	1.60	1.17	1.60	1.17	1.17	1.53	1.52	2.23	2.41	0	2.41	2.41
Production (kg)	320	966	1,840	1,347	1,840	1,347	1,347	1,450	1,447	2,559	2,771	0	2,772	2,772
Asset Allocation (3 major crops)														
Land (ha)	1.00	1.43	1.60	1.47	1.60	1.47	1.47	1.88	1.82	2.92	2.71	2.38	2.71	2.71
Labor (person days)														
total	103	206	243	225	243	182	225	184	191	351	346	273	326	326
peak season	38	43	43	43	43	43	43	43	43	43	43	43	33	33
Cash requirements (Kwacha)	0	0	0	272	0	445	272	332	272	433	607	3,084	706	272
Crop Income (Kwacha)														
Cash earnings	334	1,060	2,021	1,479	2,021	1,333	1,479	1,556	1,553	2,574	2,746	1,723	2,610	2,545
Total sales and in-kind	783	1,640	2,021	1,787	2,021	1,614	1,787	1,803	1,860	3,122	3,017	1,993	2,918	2,853

Source: Linear Programming Optimizations.

* Safety first indicates that households aim to produce a minimum food bundle for household consumption: 625 kg of maize per household (125 kg/capita) and 50kg of groundnuts per households (10 kg/capita).

** Total cotton area in the yellow cell includes 0.76 ha under COT2 and 1.65 ha under COT2h-lite.

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