FOOD SECURITY RESEARCH PROJECT

PRODUCTIVITY IMPACT OF CONSERVATION FARMING ON SMALLHOLDER COTTON FARMERS IN ZAMBIA

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

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EXECUTIVE SUMMARY

Africa's small farms face shortages of labor, land, animal traction and financing that, together, limit their access to improved technologies. This paper evaluates a series of conservation farming technology packages as possible vehicles 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 and where conservation farming is most well established and best suited agronomically.

The results suggest that conservation farming can increase crop income by roughly 140% among the poorest smallholder farmers, with no access to cash inputs. A second category of farm households, using purchased input packages costing $60 per season, can increase crop income a further 40% under hand hoe conservation farming. A third, high-input package including herbicides and costing $130 per season enables farm households to quadruple crop income compared to low-input conventional tillage.

Area expansion made possible under conservation farming accounts for between one-third and one-half of these income gains. Because this area expansion requires a large increase in dry season land preparation labor, seasonal employment competition with nonfarm activities strongly influences the magnitude of income gains attainable under conservation farming.

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ACRONYMS

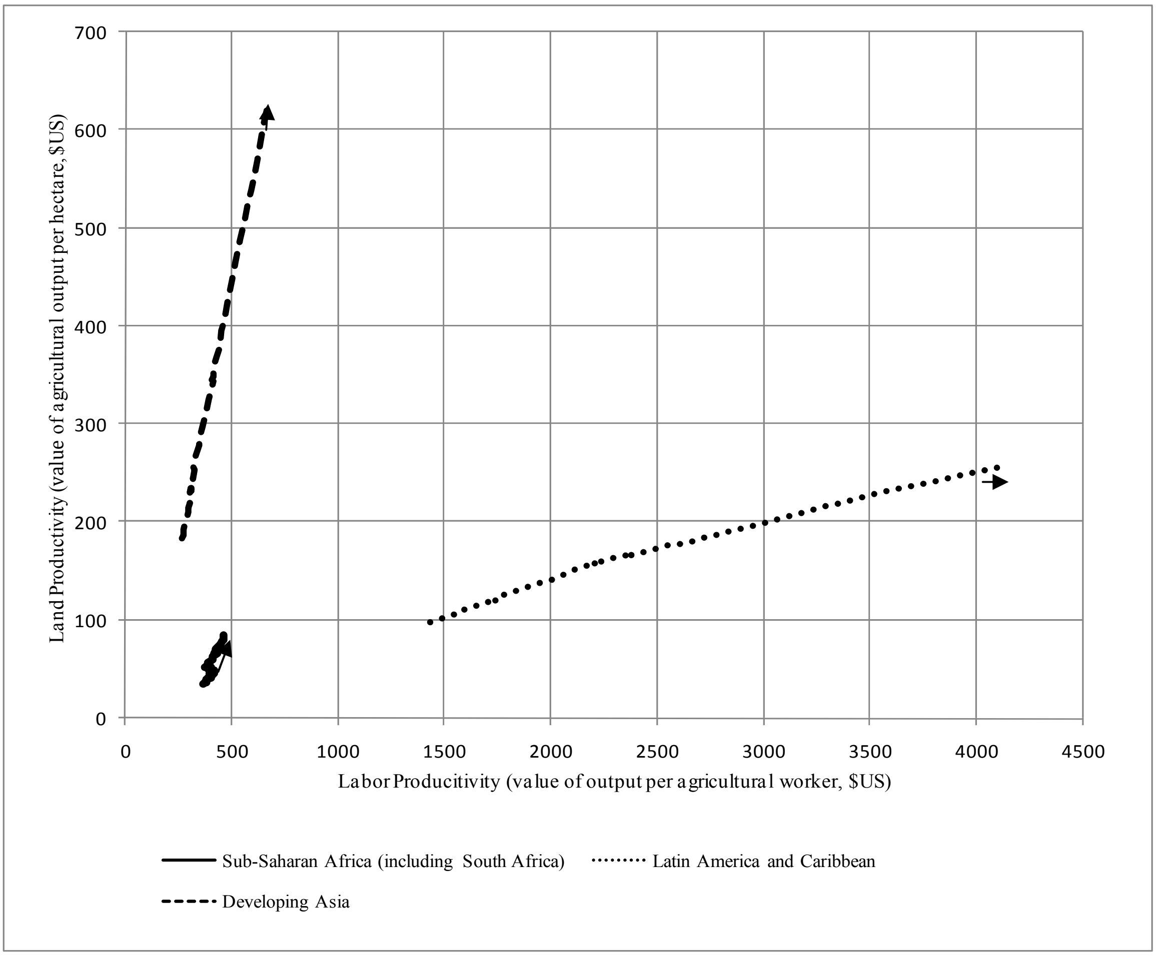
AEZ	Agro-Ecological Zone
AMIC	Agricultural Market Information Centre
CF	Conservation Farming
CFU	Conservation Farming Unit
CSO	Central Statistical Office
FAOSTAT	Food and Agricultural Organization Online Statistical Database
FSRP	Food Security Research Project
GART/IMAG	Golden Valley Research Trust/ Institute of Agricultural and Environmental Engineering
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
UNU-WIDER	United Nations University-World Institute for Development Economic Research
ZNFU	Zambia National Farmers Union

1. INTRODUCTION

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).

Increasing agricultural productivity, therefore, offers a potentially powerful tool for reducing poverty in Africa (World Bank 2008; Diao et al. 2007). Indeed, increased on farm productivity attacks poverty from three different directions (Diao, Heady, 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 (Haggblade, Hazell, and Dorosh 2007). As a result, most empirical studies document strong poverty reduction from agricultural income growth (Thirtle, Line, and Piesse 2003; Christiaensen, Demery, and Kuhl 2006 and 2010; Bezemer and Headey 2008; World Bank 2008; Diao et al. 2007; Diao, Heady, and Johnson 2008).

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



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

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, low-income treadmill. Skeptics question the efficacy of an escape route via agriculture.

This paper examines conservation farming as a possible vehicle 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 family labor constraints limit cultivated area to roughly one hectare per household.

Conservation farming (CF) offers a set 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. Dry season minimum tillage enables farmers to plant early, thereby improving plant establishment, growing period, and access to early season microbial nitrate production (Birch 1958). Crop residue retention builds up soil organic matter, soil structure and water retention capacity, thus improving plant responsiveness to small but targeted doses of mineral fertilizer. Leguminous crop rotations raise soil fertility through biological nitrogen fixation. Conservation farming, thus, increases land productivity through a variety of improved agronomic practices.[2]

A second important but much-less-discussed benefit of conservation farming 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; Upton 1987; Eicher and Baker 1992; INESOR 1999; CFU 2002; Lee, Barrett, and McPeak 2006; Ruben, Kruseman, and Kuyvenhoven 2006). During the four to six week period following the first rains, farmers must prepare their soil, plant crops and conduct the critical first weeding. Under conservation farming, minimum tillage allows dry-season land preparation, thus enabling farmers to reallocate heavy land preparation to the slack agricultural season. Right after the first rains, during the peak agricultural season, they are able to concentrate household labor on early planting and early 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 conservation farming. 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

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

[2] See Giller et al. (2009) for a critical review of conservation farming in Africa. The authors point to very scattered and generally low adoption rates as well as wide differences in situation-specific outcomes. This paper addresses these differences in some detail.

different conventional and conservation farming 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 methods; crop residue retention; seeding and input application in fixed planting stations; nitrogen-fixing crop rotations; and reduced but precise doses of mineral fertilizer (CFU 2007a and 2007b).[3] 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 sun hemp completes the ladder of conservation farming technologies.[4]

2.1.2. Yield Gains

Conservation farming 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. Improved water control, in turn, increases plant responsiveness to small but strategic doses of mineral fertilizer. Over time, CF systems aim to improve soil fertility, soil structure and soil organic matter in the fixed planting stations. By reallocating land preparation to the dry season, in advance of the rains, conservation farming redistributes heavy labor and draft power requirements outside the peak agricultural season. Early land preparation enables farmers to sow with the first rains. As a result, plants benefit from the initial nitrogen flush in the soil, improved plant establishment and a longer growing period (Semb and Robinson 1969). Long-term agronomic data suggest maize yield losses of 1% to 2% per day for each day a farmer delays planting after the first planting rains (Nyagumbo 2007). So a farmer planting two weeks earlier than her neighbor will enjoy a yield advantage of 15% to 30%.

As a result, most studies of conservation farming document substantially higher yields on CF plots – often double those achieved under conventional tillage (Arulussa 1997; INESOR 1999; Langmead 2001, 2002; Stevens et al. 2002; Haggblade and Tembo 2003; Twomlow and Hove 2006; Kabwe, Donovan, and Samazaka 2007). Though gains vary across locations and over time, evidence from central Zambia suggests that about 25% of observed gains

[3] Although conservation agriculture comes in many flavors, most proponents consider three characteristic components essential: minimum tillage, organic soil cover (which, in turn, implies no burning, crop residue retention, use of cover crops and mulching), and leguminous crop rotations (FAO 2001; Goddard et al. 2008; Rockström et al. 2009).

[4] For a fuller description of these technologies, see Vowles (1989); Oldrieve (1993); Hudson (1995); The Farmer (1995); Arulussa (1997); Stevens et al. (2002); and CFU (2007a and 2007b).

under conservation farming stem from higher input use, another 25% from early planting, and about 50% of the yield difference stems from the interaction among other CF cultural practices, such as 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 semi-arid zones of Africa (Haggblade and Tembo 2003).

2.1.3. 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. Early season labor constraints, particularly during the first weeding, set an upper bound on the cropped area a family can manage using household labor. For the average farm household in central Zambia, with five family members practicing conventional hand-hoe tillage, peak-season labor bottlenecks limit the area they can cultivate to about one hectare.

In contrast, conservation farming 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 2). Veteran CF farmers prefer land preparation at the very beginning of the dry season, when residual moisture makes basin preparation easiest. 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 their expanded plots. Labor productivity increases under CF because it enables farm families to achieve higher yields and cultivate greater areas with available household labor.

2.2. Agro-Ecological Zones

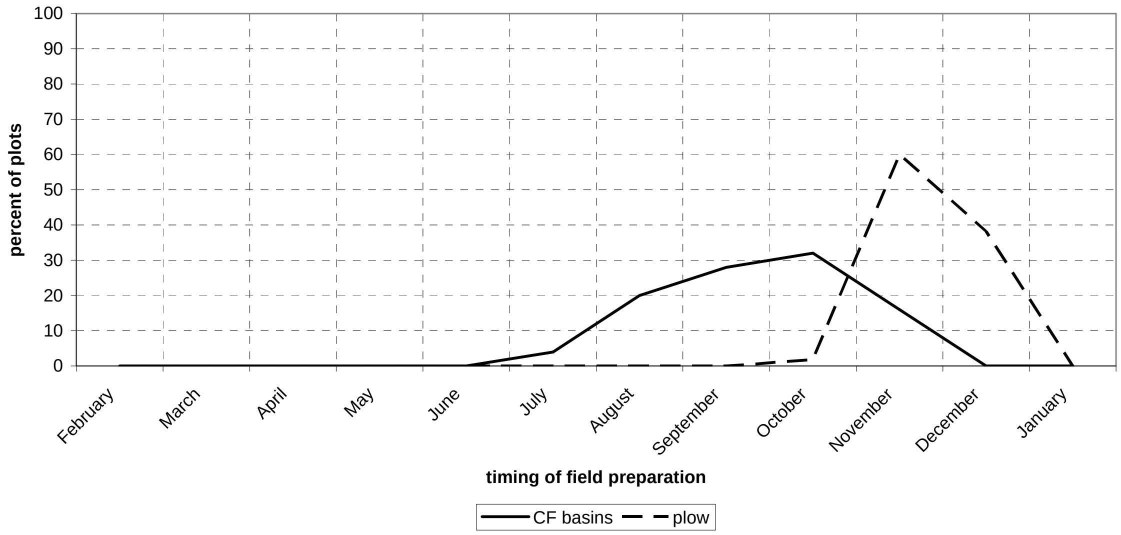
Conservation farming technology development and extension efforts in Zambia have focused on the arid and semi-arid central and southern sections of Zambia. Semi-arid AEZ2a occupies the populous middle section of Zambia where forty percent of Zambian farm households and over 95% of cotton farmers operate (Table 1). In AEZ2a, rainfall ranges between 800 and 1,000 mm per year, and generally good access to markets makes commercial farming attractive (Figure 3). 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, for both maize and cotton.

2.3. Cotton and Conservation Farming

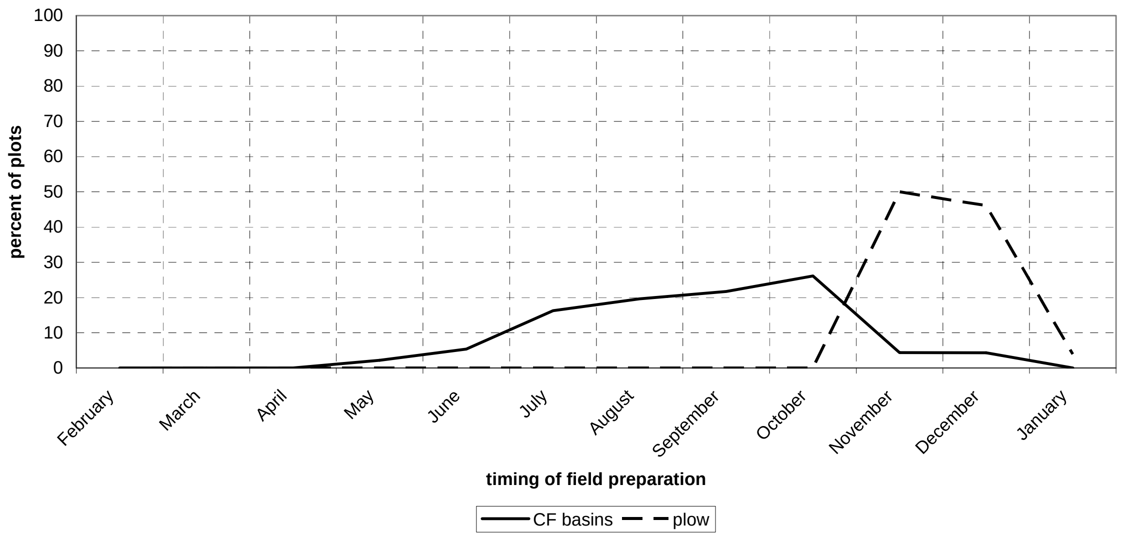
Cotton farmers rank among the earliest and most loyal adopters of conservation farming in Zambia. Indeed, CFU focused its first decade of field trials, demonstrations and extension efforts in the cotton belt of Central Province, attracted by the discipline of the cotton farmers, the effectiveness of CF practices on cotton production, the keen interest of the Dunavant cotton company and Dunavant's willingness to financially support CF extension for its lead cotton farmers.

Figure 2. Timing of Land Preparation, by Tillage Method, Zambia 2001

a. Cotton Plots



b. Maize Plots



Source: Haggblade and Tembo 2003.

The mutual attraction between cotton and conservation farming arises, 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 production. 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 kilograms for each week late the crop is planted (Birgess 2009).[5] This makes CF dry season land preparation particularly valuable, not only to cotton farmers but also to ginners, whose viability depends on high levels of capacity utilization and hence on the productivity of smallholder cotton farmers who supply them with cotton lint.

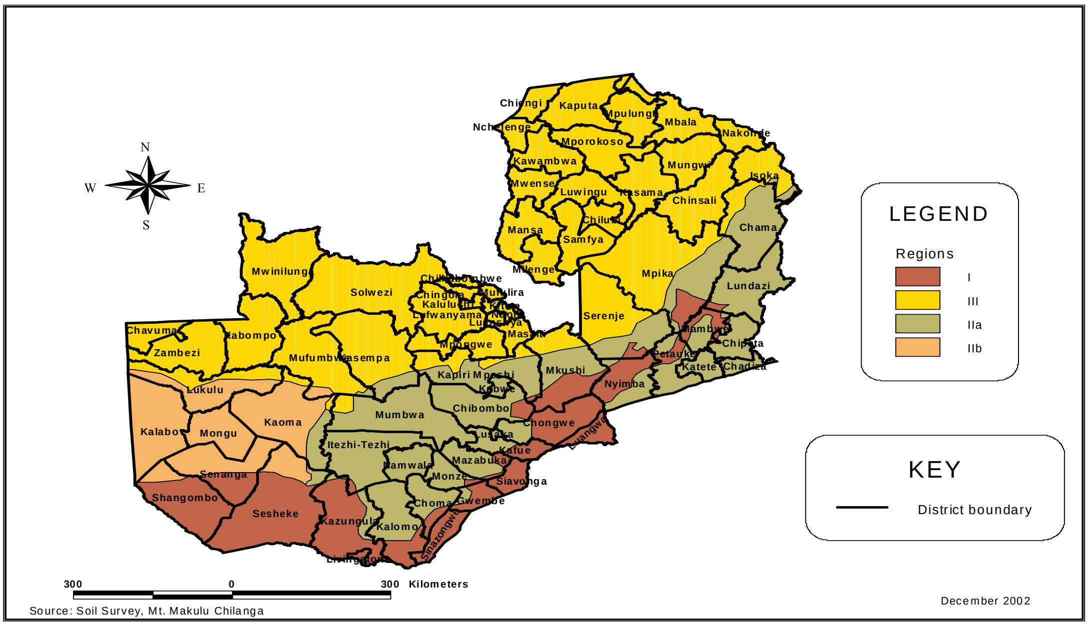
[5] Econometric estimates during one season place the losses at about 30-60 kg per week (Haggblade and Tembo 2003).

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.

Figure 3. Zambia's Agro-Ecological Zones



Because of these complementarities between cotton production and conservation farming, the Dunavant Cotton Company,[6] Zambia's largest, actively engaged the CFU, at its inception, to help in the company's cotton 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, adopting CF at roughly double the rate of non-cotton farmers (Haggblade and Tembo 2003).

[6] 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.

The discipline required for successful cotton production likewise meshes well with the disciplined management required by conservation farming. 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. As a result, since the beginning of CF extension efforts in Zambia, during the mid 1990's, conservation farming 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 conservation farming has been promoted the longest and has advanced furthest. So conservation farming 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. The following analysis quantifies the potential contribution CF packages can make to this large group of highly disciplined, resource-poor farmers.

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 fixed input-output coefficients and subject to a set of household asset constraints on farm labor, land, and cash. Equation (1) formulates the optimization problem formally, as follows:

(1) Maximize crop income = $\Sigma_i P_i Q_i - \Sigma_n P_n N_{n,}$

where "P" refers to price, "Q" indicates output quantities, "N" indicates input quantities, the subscript "i" refers to the three outputs (maize, groundnuts and cotton) and "n" enumerates 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. Undertaken 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 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 conservation farming packages, with and without 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), from input suppliers and cotton companies (Annex Table A.2).[7] The following section uses these data to provide an empirical profile of smallholder cotton farmers in Agro-Ecological Zone 2a of Zambia.

[7] All values in this paper convert from Kwacha to dollars using an exchange rate of 4,700 Kwacha per U.S. dollar.

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 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

Farms with less than 5 hectares account for over 98% of Zambian cotton production (World Bank 2003). Using Zambia's Ministry of Agriculture and Cooperatives (MACO) size classification system, Table 3 describes the size distribution of these small and medium-scale holdings in AEZ2a.

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 do. Among the smallest of these farms, the A1 group, cotton 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 3). Though both cotton and non-cotton farmers cultivate about half a hectare of maize and 0.1 hectare of groundnuts, the cotton farmers add 0.4 hectare of cotton to the mix, leading to larger overall cropped area.

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: Supplemental Post-Harvest Survey of 2002/03.

Table 3. Cropping Pattern, by Farm Size in AEZ2a

	Average Area Cultivated per Household (ha/hh)					Households	
Farm Size	maize	cotton	groudnuts	other	total	numbers	percent
Households not growing any cotton							
A1. 1.5 ha or less	0.58	0.00	0.09	0.12	0.79	237,608	46%
A2. 1.51 to 2.5 ha	1.16	0.00	0.23	0.35	1.74	133,824	26%
B. 2.51 to 5 ha	1.81	0.00	0.29	0.53	2.63	107,359	21%
C. 5 to 20ha	4.89	0.00	0.47	1.23	6.60	34,427	7%
Total	1.19	0.00	0.18	0.31	1.69	513,218	100%
Cotton farming households							
A1. 1.5 ha or less	0.50	0.42	0.09	0.06	1.07	36,967	29%
A2. 1.51 to 2.5 ha	0.79	0.71	0.23	0.12	1.86	38,788	31%
B. 2.51 to 5 ha	1.39	1.16	0.27	0.22	3.04	38,113	30%
C. 5 to 20ha	2.87	2.51	0.42	0.70	6.48	12,228	10%
Total	1.09	0.94	0.22	0.19	2.43	126,096	100%

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

4.3. Tillage Systems

The smallest size category of cotton farmers, the Category A1 farmers 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 4). Because of the prevalence of hand hoe agriculture among small farmers in Zambia, early CF technology development and extension efforts in Zambia devoted the majority of their attention to the hand-hoe variant of conservation farming, using fixed planting basins.

Table 4. Share of Cropped Area, by Tillage Method, among Famers in AEZ2a of Zambia

	Hand hoe labor		Oxen			Tractor		Total
	household	hired	own	hired	own+hired	own	hired	hectares
Non-cotton farming households in AEZ2a								
A1. 1.5 ha or less	60%	4%	12%	21%	0%	0%	3%	100%
A2. 1.51 to 2.5 ha	51%	4%	21%	19%	1%	0%	5%	100%
B. 2.51 to 5 ha	32%	4%	39%	24%	1%	0%	1%	100%
C. 5 to 20ha	11%	4%	63%	15%	0%	1%	5%	100%
Total	39%	4%	33%	20%	0%	0%	3%	100%
Cotton farming households								
A1. 1.5 ha or less	69%	4%	9%	17%	0%	0%	1%	100%
A2. 1.51 to 2.5 ha	59%	4%	20%	16%	0%	0%	1%	100%
B. 2.51 to 5 ha	30%	3%	40%	23%	2%	0%	2%	100%
C. 5 to 20ha	22%	7%	51%	18%	0%	1%	2%	100%
Total	40%	4%	34%	19%	1%	0%	2%	100%

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

4.4. 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 5). Indeed, the difference in nonfarm earnings is striking. Although cotton farmers earn higher total agricultural incomes ($494 per household) than non-cotton farmers do ($333), the disparity in non-farm income is striking, with cotton farmers earning only 20% to 30% as much nonfarm income as non-cotton farmers (Table 5).

These data suggest that cotton may 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. And they do so on a large scale; cotton is Zambia's largest out-grower crop. 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 participation in high-input commercial crop production.

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 conservation farming technology packages can improve household productivity and incomes among this resource-constrained group of smallholder cotton farmers.

Table 5. Asset Holdings by Farm Size, Agro-Ecological Zone 2a

	Land (ha/hh)		Labor		Cattle (per hh)		Tractors	Net Income ($/hh)		
Farm Size	total*	cultivated	hh size	FTE**/hh	total	trained oxen	(per hh)	Nonfarm	Farm	Total
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	209	161	370
A2. 1.51 to 2.5 ha	2.0	1.7	6.0	2.0	2.9	0.7	0.1	257	384	642
B. 2.51 to 5 ha	3.4	2.6	6.6	2.1	4.5	1.0	0.0	367	601	968
C. 5 to 20ha	10.6	6.6	7.8	2.6	11.2	1.6	0.1	949	2640	3589
Total	2.1	1.7	5.8	1.9	3.5	0.6	0.1	259	333	593
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	35	203	238
A2. 1.51 to 2.5 ha	2.0	1.9	6.0	1.9	1.6	0.4	0.0	66	307	373
B. 2.51 to 5 ha	3.4	3.0	6.5	2.1	0.9	0.0	0.0	79	536	615
C. 5 to 20ha	7.8	6.5	8.3	2.7	2.0	0.1	0.1	196	1138	1333
Total	2.7	2.4	6.1	2.0	0.7	0.0	0.0	84	494	578

* total land = cultivated land plus fallow land.
** FTE = full-time adult male labor equivalent. See Table A.1 for details.
Source: Supplemental Post-Harvest Survey of 2002/03.

5. ALTERNATE TECHNOLOGY PACKAGES

5.1. Conventional Hand Hoe Packages

Smallholder farmers can choose from among a range of input packages for all three major crops (Table 6). For maize cultivation, many farmers select the low-input package (M1) that 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, a high-input hand hoe maize package (M2) costing about $260 per hectare involves the purchase of hybrid seeds and an average of 250 kilograms of fertilizer per hectare.[8] Maize yields more than double, from 900 kilograms per hectare to 2.2 tons, when farmers move from M1 to M2. Groundnuts, similarly, come in low- and high-input packages (GR1 and GR2).

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, most smallholder cotton farmers use the standard company-supplied one-hectare cotton pack costing about $30 per hectare and including improved seeds and sprays, but no fertilizer. Cotton yields under conventional hand hoe tillage (COT1) rarely exceed 800 kilograms per hectare (Tschirley and Kabwe 2007).

5.2. Hand Hoe Conservation Farming

5.2.1. Hand Weeding

Conservation farming technologies for maize (M3, M4, and M5) enable farmers to move land preparation from the peak season, following the initial rains, to the dry season. This enables farmers to plant and begin weeding early. Even under low-input conservation farming (M3), maize yields rise roughly 400 kilograms per hectare above low-input conventional tillage (M1) because of improved soil structure and early planting made possible under CF (Table 6).[9] Under high-input conservation farming (M4), farmers easily achieve maize yields in the range of 3 tons per hectare because of improved fertilizer responsiveness and early planting, resulting in a doubling of returns to land and a tripling of returns to labor when compared to conventional (M2) tillage (Table 7).

Cotton farmers also see productivity gains under conservation farming. Because of early planting, early weeding, improved soil structure and water retention, returns to land increase by roughly 50% under conservation farming, while returns to peak season labor roughly double (Table 7).

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[8] 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 CSO crop survey data (CSO 2004).

[9] 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; Nyabumgo 2007).

Table 6. 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 ($)	Ripper Rental	Plow Rental
M1	Maize	Hoe	Local			900	43	24	21	11	99								
M2	Maize	Hoe	Hybrid	Yes		2,200	54	34	25	15	128	125	125		25				
M3	Maize	CF Basins	Local			1,300	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		36		
M4h-full	Maize	CF Basins	Hybrid	Yes	2 rounds	3,000	15	9	50	34	108	125	125		25		73		
M5	Maize	CF Ripper - rental	Hybrid	Yes		3,000	35	29	50	3	117	125	125		25			1	
M6	Maize	Ox - rental	Local			500	26	19	16	6	67								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			36		
COT2h-full	Cotton	CF Basins	Hybrid		2 rounds	1,150	7	5	66	34	112			1			59		
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					

* Kilograms per hectare unless otherwise indicated.

** Shading indicates conservation farming technologies.

Source: Siegel and Alwang 2005; Supplemental Post-Harvest Survey 2002/03; Conservation Farming Unit Annex Table A.1.

Table 7. Returns to Labor and Land among Hand Hoe Farmers in AEZ2a

					Costs and Returns (US dollars)							Returns to Labor	
Technology			Yield			Input Cost		ANTRAC	Gross	Labor (days)		(US dollars/day)	
Code	Crop	Tillage	(kg/ha)		Revenue	Cash	Credit	Rental	Margin	Peak	Total	Peak	Total
M1	Maize	Hoe	900	0	139	0	0	0	139	43	99	3.24	1.40
M2	Maize	Hoe	2200	0	339	257	0	0	82	54	128	1.52	0.64
M3	Maize	CF Basins	1300	0	200	0	0	0	200	31	127	6.46	1.58
M4	Maize	CF Basins	3000	0	462	257	0	0	205	35	148	5.86	1.39
M4h-lite	Maize	CF Basins	3000	0	462	293	0	0	169	17	112	9.93	1.51
M4h-full	Maize	CF Basins	3000	0	462	330	0	0	132	15	108	8.82	1.23
M5	Maize	CF Ripper - rental	3000	0	462	257	0	27	179	35	117	5.10	1.53
M6	Maize	Ox - rental	500	0	77	0	0	64	13	26	67	0.50	0.20
M7	Maize	Ox - rental	1800	0	277	257	0	64	-43	28	88	-1.56	-0.49
M8	Maize	Ox - owned	2400	0	370	257	0	0	113	28	91	4.07	1.24
GR1	Groundnuts	Hoe	340	0	221	0	0	0	221	46	148	4.85	1.49
GR2	Groundnuts	Hoe	565	0	367	85	0	0	282	49	187	5.81	1.51
COT1	Cotton	Hoe	800	0	272	0	27	0	246	38	112	6.55	2.19
COT2	Cotton	CF Basins	1150	0	391	0	27	0	365	27	152	13.51	2.41
COT2h-lite	Cotton	CF Basins	1150	0	391	36	27	0	328	9	116	36.50	2.84
COT2h-full	Cotton	CF Basins	1150	0	391	59	27	0	306	7	112	43.70	2.74
COT3	Cotton	CF Ripper - rental	1150	0	391	0	27	27	338	27	121	12.53	2.80
COT4	Cotton	Ox - rental	800	0	272	0	27	64	182	21	89	8.77	2.04
COT5	Cotton	Ox - owned	950	0	323	0	27	0	297	21	94	14.30	3.14

Source: Table 6; Annex Table A2.

5.2.2. Herbicides

Herbicide application cuts peak season labor requirements in half (Table 6). Under a light herbicide regime (COT2h-lite and M4h-lite) which involves a single early application of a non-selective, pre-emergent glyphosate spray (such as Roundup) followed by ten days of follow-up hand weeding, herbicide costs come to about $40 per hectare. Returns to peak season labor on maize plots increase from $6 per day under standard CF (M4) to $10 per day under herbicide-based CF (M4h-lite). Herbicide use proves even more attractive to cotton farmers, as it raises peak season labor productivity from $14 per day under standard conservation farming (COT2), to $36 per day under hand hoe CF with a single herbicide application (COT2h-lite) (Table 7).

A heavier herbicide regime involves two rounds of herbicide use. The first includes a pre-emergent application of non-selective glyphosate. The second round involves post-emergence spraying with either a maize-selective (blayzine) or cotton-selective (pantera) herbicide to kill late-emerging perennial weeds. Input costs increase by about $70 compared to hand hoe weeding (M4).[10] Under a two-cycle herbicide regime, returns to land exceed conventional tillage by a wide margin, for both cotton and maize. But returns fall below those achieved under the single herbicide application (COT2h-lite and M4h-lite).

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. But this area expansion comes at a cost. Given the high cost of asset ownership (about $780 for a team of working oxen and related equipment), this option lies beyond the financial capacity of most smallholder (A1 category) farmers (Haggblade and Tembo 2003).

Rental or borrowing of plowing teams may be financially feasible for poor households, but it proves much less profitable than owner-operated plowing or hand hoe conservation farming. Plow rental costs about $60 per hectare. But 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 COT4). Cotton production with rented plowing teams (COT4) reduces returns to land by roughly 50% compared to CF basins (COT2). With maize production, plow rental generates negative returns (Table 7).

5.4. Conservation Farming Animal Traction: Rippers

Using minimum tillage animal traction, conservation farming 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,

[10] Weeding with hired labor costs still more, about $180 per hectare (Hodson 2009). But hiring labor does not offer a general solution to peak-season bottlenecks in labor-scarce, land-surplus rural Zambia where smallholder farms hire labor on only about 4% of their cultivated area (Table 4).

rippers chisel only a small crack in the earth. As a result, ripping requires less energy than plowing, and so ripping becomes possible during the dry season.

Dry season rental of ripping services costs about $25 per hectare and offers several major benefits: on-time planting, soil organic matter retention, and area expansion made possible through animal traction. Under rented ripping services, as with hand hoe CF, weeding labor limits area planted. Returns to peak season labor are, therefore, roughly equal under ripper rental (M5 and COT3) and hand hoe CF basins (M4 and COT2) (Table 7).

As this overview suggests, farm households face an array of technological choices. In addition, 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. So technology selection involves elements of risk and uncertainty. The ensuing analysis uses prices and yields from a normal harvest year to assess the tradeoffs involved in selecting among these various technical packages. Given acute cash constraints among the poorest farm households, analysis evaluates options at varying levels of cash requirements.

6. RESULTS

6.1. Baseline Farm Profitability

Cropping data from smallholder cotton farmers in AEZ2a indicate that the smallest 30% of cotton farmers (the A1 group) cultivate a total of roughly 1 hectare each: 0.5 hectares of maize, 0.1 hectares of groundnuts and 0.4 of cotton hectares of cotton (Table 3). Baseline optimization runs suggest that pure income maximization would result in complete household specialization in cotton production (Table 8, Simulation 1b). Yet very few households specialize completely. Over 95% produce maize as well as cotton, and over half grow groundnuts as well (Table 2). For this reason, the optimizations below all impose the *safety first* decision rule.

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 allocates 0.69 hectares to maize (M1), 0.15 hectares to groundnuts (GR1) and 0.18 hectares to cotton (COT1) (Table 8, Simulation 1a). This allocation tracks observed planting behavior closely. Comparison with unconstrained land allocation (Simulation 1b) suggests an income penalty of about 40% under the safety first 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, the smallest cotton farmers earn only about 20% as much nonfarm income (Table 5).

Households without any ready cash during the November to December planting season are unable to purchase improved input packages. This limits their options to low-input maize (M1, M3) and groundnut (GR1) technologies. Nonetheless, 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.

For farm households with no cash available for purchasing inputs, low-input conservation farming (M3) raises maize yields by an average of 40% because of early planting and improved soil quality. This enables households to reduce land area devoted to maize by about 0.2 hectares while still meeting their expected food security needs (Table 8, Simulations 2a and 1a). Under conservation farming, cotton yields (COT2) increase by roughly the same percentage as for maize.

In addition to these gains in land productivity, conservation farming enables 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 40%, from 1 to 1.4 hectares, using only household labor

(Table 8, Simulations 1a and 2a). Under these conditions, total crop income increases by over 140%. 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 conservation farming.

Table 8. Gains from Hand Hoe Conservation Farming among Cash-Constrained Smallholder Cotton Farmers

	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)	0.69444	0	0.48	-31%
Production (kg)	625	0	625	0%
Groundnuts				
Technology	GR1	GR1	GR1	
Land (ha)	0.15	0	0.15	0%
Production (kg)	50	0	50	0%
Cotton				
Technology	COT1	COT1	COT2	
Land (ha)	0.18	1.15	0.80	340%
Production (kg)	146	922	920	532%
Asset Allocation (3 major crops)				
Land (ha)	1.02	1.15	1.43	40%
Labor (person days)				
total	111	129	204	84%
peak season	43	43	43	0%
Cash requirements (US dollars)	0	0	0	0%
Crop Income (US dollars per season)				
Cash income	45	283	292	553%
Total crop income	173	283	421	143%
Returns to Assets				
Land (US dollars/ha)	169	246	295	74%
Labor (US dollars/person day)				
total	1.56	2.19	2.06	32%
peak season	4.01	6.55	9.74	143%

* 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).
Source: See Annex Table A.3 and A.4.

6.2.2. No Cash Constraints

Among households with ready access to nonfarm income, high-input technologies become feasible for both maize (M2, M4) and groundnuts (GR2). With $60 in purchased inputs, small farm households can afford high-input hand hoe CF technology enabling them to expand total planted area by roughly 50%, from 1 to 1.5 hectares, by redeploying land preparation labor to the dry season and focusing family labor on planting and weeding during the first month of the rainy season. Together, the conservation farming packages (M4 and COT2) more than double household crop income, from about $200 under conventional hand hoe production to $495 under hand hoe CF (Table 9, Simulations 1c and 2c). As with low-input packages, about two-thirds of this gain comes from yield increases under CF and one-third comes from area expansion.

Table 9. Gains from Input-Intensive Conservation Farming among Smallholder Cotton Farmers

	Hand Hoe Only		Animal Traction Rental		Herbicides plus CF Hand Hoe			
	Conventional	CF basins	Plow	Ripper	max income	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	M2	M4	M7	M5	M3	M4h-lite	M4h-lite	M4h-lite
Land (ha)	0.28	0.21	0.35	0.21	0.48	2.288704	0.21	0.21
Production (kg)	625	625	625	625	625	6,866	625	625
Groundnuts								
Technology	GR2	GR2	GR2	GR2	GR2	GR2	GR2	GR2
Land (ha)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Production (kg)	50	50	50	50	50	50	50	50
Cotton								
Technology	COT1	COT2	COT4	COT3	COT2h-lite	COT2h-lite	COT2h-lite	COT2h-lite
Land (ha)	0.63	1.17	1.41	1.17	2.30	0	2.41	2.41
Production (kg)	503	1,347	1,129	1,347	2,429	0	2,771	2,771
Asset Allocation (3 major crops)								
Land (ha)	1.00	1.47	1.85	1.47	2.87	2.38	2.71	2.71
Labor (person days)								
total	123	225	173	182	350	273	346	346
peak season	43	43	43	43	43	43	43	43
Cash (US dollars)	81	61	209	98	84	679	129	69
Crop Income (US dollars)								
Cash income	154	427	257	396	761	351	819	806
Total crop income	203	495	266	458	883	411	879	866
Returns to Assets								
Land (US dollars/ha)	202	337	144	312	308	173	325	320
Labor (US dollars/person day)								
total	1.64	2.20	1.54	2.51	2.52	1.51	2.54	2.50
peak season	4.69	11.46	6.17	10.61	20.43	9.52	20.35	20.05
Cash (dollar/dollar)	n.a.	8.11	1.28	4.69	10.45	0.61	6.83	12.62

* 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).
Source:. See Annex Tables A.3 and A.4.

6.3. Plow Rental

Plow rental, though possible for households with access to cash, involves planting late, usually 4 to 8 weeks later than cattle owners who prepare their own fields first and then rent out oxen later in the season, after they have finished (Haggblade and Tembo 2003). Although plow rental enables households to increase cropped area to about 1.8 hectares, yields remain low under late-planted conventional plowing (Table 9, Simulation 1e). The resulting household income of about $270, though significantly higher than the $170 earned under conventional hand hoe cultivation (Simulation 1c), remains only about half of the $495 attainable under hand hoe conservation farming (Simulation 2c).

6.4. Ripper Rental

Animal drawn rippers, the animal traction technology recommended under conservation farming, circumvent the problem of late planting with rented plowing teams. Because conservation farming in all its variants involves dry season land preparation, households that do not own large herds of cattle 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 $460 (Simulation 2e), more than double the $200 earned under conventional hand hoe tillage (Simulation 1c) but about 10% below earnings attainable under hand hoe conservation farming (Simulation 2c). Although households are able to cultivate about 1.5 hectares under conservation farming with a rented ripper (Simulation 2e), they earn less income than they would farming 1.5 hectares under CF basins (Simulation 2c) because yields, and therefore revenue, remain comparable while the $27 cost of renting the oxen and ripper reduces household cash income.

Nevertheless, ripper rental may still make sense, if households have significant nonfarm employment opportunities during the dry season. Note that total labor required under ripper rental falls 20% below that required for hand digging CF basins (182 days versus 225). Households with off-season nonfarm income that earns them in excess of $2.50 per day will be better off renting ripper services and redeploying skilled household labor in off-season nonfarm pursuits.

6.5. Herbicides

Access to herbicides radically reduces peak season weeding labor requirements, from 50 days per hectare under standard CF cotton and maize to 14 days per hectare under the single-pass herbicide regime (M4h-lite and COT2h-lite) (Annex Table A.1). But herbicides also raise cash input requirements. Under a maize-based cash cropping scheme, use of herbicides and fertilizer would raise cash input costs to $680 per season (Simulation 2k), far in excess of the annual cash earnings of the typical Category A1 cotton farmer (Table 5). Farmers could considerably lower their input costs by reducing high-input maize area (which requires expensive fertilizers) to the “safety first” minimum of 0.2 hectares and limiting herbicide application to cotton plots only. Under this scenario, farmer-financed input costs for maize and groundnut seeds, maize fertilizer, and cotton herbicides amount to $130 (Simulation 2l).

For the most resource-poor households, an even more 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 potentially cultivate 2.4 hectares of cotton, 0.2 hectares of maize and 0.1 hectares of groundnuts (Simulation 2m). They would require cash totaling $70 to self-finance their maize and groundnut inputs and rely on cotton company financing for the cotton seed, sprays, and herbicides for their cotton. Under this scenario (Simulation 2m), households would earn $866 in income from these three crops, roughly quadruple what they can under conventional tillage (Simulation 1c) and 75% more than under standard hand hoe CF (Simulation 2c).

This suggests that cotton company financing of one round of herbicides in their cotton packs could potentially raise cotton production and household income considerably. Given high excess capacity among Zambia's major ginners, cotton companies face strong incentives to ramp up cotton production from their existing farmers (Tschirley and Kabwe 2007). Under a light herbicide regime (COT2h-lite), the typical resource-poor household could more than double cotton output compared to standard conservation farming (2.8 tons under Simulation 2m compared to 1.3 tons under Simulation 2c) and increase output an order of magnitude more than under conventional tillage (143 kilograms under Simulation 1c).

In Zambia, several major cotton companies have begun selling herbicides as an optional input to their most productive cotton farmers. Similarly, cotton companies in West Africa and in northern Mozambique are currently experimenting with herbicides in their cotton input packs (Tschirley, Poulton, and Labaste 2009; Pitoro, Govene, and Boughton 2008).[11]

6.6. Nonfarm Income Interactions

Returns to peak season farm labor increase dramatically under conservation farming, roughly doubling under standard CF packages, from $4 to $5 per day under conventional tillage (Simulations 1a and 1c) to between $10 and $11 per day under conservation farming (Simulations 2a and 2c). Use of herbicides pushes returns to peak season labor to over $20 per day (Simulations 2l and 2m).

Overall returns to farm labor increase by 40-50%, from about $1.60 per day under conventional tillage to about $2.20 under hand hoe CF to $2.50 under CF with herbicides (Table 9). How, then, does farm income double under conservation farming and quadruple under CF plus herbicides? The key lies in the output and area expansion enabled by conservation farming. These, in turn, require additional family labor during the dry season to prepare land and in the middle and harvest season, to handle increased mid-season weeding and spraying, late-season harvesting, and post-harvest processing of larger output. As a result of the area and output increases under CF, total labor use increases from 123 person days under low-input conventional farming (Simulation 1c) and 173 under high-input conventional plowing (Simulation 1e) to 225 person days under high-input CF (Simulation 2c) and 346 under herbicide-based CF production (Simulation 2m). Thus, the 330% increase in cropping income (from $203 to $866) under herbicide-based conservation farming (Simulation 2m

[11] One major Malawian tobacco firm has included herbicides in its maize input pack for the past three seasons in order to minimize labor pressure on maize plots and allow contract farmers to focus attention on their on tobacco plots (Chidzanja 2010).

compared to 1c) requires a 180% increase in total family labor time (from 123 days to 346). Essentially, conservation farming enables families to activate under-employed seasonal labor during the non-peak seasons.

Given highly cyclical farm calendars, seasonal underemployment is common in African agriculture, making output and area expansion under CF attractive for large numbers of rural households. But the increase in non-peak season labor inputs also means that families with significant nonfarm income-earning opportunities late in the agricultural season may prefer not to expand production 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. In addition, they offer an alternate productive outlet for deploying household labor. Households without significant mid- and late-season nonfarm employment prospects are the most likely to benefit from conservation farming. 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 (Table 5).

This makes cotton farmers a doubly attractive group for conservation farming. Their low level of nonfarm earnings makes them likely to have surplus seasonal household labor with low opportunity costs. Likewise, their attentiveness and management skills, required for successful cotton farming, make them well suited to the discipline of conservation farming. As a result, Zambia’s cotton farmers constitute a self-selected group of disciplined, cash-poor farmers with low opportunity cost of off-season agricultural labor. Together, these attributes dispose them to favor output and area expansion under conservation farming.

7. CONCLUSIONS

Conservation farming enables even the smallest, most cash-constrained Zambian farm households to achieve yield gains of about 40% over conventional tillage. Area gains of 40% to 50% permit cultivation of up to 1.5 hectares, compounding the income benefits achievable under hand hoe conservation farming. As a result, the existing conservation farming packages reviewed in this paper offer a feasible means of doubling household crop income among resource-poor smallholder cotton farmers in central Zambia. With zero cash inputs, resource-poor cotton farming households can increase their crop income by 140%, from $170 to $420 by adopting CF hand hoe packages for cotton as well as for low-input maize. A second category of farmers, with access to cash inputs of about $60 per season, can access high-input CF maize and groundnut packages along with the standard company-financed cotton packs, thus raising crop income further, to $495 per season (Table 10).

Adding herbicides to the standard CF hand hoe packages enables smallholder farmers to increase cultivated area much further, to as much as 2.7 hectares, potentially quadrupling crop income. Farmer-financed herbicides, fertilizer, and seeds costing $130 per season generate crop income of $880 per season. Herbicide financing through cotton companies reduces farmer-financed inputs costs to $70 per season, while cropping income attains $870 per season, quadruple the level achievable under conventional tillage (Table 10). Given the prevalence of peak season labor bottlenecks in rainfed African agriculture, herbicides merit serious consideration as a means of raising smallholder income. Currently, massive fertilizer subsidies dominate agricultural input discussions. In many cases, they dominate government resource allocations for agriculture (Sachs 2006; Morris et al. 2007; Minde et al. 2008).

Table 10. Summary Results

		Hectares Cultivated	Crop Income ($US)	Input cost ($US)	Labor inputs (days) peak	total
Cash-constrained households						
Hand hoe						
conventional	1a	1.02	173	0	43	111
CF basins	2a	1.43	421	0	43	204
Cash available						
Conventional tillage						
hand hoe	1c	1.00	203	81	43	123
plow rental	1e	1.85	266	209	43	173
own cattle*	1g	1.88	507	74	43	184
Conservation farming						
CF basins	2c	1.47	495	61	43	225
CF ripper rental	2e	1.47	458	98	43	182
CF basins + herbicides						
maximum income	2i	2.87	883	84	43	350
maximum maize	2k	2.38	411	679	43	273
cotton herbicides	2l	2.71	879	129	43	346
herbicides financed	2m	2.71	866	69	43	346

Source: Tables 8 and 9.

A more balanced, cost-effective approach would involve consideration of herbicides as well as promotion of improved agronomic practices, such as early planting and retention of soil organic matter, which offer additional, complementary vehicles for raising farmer productivity in Africa.

Clearly, African smallholders face difficult tradeoffs in allocating labor across alternative crops, technology packages, and nonfarm activities. The alternatives evaluated in this paper demonstrate the complexity of designing feasible technologies for resource-poor farm households in Africa. At the same time, the conservation farming packages analyzed here suggest that with a careful understanding of smallholder cropping systems it is indeed possible to develop feasible, affordable technologies that can significantly raise incomes for large blocks of resource-poor farm households.

Zambia's cotton farmers constitute a large group of cash-poor but disciplined smallholder households well positioned to benefit from conservation farming. They combine the management skills and motivation required to succeed under conservation farming. Given the paucity of off-season nonfarm income-earning opportunities available to them, smallholder cotton farmers are able to transfer land preparation labor to the dry season, as required under CF, without affecting dry season nonfarm occupations. As a result, conservation farming offers an array of technology packages with the potential to double or even quadruple crop income among this large group of disciplined but resource-poor small farms.

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	Herbicide	Yield Kg/Ha	Prep	Plant	Weed	Fert	Guard/Spr	Harvest	P-Harvest	Total
M1	Maize	Hoe	Local			900	30	7	30	0	10	11	11	99
M2	Maize	Hoe	Hybrid	Yes		2,200	34	6	40	8	11	14	15	128
M3	Maize	CF Basins	Local			1,300	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	2 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			500	9	6	30	0	10	6	6	67
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		2 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 2002.

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

Item	Unit	Price (USD)
Outputs		
maize	kg	0.15
groundnuts	kg	0.65
cotton	kg	0.34
Inputs		
maize seed	kg	2.46
groundnut seed	kg	3.06
cotton pack	1 ha pack	26.60
basal fertilizer	kg	0.81
urea	kg	0.76
lime	kg	0.04
glyophosate	liter	10.64
blayzine	liter	8.00
pantera	liter	18.09
antrac rental	ha	63.83
ripper rental	ha	26.60

Sources: Agricultural Market Information Centre (AMIC);
Allenberg Cotton; Zambia 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	M2	M2	M7	M7	M8
Land (ha)	0.50	0.69	0.00	0.28	0.00	0.35	0.00	0.26
Production (kg)	450	625	0	625	0	625	0	625
Groundnuts								
Technology	GR1	GR1	GR1	GR2	GR2	GR2	GR2	GR2
Land (ha)	0.10	0.15	0.00	0.09	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	0.18	1.15	0.63	1.15	1.41	2.08	1.53
Production (kg)	320	146	922	503	922	1,129	1,666	1,450
Asset Allocation (3 major crops)								
Land (ha)	1.00	1.02	1.15	1.00	1.15	1.85	2.08	1.88
Labor (person days)								
total	109	111	129	123	129	173	186	184
peak season	41	43	43	43	43	43	43	43
Cash requirements (Kwacha)	0	0	0	378	0	982	625	350
Crop Income (Kwacha)								
Cash earnings	462	210	1,331	726	1,331	1,206	1,780	2,130
Total sales and in-kind income	892	815	1,331	953	1,331	1,252	1,780	2,385

* 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).
Source: Linear programming optimizations.

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	M4h-lite	M4h-lite
Land (ha)	0.50	0.48	0.00	0.21	0.00	0.21	0.21	0.26	0.21	0.48	0.21	2.29	0.21	0.21
Production (kg)	450	625	0	625	0	625	625	625	625	625	625	6866.11	625	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	0.80	1.60	1.17	1.60	1.17	1.17	1.53	1.52	2.30	2.41	0	2.41	2.41
Production (kg)	320	920	1,840	1,347	1,840	1,347	1,347	1,450	1,447	2,429	2,771	0	2,771	2,771
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	2.87	2.71	2.38	2.71	2.71
Labor (person days)														
total	109	204	243	225	243	182	225	184	191	350	346	273	346	346
peak season	41	43	43	43	43	43	43	43	43	43	43	43	43	43
Cash requirements (Kwacha)	0	0	0	287	0	459	287	350	287	397	605	3,190	605	323
Crop Income (Kwacha)														
Cash earnings	462	1,372	2,744	2,008	2,744	1,862	2,008	2,130	2,126	3,579	3,850	1,651	3,850	3,788
Total sales and in-kind income	892	1,977	2,744	2,326	2,744	2,154	2,326	2,385	2,444	4,148	4,133	1,933	4,133	4,071

* 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 Simulation 2j, 2l, and 2m includes 0.76 ha under COT2 and 1.65 ha under COT2h-lite.

Source: Linear programming optimizations.

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