Modeling minimum tillage among smallholders in Eastern Zambia

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INTRODUCTION

Although conservation farming (CF) has been promoted in Zambia for 20 years, rates of adoption remain low with evidence of widespread dis-adoption. The most commonly used CF technique is minimum tillage (MT), in which farmers prepare land by hand with permanent planting basins or with an ox-drawn ripper. In this exercise, we use a set of linear programming (LP) household models to understand the likelihood of adoption of minimum tillage techniques for maize production in study site 2, located in Eastern Province. We explore the following questions: What is the relative profitability of minimum tillage production? Are farmers likely to increase production and/or expand area under cultivation when options for minimum tillage are included in their choice set? If not, what are the obstacles to adoption, such as labor bottlenecks and budget constraints? Finally, which household type is most likely to benefit from minimum tillage production?

This exercise makes several contributions to the literature: (1) We use mathematical programming to understand the trade-offs faced by farmers when selecting between conventional and MT management regimes. Furthermore, model parameters are drawn from empirical data of rural households, rather than on-station trials or expert opinion. The model is able to realistically capture the complex decisions made by farmers. (2) Our model includes biweekly labor requirements in order to explore labor constraints at a fine temporal scale. This is particularly relevant to MT practices, as promoters emphasize that MT can ease the on-farm labor bottleneck at the start of the rainy season. At the same time, MT regimes require either additional weeding labor or chemical inputs to control a higher weed burden. (3) We incorporate changing labor requirements and yields over time within a multi-period model. While at least one study uses mathematical programming to study conservation agriculture among farmers in Zambia (Haggblade et al. 2011), it is a one-period model. Yet MT production is unique among seasonal crop regimes with its declining costs and delayed returns. This may influence farmers' willingness to commit to MT practices.

OVERVIEW OF CONSERVATION FARMING/ MINIMUM TILLAGE

Conservation farming is a holistic crop management regime comprised of the following elements: (1) Land preparation in dry season using minimum tillage (zero tillage, ripping, and/or planting basins), along with early planting, (2) Retention of crop residues on the field after harvest, (3) Permanent planting basins or ripping lines, (4) Early and continuous weeding, and (5) Crop rotation, with one-third nitrogen-fixing plants (Baudron et al. 2007).

CF is typically presented as a method to improve soil fertility, reduce labor requirements, and increase yields. Retention of crop residue on the field is understood to prevent erosion, suppress weeds (albeit not immediately), and contribute to soil organic matter. Use of planting basins or rip lines increase soil moisture close to the plants. Because it can retain water better than conventional planting methods, CF is also viewed as an adaptation to climate change and variability (Ngoma et al. 2014). Early land preparation makes use of off-season labor and allows farmers to plant early, which in turn allows the crop to benefit from the first rains. Yields also increase with the precise and direct application of inputs near the plant.

It can be difficult to evaluate the adoption and effectiveness of CF because it is "package", whereas farmers often adopt individual techniques in isolation. In 2003, the Conservation Farming Unit (CFU) reported that 9% of smallholder farmers in Zambia used CF. In actuality, most adopted just some elements of CF, with minimum tillage as the most commonly adopted practice (Baudron et al. 2007). For this reason, we look only at minimum tillage practices in this paper. Ripping involves the use of oxen to create furrows in which seeds are planted and inputs applied. It is recommended that the same rip lines be used each year, and that farmers repeat the ripping process two or three times on the same field in early years. This ensures adequate depth of the rip lines. Planting basins entail the construction of evenly spaced pits covering just 10% of the soil surface (CFU 2014a). These pits should be dug at a depth of 20 cm (considerably deeper than the depth achieved with conventional hand hoe over the entire soil surface), and it is recommended that farmers use the same basins each year. In later years, less labor is needed to prepare the same basins for another planting.[1]

WHY DON'T MORE FARMERS PRACTICE MINIMUM TILLAGE?

After two decades of CF promotion in Zambia, minimum tillage (MT) rates remain low, and this is true even in those districts where CF programs have been most active. In the 10 districts in which CF was most common in 2012, 9% of smallholder farmers used planting basins and/or ripping. For the whole country, this value was 3.9%. A qualitative study among farmers in Eastern Province reveals a number of reasons for the low use rates of MT: Planting basins require substantial labor, and farmers lack finances for the equipment (*chaka* hoes for basins, oxen drawn implements for ripping) and inputs (herbicides, hybrid seeds, and fertilizer) typically included in the CF package (Ngoma et al. 2014). The planting basins must be dug deeper than conventional inversion tillage (20 cm as compared with 10 cm), and to break the plough pan, land preparation should be done during the dry season. However, this makes the task of land preparation more difficult, and in one study, some farmers were found to construct their basins after the rains had started (Goeb 2013). Furthermore, farmers value their time during the dry season, implying that farmers may not have excess labor during this period. The higher weed burden associated with MT requires more weeding labor, such that the labor bottleneck may simply be shifted later in the season (Giller et al. 2009). This is particularly true if farmers cannot afford herbicides. In contrast, conventional farmers that invert the entire soil surface of a field use land preparation as a first weeding (Goeb 2013).

Studies have also identified reasons that farmers are reluctant to adopt the other elements of CF. For example, farmers may not retain plant material on the field because there are competing uses for crop residue, such as livestock feed. When not cultivated, fields may be considered as common grazing lands, such that farmers cannot restrict livestock entry to the field. Plant residue may be eaten by termites in the dry season or burned in order to control the rodent population on a field (Giller et al. 2009). Some CF skeptics claim that, in the absence of mulch, runoff and erosion can actually be exacerbated by not tilling the soil. Farmers may not rotate crops if they cannot afford to devote scarce land to inedible crops, or if there is no market for non-maize crops.

In the short-term, CF yields are found to be variable. One study from western Kenya finds that the yield effects of minimum tillage differ with soil quality, such that it is beneficial in fields of medium soil fertility, but had a negative (neutral) effect in poor (good) fields (Guto et al. 2011). In Zimbabwe, conservation agriculture is found to depress maize yields in the absence of fertilizer, but improve yields when fertilizer is included in the management regime (Nyamangara et al. 2013). In another study based in Zimbabwe, CF cotton yields improved during dry years but declined during wet years, relative to conventional production methods (Personal communication cited in Giller et al. 2009). At least one study in Zambia finds that use of planting basins does not increase maize yield, compared with conventional methods (Gatere 2013). In Mkushi District in Central Province, a one-season study of partial CF adopters finds that planting basins were more profitable than hand-hoe cultivation in 78% of cases (Goeb 2013). Accordingly, in about one of five cases, basins were not more profitable despite the higher labor investment. The author notes that regardless of any long-term benefits to soil quality, short-term benefits can determine rates of (dis)adoption among farmers concerned with their immediate food security. This

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[1] Following Ngoma et al. (2014), we study only planting basins and ripping due to confusion in the data regarding the definition of zero tillage.

variability may explain why 95% of smallholder adopters in Eastern Province returned to conventional practices from 2004 to 2008, even as the total percent of farmers practicing CF increased (Arslan et al. 2013).

MODEL COMPONENTS

Minimum tillage regimes

We add three MT regimes to the choice set of crop activities in the Eastern Province household models constructed by Wineman and Crawford (2014). These are selected based on the most common MT technique/ crop combinations practiced in study site 2 over the period 2003 to 2012 (Source: CFS). Within maize fields prepared with planting basins and ripping, we select several of the most common crop regimes (bundles of seed type, fertilizer use, and time of planting) that also present a diversity of options to the representative farm model.

Table 1. *MT crop regimes*

CROP	Seed Type	Tillage Method	Fertilizer	Planting time	Code
Maize	Local	Basins	No	Early	MZ-BAS1
Maize	Hybrid	Basins	Yes	Early	MZ-BAS2
Maize	Hybrid	Ripping	Yes	Early	MZ-RIP2

Labor requirements

Minimum tillage is promoted as both a labor-saving and yield-enhancing management regime. However, in a study of first-year adopters in Central Province, the use of planting basins requires 40 additional labor days per ha than use of conventional hand-hoe (Goeb 2013). This is mostly due to the labor required for land preparation, and although fields with basins are more likely to be treated with herbicide, weeding labor was comparable between fields prepared with basins and conventional hand-hoe.

In our model, we derive the labor requirements for minimum tillage regimes by computing median labor requirements from the 2010 and 2011 CFS. These estimates are specific to each study site for maize planted with basins or ripping, and this method is generally consistent with that used for the conventional regimes. However, we do adjust the numbers slightly where the empirical values are not intuitive (e.g. labor requirements for planting basins should not differ across MZ-BAS1 and MZ-BAS2). We also run all models with an alternate source of labor requirements. In Mkushi district, Goeb (2013) calculates the mean labor days for various agricultural tasks on fields prepared with basins, ripping, plough, and conventional hand-hoe. We calculate the proportional relationship in labor used for conventional methods and MT techniques, and then apply this proportional increase to the labor estimates for conventional methods in our model. We assume that labor required for other agricultural tasks, such as harvest, are only negligibly affected by the use of MT. However, because the results with the second method are very similar to those obtained with first method, we report only the model results using the CFS labor estimates.

Several sources indicate that labor requirements decline over time as farmers return to the same planting stations (Haggblade and Tembo 2003). Under best CF practices (permanent planting basins and consistent weeding), land preparation labor decreases by 50% after five years and weeding labor decreases by 50% after six years (Baudron et al. 2007). The labor requirements in our model decline incrementally at this rate. Given the high rate of dis-adoption of MT practices (Arslan et al. 2013), we assume that the labor estimates found in the CFS data set reflect the second year of implementation.

Table 2. *MT labor requirements*

YEAR 1	Regime	Land	Planting	Weeding	Fertilizer	Guarding	Harvest	Post-harvest

		preparation			application			activities
Method 1 (using CFS)	MZ-BAS1	50.90	10.45	48.45	0.00	10.00	17.87	27.33
	MZ-BAS2	50.90	10.45	48.45	5.78	10.00	23.79	35.33
	MZ-RIP2	10.14	5.95	52.83	8.58	10.00	23.79	35.33
Method 2 (using Goeb 2013)	MZ-BAS1	54.46	8.44	45.90	0.00	10.00	19.75	21.87
	MZ-BAS2	54.46	6.30	34.00	4.70	10.00	18.81	23.53
	MZ-RIP2	8.89	13.14	46.78	6.50	10.00	24.69	23.28

Labor timeline

The labor timelines for the MT regimes are identical to conventional hand-hoe or plough regimes. We considered adjusting the land preparation time to extend over six weeks, rather than the shorter period identified by focus group participants for conventional land preparation methods. These estimates roughly reflect those found in a 2001/02 survey (Haggblade and Tembo 2003). However, if labor requirements for dry season digging are too high, farmers may prepare land at the onset of the rainy season (Goeb 2013), and our model reflects such a case. It should be noted that labor is generally not constraining in our model at the start of the season. We also explore whether farmers adjust the timing of weeding when using minimum tillage. In the 2012 CFS, we compare the number of weedings on maize fields in Eastern Province between those prepared with MT and conventional methods. The average number of weeding rounds are roughly similar (1.94 for planting basins, as compared with 1.74 for conventional hand hoe; 1.82 for ripping, as compared with 1.57 for plough), indicating that farmers using MT do not necessarily follow the CF best practices of more frequent weeding. We therefore retain the timing of weedings used for similar regimes in the basic household model.

Yields

Expected yields are calculated from CFS 2003-2012 for the MT regimes. We also compare these values to the median yields achieved with comparable conventional land preparation regimes in the same region. Note that we do not control for *amount* of fertilizer or other inputs, including herbicides. In the model, these median yields are assumed to reflect the second year of MT implementation, with yields increasing in year 2 and again in year 5.

Table 3. *Maize yields under minimum tillage*

SITE 2					Comparison with conventional methods	
Regime	Mean (kgs/ha)	SD	Median	No. obs.	Difference (medians)	Proportion difference
MZ-BAS1	1,399.08	(1,165.15)	1,150.00	137	156.17	+0.16
MZ-BAS2	2,490.93	(1,389.56)	2,271.61	72	189.31	+0.09
MZ-RIP2	3,542.15	(2,240.08)	3,194.44	79	1,124.44	+0.54

Timeline of returns

The timeline of returns on MT is critical to understand the likelihood of adoption and dis-adoption, as yields are assumed to increase over time with consistent use of MT on the same field (CFU 2014b). We account for this change in expected yield over a timespan of four years. In a study of CF in eastern and southern Zambia, Thierfelder et al. (2013) find that maize yield increases under conservation farming with ripline tillage will take 3-5 seasons before they become significant. Although we are modeling just one element of CF, we borrow the approximate yield increases found in this paper: Given the high rate of dis-adoption found in this study area (Arslan et al. 2013), we assume that the MT yields observed are those seen in the second year of MT practice. The expected yields in years 1, 3, and 4 are 90%, 100%, and 110% of the year 2 yields, respectively.

Crop budgets

Similar to the larger household modeling paper, all quantities and costs (with the exception of herbicide) are valued at their median and are specific to the study site. Monetary values have been inflated to 2011/12 shillings and adjusted to reflect the fact that Zambian currency has since been rebased (1,000 old kwacha = 1 new kwacha). We first create a budget that assumes the farmer receives assistance in the form of *free* equipment and subsidized inputs. The main difference between the conventional and MT crop budgets is the inclusion of herbicide costs in one of the MT regimes. These are taken from expenditures on herbicide used for maize, divided by total hectares of maize cultivated (CFS 2012 and 2011). Note that, in many cases, famers may be given herbicides at reduced cost.

Table 4. *MT crop budgets with subsidies*

Regime	Basal Fert Kg/Ha	Top Fert Kg/Ha	Seed Kg/Ha (Median)	Plough Yes/No	Basal Fert ZMK/Kg	Top Fert ZMK/Kg	Fertilizer transport ZMK/Kg (Median)	Seed ZMK/Kg	Plough ZMK/Ha	Herb-icide ZMK/Ha	Total Variable Costs ZMK/Ha
MZ-BAS1			28.08					1.07			30.00
MZ-BAS2	123.46	123.46	23.11		2.67	2.82	0.10	6.90			862.31
MZ-RIP2	123.46	123.46	26.96	Yes	2.67	2.82	0.10	6.90	40.00	19.57*	948.45

*This reflects the mean, not median, expenditure on herbicide for maize. The median value for this management regime is zero (CFS 2011 and 2012).

We next create a budget that assumes the farmer is responsible for the entire cost of equipment and inputs. This may more accurately reflect the profitability of MT in the absence of CF promotion programs. Both basins and ripping require fixed cost investments for purchase of a *chaka* hoe (specially designed to dig deep basins), ripper, or knapsack sprayer for herbicide. The estimated equipment values are given below. Because this is a LP model, we treat these equipment expenditures as variable costs. While not realistic, this does ensure that all farmers can partially adopt MT on at least a fraction of their land.

Table 5. *MT crop budgets without subsidies*

Value of equipment, Eastern Province (ZMK/unit)

Item	Mean	SD	Median	No. obs.
Ripper	435.12	(224.22)	400.00	63
Knapsack sprayer	221.12	(150.90)	200.00	517
Chaka hoe			79.79	

Source: RALS 12 (ripper and sprayer) and Joey Goeb, personal communication (chaka hoe, estimated).

Regime	Basal Fert ZMK/Kg	Top Fert ZMK/Kg	Fertilizer transport ZMK/Kg (Median)	Seed ZMK/Kg	Plough ZMK/Ha	Herb-icide ZMK/Ha	Equipment ZMK/unit	Total Variable Costs ZMK/Ha
MZ-BAS1				1.07			79.79	109.79
MZ-BAS2	3.53	3.57	0.10	6.90			79.79	1,140.17
MZ-RIP2	3.53	3.57	0.10	6.90	40.00	159.58*	600.00	1,886.52

*This reflects the recommended rate of herbicide application (Goeb 2013), but not necessarily the actual rate of use.

Gross margins

The productivity of MT maize is generally higher than conventional methods. However, the higher costs associated with MT practices mean that the calorie-to-kwacha ratio is not necessarily higher than other maize regimes.

Table 6. *Returns to MT regimes*

Regime	Median Yield (kgs/ha)	Costs (ZMK/ha)	Sale price (ZMK/kg)	Net revenue (ZMK/ha)	Calories/kg	Calories/ha (1,000s)	Calories/ZMK (1,000s)
MZ-BAS1	1,150.00	30.00	1.08	1,209	3,570	4,105.50	136,850.01
MZ-BAS2	2,271.61	862.31	1.08	1,904	3,570	8,109.65	9,404.52
MZ-RIP2	3194.444	948.45	1.08	2,812	3,570	11,404.17	12,024.03

Using commercial prices of chemical inputs, the last column becomes:

Regime	Calories/ZMK (1,000s)
MZ-BAS1	136,850.01
MZ-BAS2	7,647.88
MZ-RIP2	8,864.35

Discount rate

We assume a discount rate of 10% in the multi-period models. Thus, whether the farmer is maximizing profit or calories, the stream of returns over four seasons is discounted accordingly. Although not reported here, a sensitivity analysis with a discount rate of 20% does not produce markedly different results.

RESULTS

We first solve the farmer's problem with a one-period model, in which the farmer has only a one-season planning horizon. We then re-solve the problem with a four-period model that accounts for the increasing yields, decreasing labor requirements, and a discounted stream of returns. Finally, we solve the problem in a four-period model where financial assistance is only available in years 1-2. In this case, yields and labor requirements remain constant (at year 2 estimates) and the farmer is allowed to move in and out of MT production.

Emergent farmer

Results for the emergent farmer as a calorie-maximizer are presented in Table 7. Assuming the farmer can access free equipment and subsidized inputs, the farmer does *not* adopt any MT regime in a single period model. However, when the model is expanded to a four-period planning horizon in which the farmer must commit to continuous use of MT regimes, the farmer does adopt the MZ-RIP2 regime. Yet she still allocates over three times as much land to a conventional maize regime. In response to the declining labor requirements, the farmer incrementally expands the area under sunflower. The results are similar when the farmer must pay commercial prices for fertilizer, herbicide, and physical capital, and the farmer still uses the MZ-RIP2 regime along with over three times as much land allocated to conventional maize production.

Results for the emergent farmer as a profit-maximizer are presented in Table 8. When inputs are subsidized in a one-year model, the farmer does not adopt any MT regime. With a four-period planning horizon, she selects MZ-RIP2 for about one-third of all maize production and responds to decreasing labor requirements by adding more conventionally-produced maize to the portfolio of crop activities. When the farmer must pay full price in a one-year model, she allocates no land to MT regimes. However, she does plant with a ripper in a four-period model.

We also experiment with a scenario in which financial assistance is offered in the first two years and then removed thereafter (Table 9). As a calorie-maximizer, the area under both MT and conventional maize production is reduced in year 3, and cotton and sunflower production are increased accordingly. As a profit-maximizer, the farmer behaves similarly but also adds a new crop regime (SUN2) when the subsidy is removed.

Small-scale farmer

Assuming the small-scale farmer can access subsidized inputs, the calorie-maximizing crop choices do not differ between the one-period and four-period model (Table 10). All maize is grown under MT regimes, mostly with planting basins and few cash inputs (MZ-BAS1). Note that the farmer must commit the land area to MT throughout the 4 periods, and with the remaining land, the farmer's optimal choice is to grow cotton. Compared with the model that lacks MT options, the farm-household now produces more calories under roughly the same land area (see Wineman and Crawford 2014). Even when the farmer must pay for all inputs, she selects two MT regimes for maize production, with a heavy emphasis on the low-input maize grown with planting basins. The farmer responds to changing yields and labor requirements over time by shifting to a different cotton regime and adding conventionally-grown maize to the mix. When financial assistance is available for two years and then removed, the farmer reallocates some land from maize grown with a ripper to maize grown with planting basins, although she now shifts to a cotton regime that uses animal traction (Table 11). Note that cash requirements for the ripping regime are relatively high, including commercially-priced herbicide.

DISCUSSION AND CONCLUSIONS

These preliminary results suggest that, with a long-term planning horizon, MT maize production is among the optimal choices for both small-scale and emergent farmers. Although not reported here, a sensitivity analysis with a higher discount rate does not alter these results. However, in the one-period models, farmers generally avoid MT regimes (with or without financial assistance) or allocate less land to MT maize production. As expected, when we adjust the models to reflect the removal of financial assistance, the representative farmers often do shift away from the more expensive MT regimes. This occurs even though the commercial prices in years 3 and 4 only include variable costs (i.e. the farmer does not pay for equipment).

These household models also highlight some interesting points related to labor: The estimates derived from the CFS for both conventional and MT crop regimes show that MT does include a higher labor burden for land preparation and weeding (Table 2). However, the differences are smaller than we expected. Although we have restricted the representative households to relying on household labor, the results indicate that farmers are not labor-constrained at planting time. MT proponents point out that it can ease labor bottlenecks at the start of the rainy season (Haggblade and Tembo 2003), but perhaps this is not a large constraint for farmers that regularly have access to animal traction.

What can these results tell us about farmer motivations when (not) adopting MT production regimes? It seems possible that even if MT is expected to be profitable in the long run, farmers do not make such long-term plans for their farms. According to Siegel (2008), "some note that the greatest constraint facing Zambian smallholders is the lack of a more business-oriented approach to farming, since most of them view agriculture as a way of life and not as a business." In our models, when the farmer is assumed to be myopic with regard to minimum tillage, the models come closer to mirroring the behavior of farmers in reality.

Generally, if a model does not reflect the observed choices of farmers under known conditions, then the model needs to be improved. Although we've tried to be rigorous in the estimation of model parameters for the MT regimes, much uncertainty remains regarding these numbers. For example, we are not positive if and how quickly yields increase with consistent use of MT. Linear programming models are notoriously sensitive to parameter estimates. More effort should be made to cross-check these model parameters and validate them with feedback from farmers of Eastern Province.

In addition to the refinement of this model, future research may combine this static LP model with a risk analysis. Our model includes only expected yields for each crop activity. However, some authors have observed that MT tends to produce yields equivalent to conventional tillage in years of adequate rainfall, while producing higher yields in years of poor rainfall (Giller et al. 2009). Assuming this pattern can be validated empirically, it may be incorporated into a utility-maximizing math programming model that incorporates risk aversion. Whether a farmer adopts MT may depend on whether she assigns a higher value to ensuring a minimum yield or to protecting leisure/ off-farm time. Future work may also compare MT as a risk reduction technology to other methods used as adaptation strategies to climate variability, including staggered planting (Mulenga and Wineman 2014). This should be of interest to the designers of agricultural extension programs in Zambia.

TABLES AND FIGURES (RESULTS)

Table 7. *Emergent farmer's calorie-maximizing crop choices*

Costs:	Free equipment + subsidized inputs					Commercial prices for equipment and inputs				
No. seasons:	1	4				1	4			
Season:		1	2	3	4		1	2	3	4
Gross value of production	6,599.73	6,555.35	6,646.50	6,768.31	6,860.61	6,558.22	6,507.70	6,587.94	6,673.73	6,739.28
Net revenue (ZMK)	5,099.73	5,055.35	5,146.50	5,268.31	5,360.61	5,058.22	5,007.70	5,087.94	5,173.73	5,239.28
Returns/ AE/ day (ZMK)	2.57	2.55	2.60	2.66	2.70	2.55	2.53	2.57	2.61	2.64
Cash spent on inputs	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Calories produced	21,792	21,707	21,993	22,394	22,684	21,515	21,328	21,632	21,915	22,121
Calories per AE per day	10,995	10,952	11,097	11,299	11,445	10,855	10,761	10,915	11,057	11,161
Calories per ZMK	14.53	14.47	14.66	12.58	12.75	16.52	17.60	16.87	14.61	14.75
Land cultivated (ha)	3.35	3.15	3.18	3.25	3.29	3.57	3.53	3.47	3.52	3.54
Returns to land (ZMK/ha)	787.00	780.15	794.21	813.01	827.25	780.59	772.79	785.18	798.41	808.53
Total labor days	297.78	289.32	290.47	290.25	291.43	304.74	301.92	300.28	300.07	300.89
Labor binding?	Jan, June					Jan, June				
MZ-RIP2	0.00	0.20	0.20	0.20	0.20	0.00	0.15	0.15	0.15	0.15
MZ4	1.37	1.19	1.18	1.17	1.17	1.10	0.84	0.94	0.93	0.93
SUN10	0.61	0.45	0.48	0.51	0.54	0.96	1.01	0.91	0.92	0.95
COT10	1.37	1.31	1.31	1.37	1.37	1.51	1.53	1.48	1.52	1.52
Fallow	3.13	3.33	3.30	3.23	3.19	2.91	2.95	3.01	2.96	2.94

Figure 1. *Emergent farmer's calorie-maximizing choices*

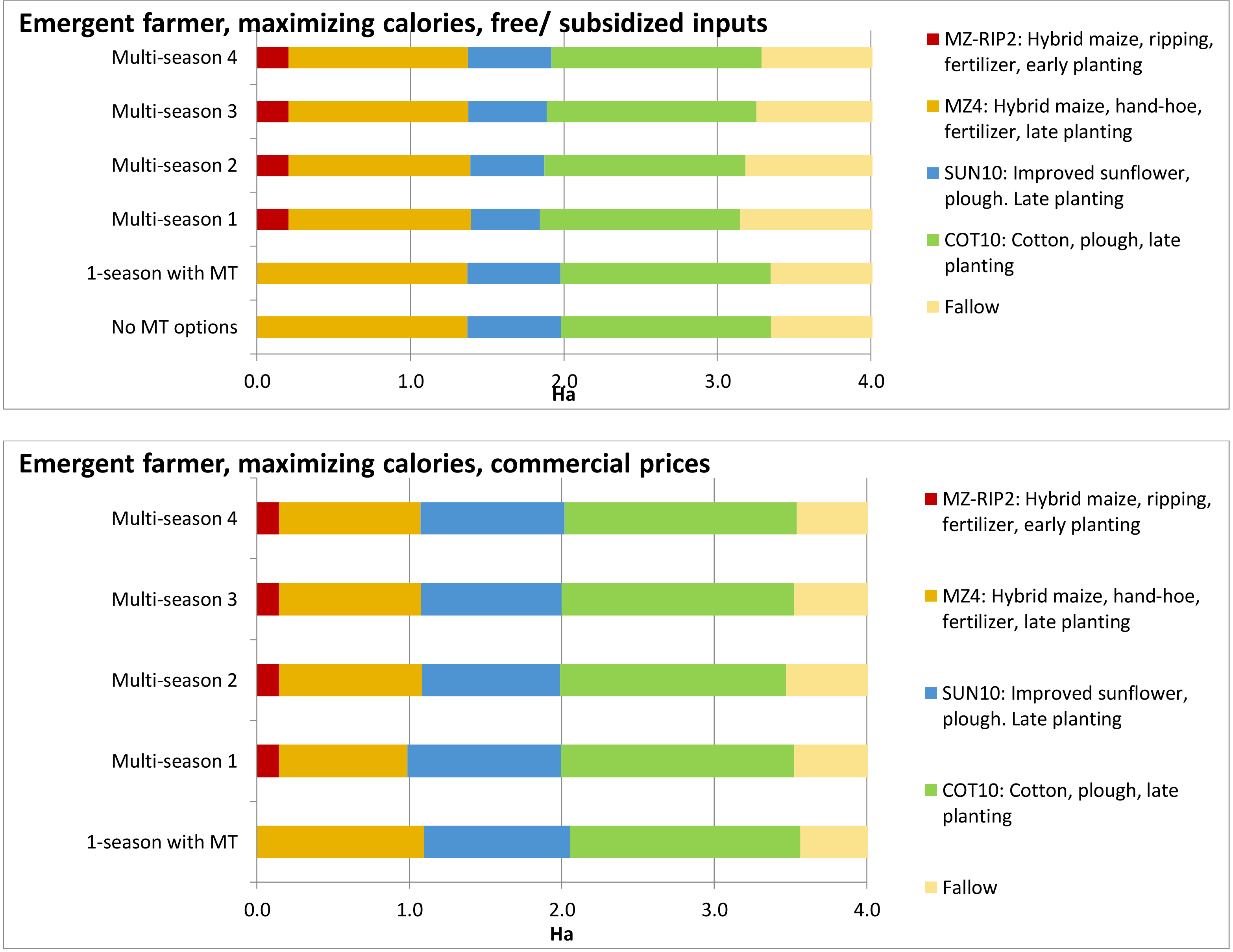


Table 8. *Emergent farmer's profit-maximizing crop choices*

Costs:	Free equipment + subsidized inputs					Commercial prices for equipment and inputs				
No. seasons:	1	4				1	4			
Season:		1	2	3	4		1	2	3	4
Gross value of production	6,529.79	6,283.90	6,384.72	6,689.07	6,789.89	5,798.62	5,810.34	5,858.95	5,913.53	5,962.14
Net revenue (ZMK)	5,362.34	5,280.52	5,360.95	5,521.24	5,601.66	5,296.03	5,230.56	5,297.72	5,348.17	5,373.26
Returns/ AE/ day (ZMK)	2.71	2.66	2.70	2.79	2.83	2.67	2.64	2.67	2.70	2.71
Cash spent on inputs	1,076	914	935	1,077	1,097	404	479	503	505	529
Calories produced	21,325.21	20,434.57	20,768.52	21,895.05	22,229.00	18,160.08	18,496.17	18,666.15	18,853.80	19,023.78
Calories per AE per day	10,759.71	10,310.33	10,478.83	11,047.22	11,215.72	9,162.73	9,332.31	9,418.07	9,512.75	9,598.52
Calories per ZMK	18.27	20.37	20.29	16.04	16.00	36.60	35.98	35.01	33.35	32.30
Land cultivated (ha)	3.72	3.64	3.65	3.62	3.63	4.13	4.07	4.07	4.09	4.09
Returns to land (ZMK/ha)	827.52	814.90	827.31	852.04	864.45	817.29	807.19	817.55	825.33	829.21
Total labor days	309.50	302.39	302.99	301.93	302.54	330.98	310.43	310.57	310.48	310.62
Labor binding?	May, June					Jan, Feb, May, June				
MZ-RIP2	0.00	0.20	0.20	0.20	0.20	0.00	0.07	0.07	0.07	0.07
MZ4	0.91	0.51	0.54	0.72	0.74	0.04	0.00	0.02	0.03	0.05
GR1	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00
SUN10	1.20	1.35	1.35	1.10	1.10	1.98	1.95	1.93	1.91	1.89
SUN2	0.00	0.00	0.00	0.00	0.00	0.22	0.29	0.28	0.30	0.30
COT10	1.61	1.57	1.56	1.60	1.59	1.73	1.77	1.76	1.79	1.78
Fallow	2.76	2.84	2.83	2.86	2.85	2.35	2.41	2.41	2.39	2.39

Figure 2. *Emergent farmer's profit-maximizing choices*

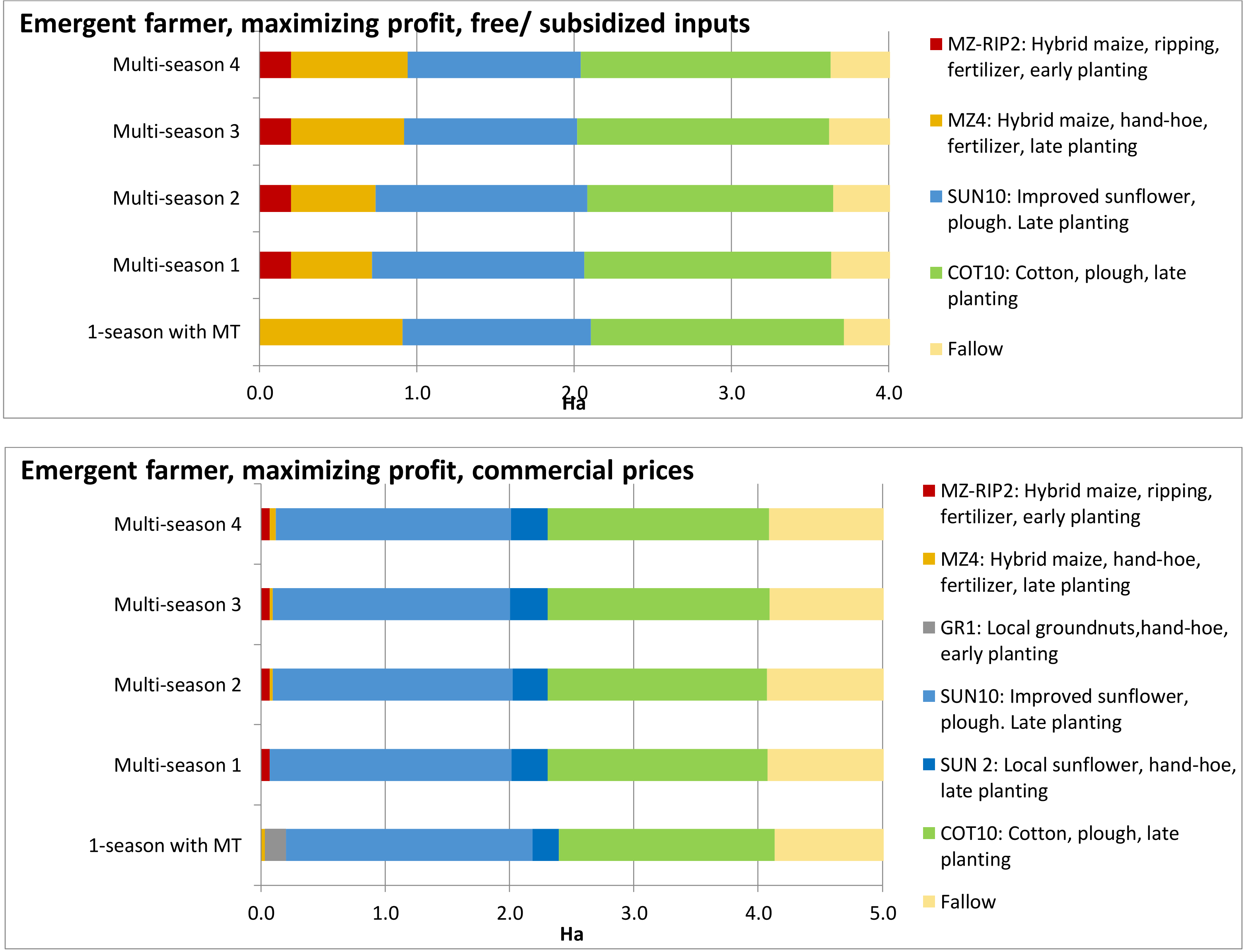


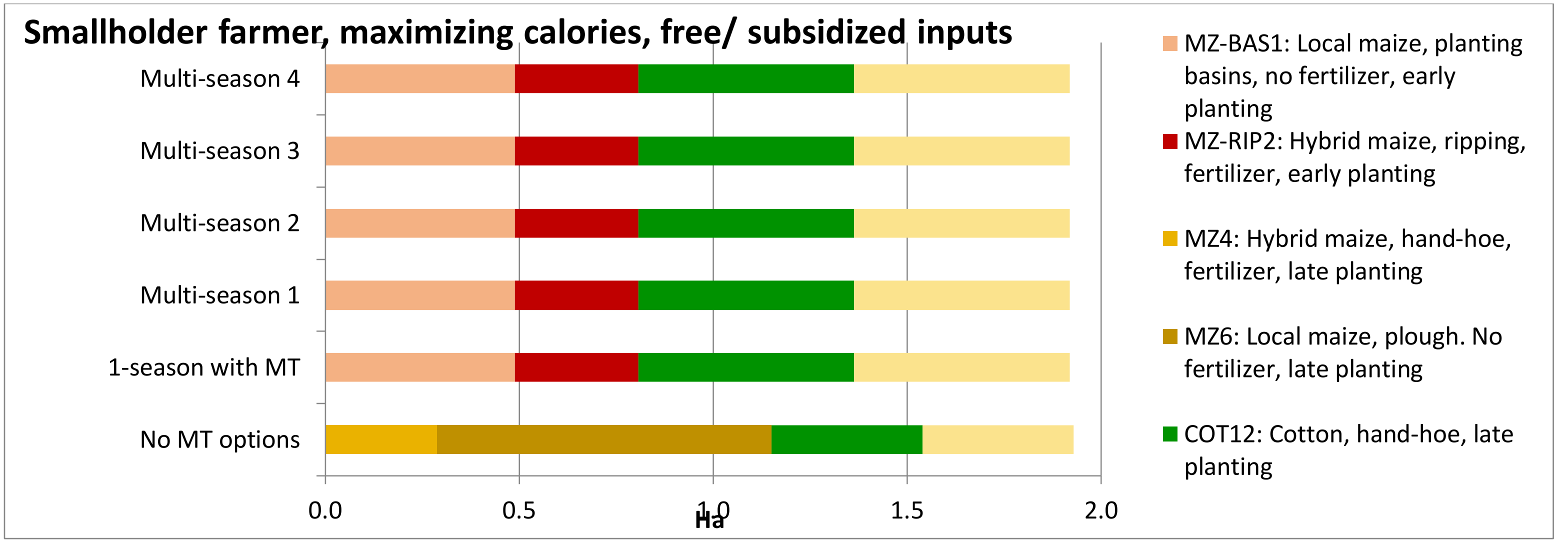
Table 9. *Emergent farmer's crop choices with dis-adoption*

Maximize:	Calories				Profit			
Season:	1	2	3	4	1	2	3	4
Gross value of production	6,647.50	6,647.50	6,590.73	6,590.73	6,564.09	6,564.09	5,964.83	5,964.83
Net revenue (ZMK)	5,147.50	5,147.50	5,090.73	5,090.73	5,386.66	5,386.66	5,298.41	5,298.41
Returns per adult equivalent per day (ZMK)	2.60	2.60	2.57	2.57	2.72	2.72	2.67	2.67
Cash spent on inputs	1,500	1,500	1,500	1,500	1,177.42	1,177.42	666.42	666.42
% cash inputs of gross value of production	22.56	22.56	22.76	22.76	17.94	17.94	11.17	11.17
Calories produced	21,996.63	21,996.63	21,643.10	21,643.10	21,477.21	21,477.21	19,084.32	19,084.32
Calories per AE per day	11,098.48	11,098.48	10,920.10	10,920.10	10,836.40	10,836.40	9,629.06	9,629.06
Calories per ZMK	14.66	14.66	14.43	14.43	18.24	18.24	28.64	28.64
Land cultivated (ha)	3.18	3.18	3.46	3.46	3.59	3.59	4.04	4.04
Returns to land (ZMK/ha)	794.37	794.37	785.61	785.61	831.28	831.28	817.66	817.66
Total labor days	290.52	290.52	299.86	299.86	304.25	304.25	311.37	311.37
MZ-RIP2	0.20	0.20	0.16	0.16	0.14	0.14	0.03	0.03
MZ4	1.18	1.18	0.92	0.92	0.80	0.80	0.18	0.18
SUN10	0.48	0.48	0.90	0.90	1.10	1.10	1.78	1.78
SUN2	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.29
COT10	1.31	1.31	1.48	1.48	1.56	1.56	1.76	1.76
Fallow	3.30	3.30	3.02	3.02	2.89	2.89	2.44	2.44

Table 10. *Small-scale farmer's calorie-maximizing crop choices*

Costs:	Free equipment + subsidized inputs					Commercial prices for equipment and inputs				
No. seasons:	1	4				1	4			
Season:		1	2	3	4		1	2	3	4
Gross value of production	2,715.40	2,715.40	2,885.60	2,885.60	3,055.79	2,411.16	2,321.37	2,641.33	2,646.42	2,803.62
Net revenue (ZMK)	2,365.40	2,365.40	2,535.60	2,535.60	2,705.79	2,061.16	1,971.37	2,291.33	2,296.42	2,453.62
Returns/ AE/ day (ZMK)	1.42	1.42	1.52	1.52	1.62	1.24	1.18	1.37	1.38	1.47
Cash spent on inputs	350	350	350	350	350	350	350	350	350	350
Calories produced	9,079	9,079	9,642	9,642	10,206	8,047	7,754	8,802	8,817	9,337
Calories per AE per day	5,443	5,443	5,781	5,781	6,119	4,824	4,648	5,277	5,286	5,598
Calories per ZMK	25.94	25.94	27.55	21.07	22.30	26.21	44.33	30.31	25.19	26.68
Land cultivated (ha)	1.36	1.36	1.36	1.36	1.36	1.52	1.50	1.57	1.58	1.58
Returns to land (ZMK/ha)	1,231.98	1,231.98	1,320.62	1,320.62	1,409.26	1,073.52	1,026.75	1,193.40	1,196.05	1,277.93
Total labor days	189.46	189.46	183.28	171.53	165.35	186.61	206.45	210.63	213.76	204.25
Labor binding?	June					Dec				
MZ-BAS1	0.49	0.49	0.49	0.49	0.49	0.00	0.98	0.98	0.98	0.98
MZ-RIP2	0.32	0.32	0.32	0.32	0.32	0.00	0.10	0.10	0.10	0.10
MZ4	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.14	0.15	0.15
MZ6	0.00	0.00	0.00	0.00	0.00	0.89	0.00	0.00	0.01	0.01
COT12	0.56	0.56	0.56	0.56	0.56	0.40	0.00	0.08	0.34	0.34
COT10	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.27	0.00	0.00
Fallow	0.56	0.56	0.56	0.56	0.56	0.40	0.42	0.35	0.34	0.34

Figure 3. *Small-scale farmer's calorie-maximizing choices*



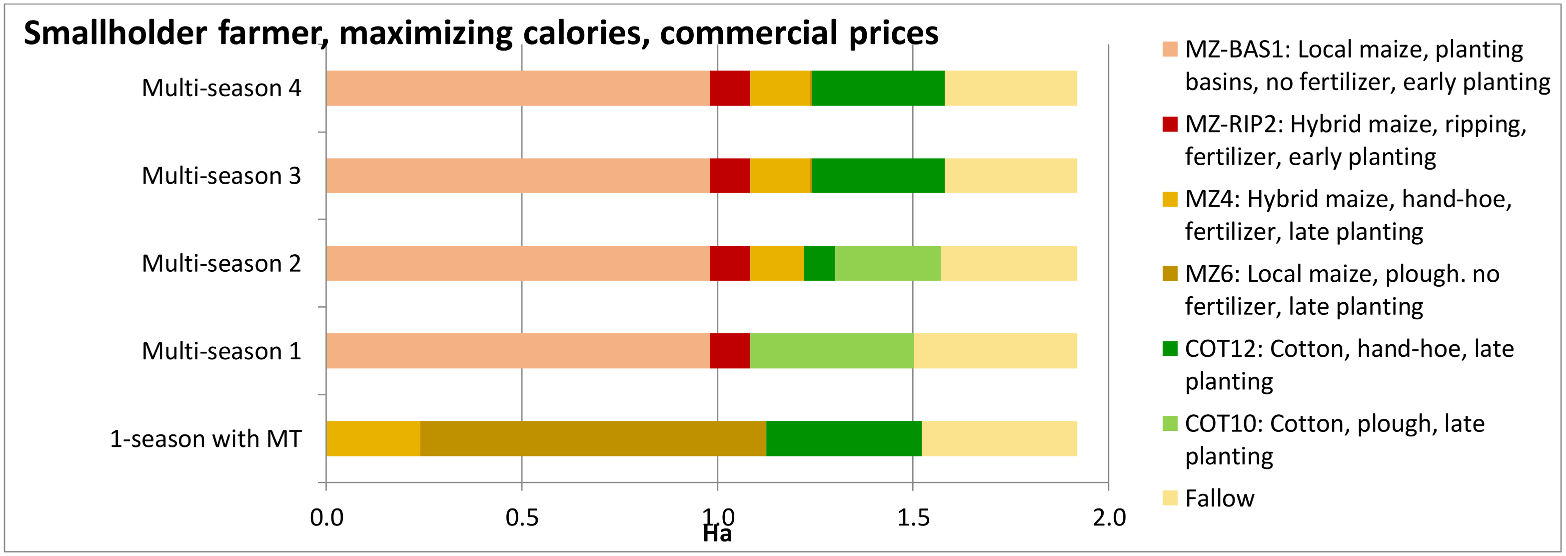


Table 11. *Small-scale farmer's calorie-maximizing crop choices with dis-adoption*

Season:	1	2	3	4
Gross value of production	2,885.60	2,885.60	2,712.48	2,712.48
Net revenue (ZMK)	2,535.60	2,535.60	2,362.48	2,362.48
Returns per adult equivalent per day (ZMK)	1.52	1.52	1.42	1.42
Cash spent on inputs	350	350	350	350
Calories produced	9,642.34	9,642.34	9,053.56	9,053.56
Calories per AE per day	5,780.61	5,780.61	5,427.63	5,427.63
Calories per ZMK	27.55	27.55	25.87	25.87
Land cultivated (ha)	1.36	1.36	1.47	1.47
Returns to land (ZMK/ha)	1,320.62	1,320.62	1,230.46	1,230.46
Total labor days	183.28	183.28	187.27	187.27
MZ-BAS1	0.49	0.49	0.81	0.81
MZ-RIP2	0.32	0.32	0.21	0.21
COT12	0.56	0.56	0.00	0.00
COT10	0.00	0.00	0.45	0.45
Fallow	0.56	0.56	0.45	0.45

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