Modeling Climate Change Impacts on Farm Households in Zambia

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Outline of presentation

- Modeling impacts of climate change on farm households, and optional adaptation strategies
- Incorporating minimum tillage options in the farm household models (Eastern Province)
- Comparison of farmers' perceptions of climate change with empirical climate trends
- Findings and conclusions
- Next steps and possible extensions

Objectives of farm household modeling*

- Connect broad-scale climate change analysis and modeling with analysis of smallholder farming systems at a much smaller spatial scale, where adaptation information is most helpful..
- To add an economics dimension to climate and crop modeling, through design and use of models that identify the set of farming activities that optimizes profit or calorie production.

Research questions

1. How will representative farm households in Zambia respond to the effects of climate change on crop yields?
2. To what extent can farmers minimize the negative effects of climate change by changing crops or production technologies?

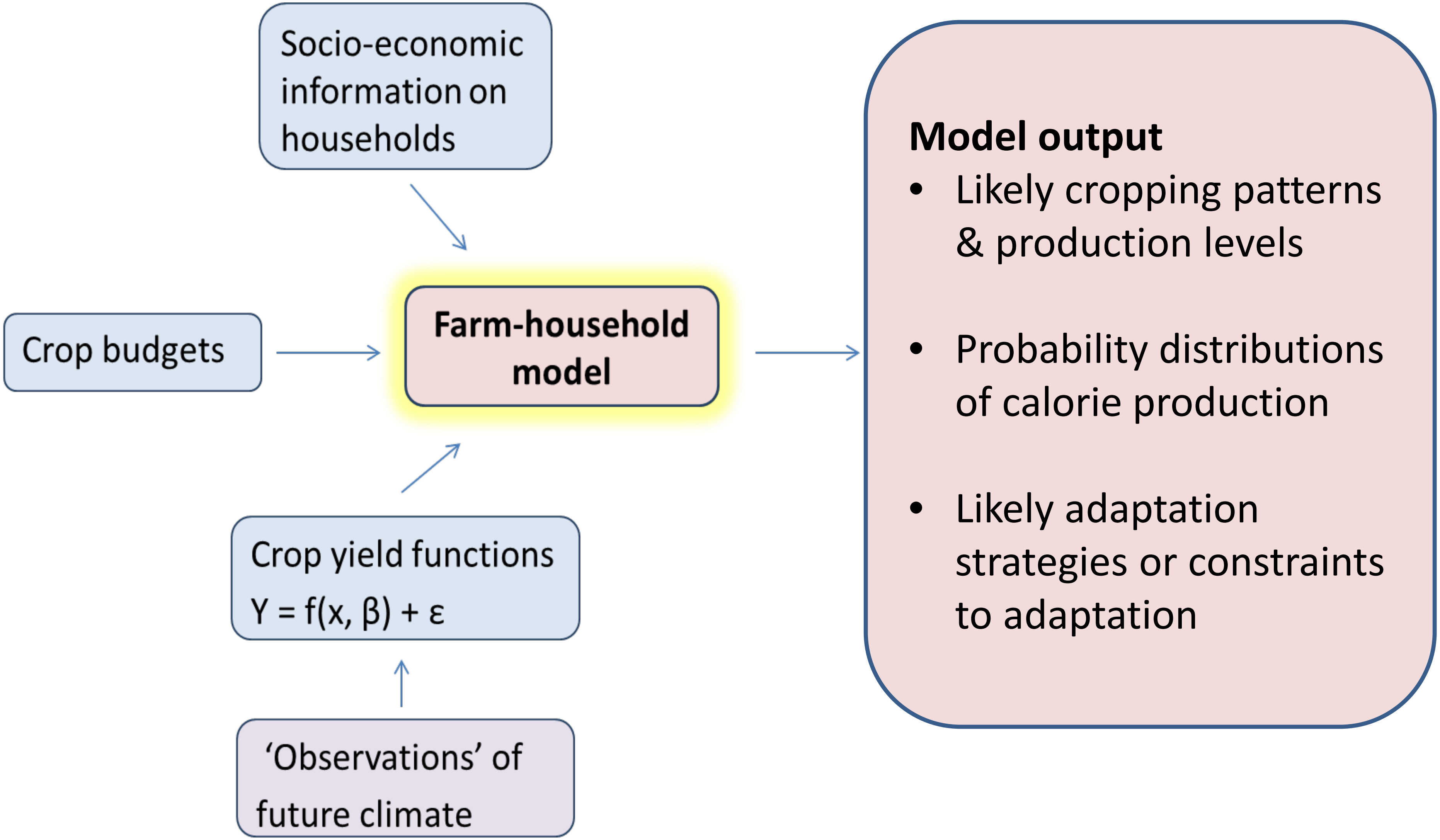
*This section draws on Wineman and Crawford (2014), "Climate Change and Crop Choice in Zambia: A Mathematical Programming Approach."

How the optimization model works

- Choose the set of crops and production technologies that best meets the household's objectives (profit, calorie production)

- Taking into account:
  - Crop yields
  - Inputs required for each production activity
  - Prices of crop outputs and inputs
  - Availability of land, labor, cash
  - Household calorie consumption needs
  - Desire to maintain soil fertility

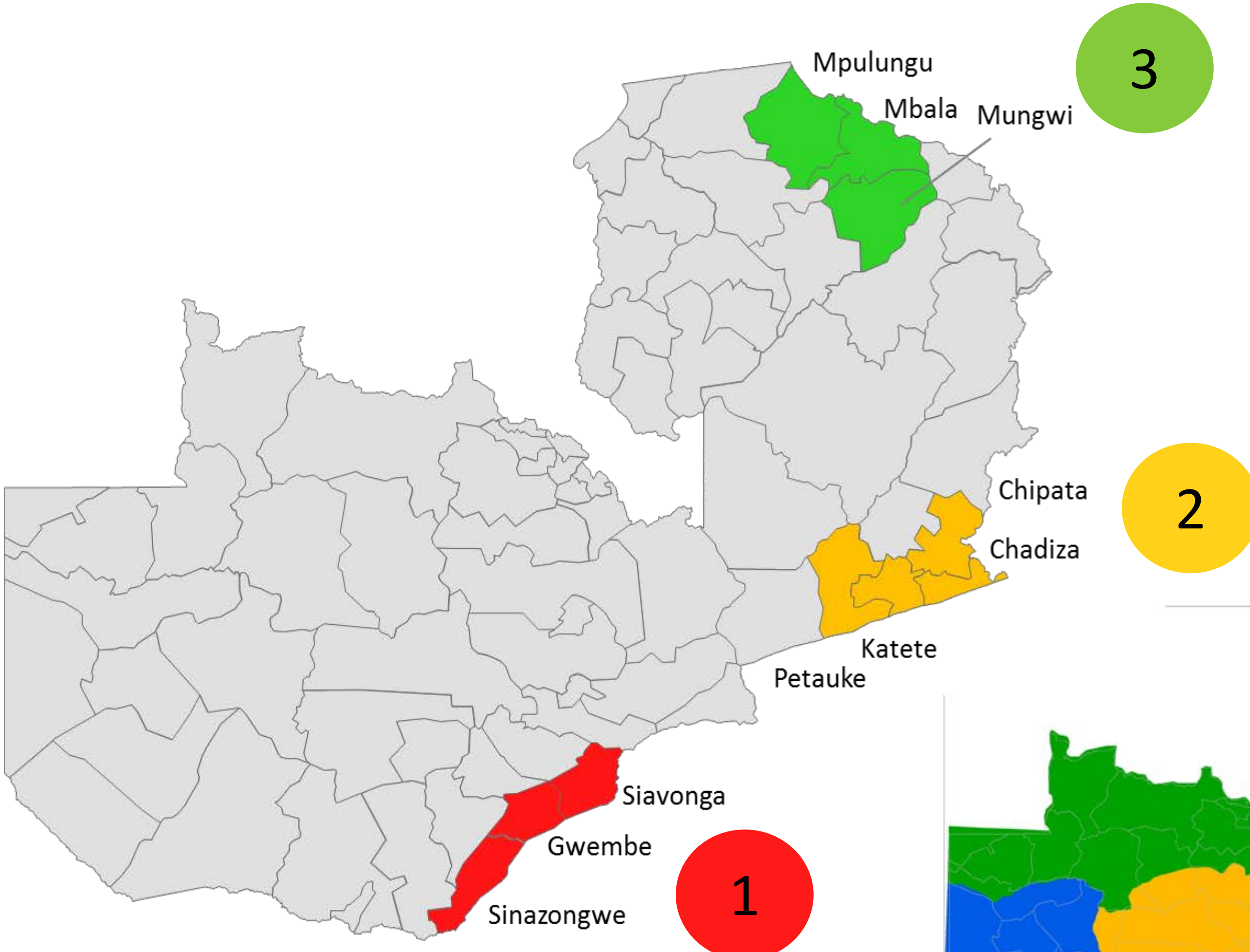
The model


Socio-economic information on households
Crop budgets
Farm-household model
Crop yield functions
Y = f(x, β) + ε
'Observations' of future climate
Model output
• Likely cropping patterns & production levels
• Probability distributions of calorie production
• Likely adaptation strategies or constraints to adaptation

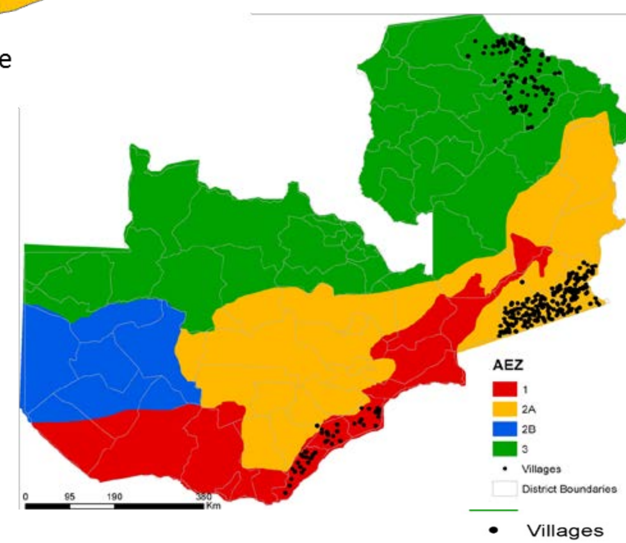
Data sources

- Crop Forecast Survey (CFS) 2003 – 2012
- Rural household surveys (SS 2004 & 2008, RALS 12)
- Secondary source (Siegel & Alwang 2005)
- Focus group input
- Zambia Meteorological Department (ZMD)
- IPCC GCM climate predictions

Study sites



3
Mpulungu
Mbala
Mungwi
2
Chipata
Chadiza
Katete
Petauke
1
Siavonga
Gwembe
Sinazongwe



AEZ
1
2A
2B
3
Villages
District Boundaries
0
95
190
380
Km
Villages

Household types*

Smallholder

- 1.9 hectares
- 2.75 working-age members
- 250 ZMK cash available

Emergent farmer

- 7 hectares
- 3.25 working-age members
- 150,000 ZMK cash available

Female-headed household

- 1.5 hectares
- 2 working-age members
- 225 ZMK cash available

*Rough averages of model values across the three study sites.

Which crops & management regimes?*

Based on data from Crop Forecast Survey

Crop	Seed Type	Tillage Method	Fertilizer	Time of tillage	Code
Maize	Local	Hand	No	Early	MZ1
Maize	Hybrid	Hand	Yes	Late	MZ4
Maize	Local	Ox	No	Late	MZ6
Groundnuts	Local	Hand	No	Early	GR1
Groundnuts	Improved	Hand	No	Late	GR12
Groundnuts	Local	Ox	No	Late	GR6

Other crops included: millet, sorghum, sunflower, sweet potato, cotton.

*Examples drawn from a much longer list of regimes included in the models.

Labor requirements by site & crop regime

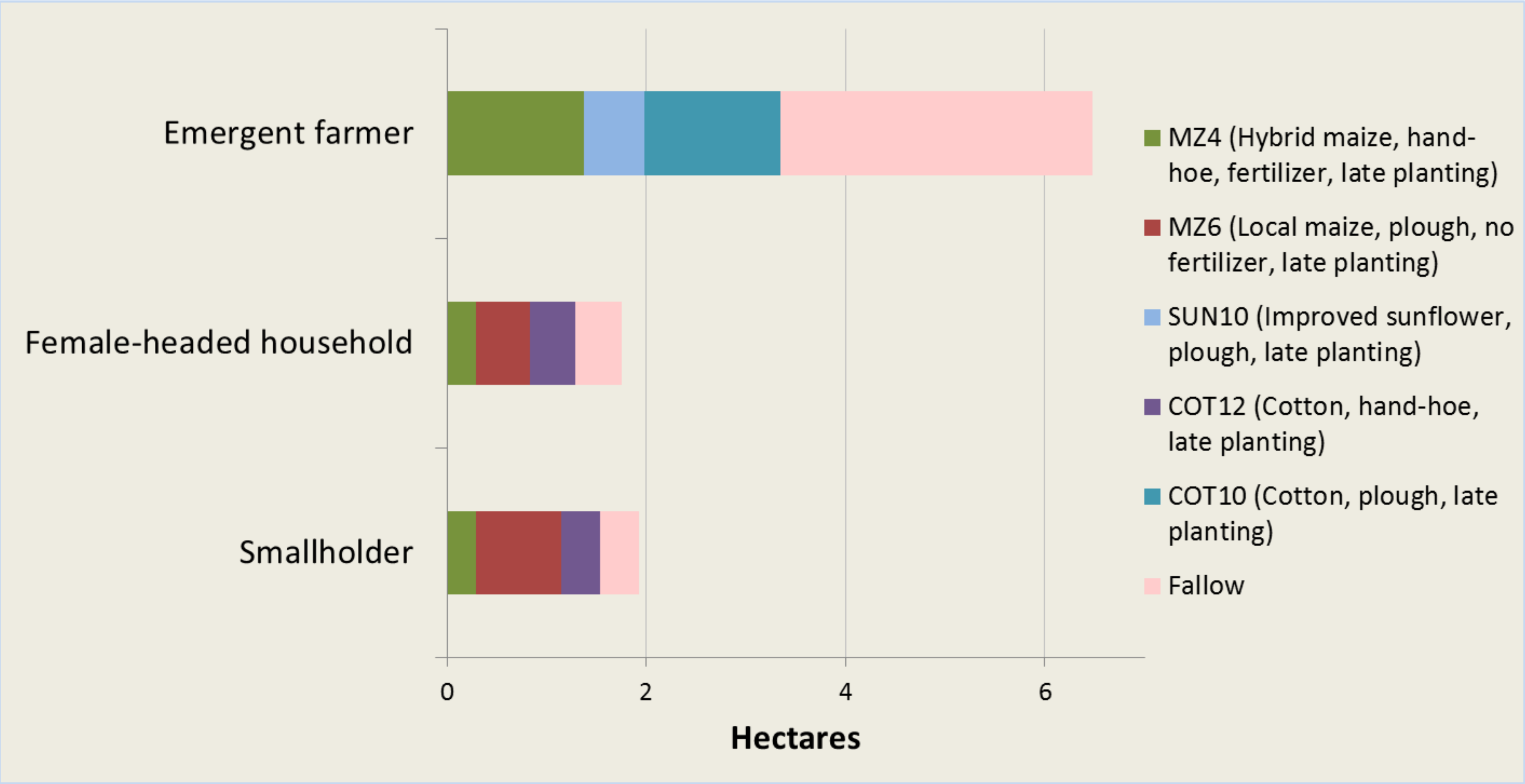
SITE 1		MZ10	MZ1	MZ6	MZ8	SOR6	SOR10	COT10	COT12
October	1								
	2	3.43		3.57	2.85			4.50	15.00
November	1	3.43		3.57	2.85			5.50	16.00
	2	10.51	27.43	10.33	9.18	17.00	1.60	1.00	1.00
December	1	11.74	27.93	10.28	10.99	19.60	4.20	5.33	8.99
	2	7.99	7.35	6.85	10.59	10.19	10.19		
January	1	7.99	13.70	6.85	7.99	7.59	7.59		8.99
	2	0.00	13.70	0.00	2.60	7.59	7.59	5.33	8.99
February	1		13.70					5.33	
	2	3.33		3.33	3.33				
March	1	3.33		3.33	3.33				
	2		10.00			18.00	18.00		
April	1					18.00	18.00		
	2								
May	1	4.57		3.81	5.23	6.20	6.20		14.17
	2	4.57	10.29	3.81	5.23	10.20	10.20	14.15	14.15
June	1	9.38	23.71	10.03	11.46	4.00	4.00	14.15	15.22
	2	4.82	13.43	6.23	6.23	4.00	4.00	15.22	1.07
July	1	4.82		6.23	6.23			1.07	1.07
	2							1.07	

Unit = 7-hour work day

Baseline output – Eastern Province

		Small-holder	FHH	Emergent
Budget (cash available, ZMK)		350	325	1,500
Net revenue (ZMK)		2,119.20	1,916.04	5,099.73
Returns per AE per day (ZMK)		1.27	1.53	2.57
Returns to land (ZMK/ha)		1,103.75	1,101.17	787
% cash inputs of gross value of production		14.17	14.5	22.73
Calories per adult equivalent (AE) per day		4,938.24	5,967.49	10,995.20
Land cultivated (ha)		1.53	1.28	4.72
→ Land constraint binding?		Yes	Yes	No
→ Labor contraint binding (months)		Dec	June	Jan, June
Hectares of crop activity	MZ4	0.29	0.28	1.37
	MZ6	0.86	0.54	0
	SUN10	0	0	0.61
	COT12	0.39	0.46	0
	COT10	0	0	1.37
	Fallow	0.39	0.46	3.13
VALIDATION TESTS				
% difference in model vs actual land use		**15.56**	**20.26**	**32.16**
% difference (gross value of production)		**29.03**	**56.06**	**0.07**
% difference (calories produced – excl. cotton)		**4.31**	**2.92**	**39.24**

Baseline crop choices, Eastern Province



Statistical crop yield models

- Yield (kg/ha) a function of:
  - **Rainfall** (amount and intra-season variability)
  - **Temperature** (average across growing season)
- Data: (1) ZMD weather records from nearby met stations, and (2) CFS field-level data (9 years) aggregated to district
- Stepwise variable selection procedure:

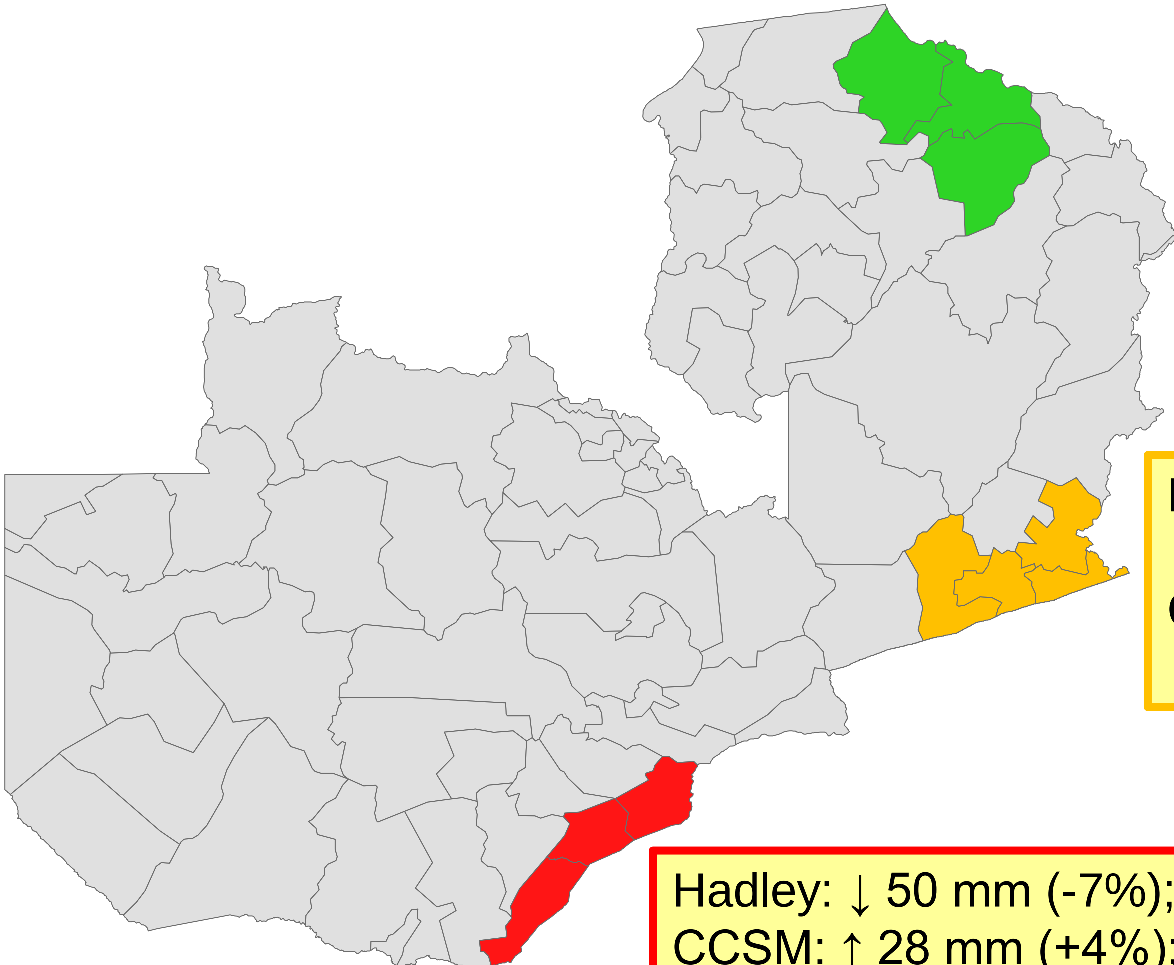
$$ln(Mean\ yield_{dcsf}) = f(rain, rain^2, avg.temp, temp^2, CV_{rain}, districts)$$

where d = district, c = crop, s = seed type, f = fertilizer use

Climate change scenarios

- The Hadley (HadCM3) model (relatively “dry”)
  - Declines in rainfall
  - Somewhat higher intra-season variability in rainfall than CCSM
  - Increases in temperature
- The CCSM model (relatively “wet”)
  - Increases in rainfall
  - Somewhat less drastic increases in temperature than Hadley

Future climate scenarios used to predict yields in 2050

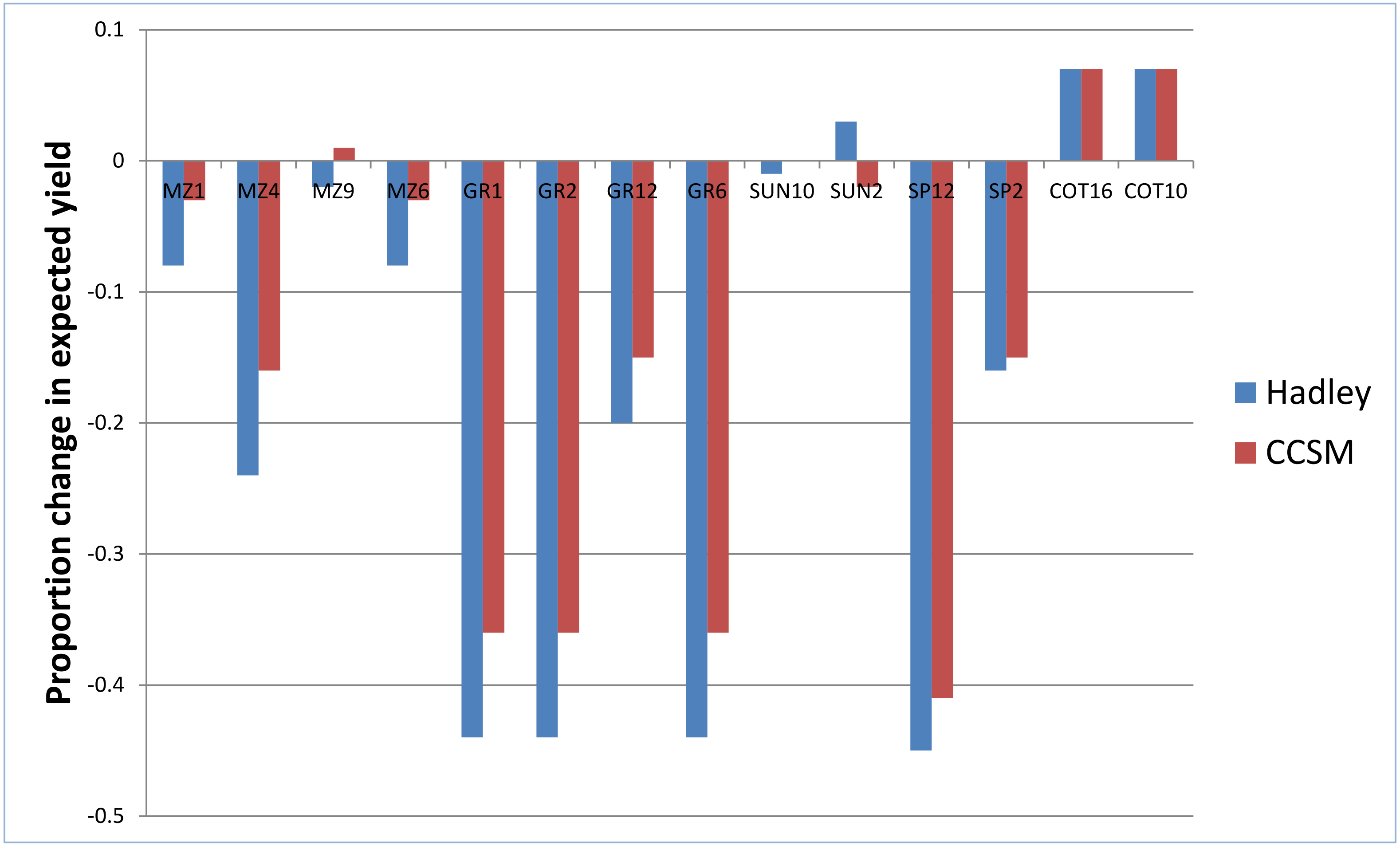


Hadley: ↓ 10 mm (-1%); ↑ 2.29 °C (+11%)
CCSM: ↑ 71 mm (+7%); ↑ 2.08 °C (+10%)

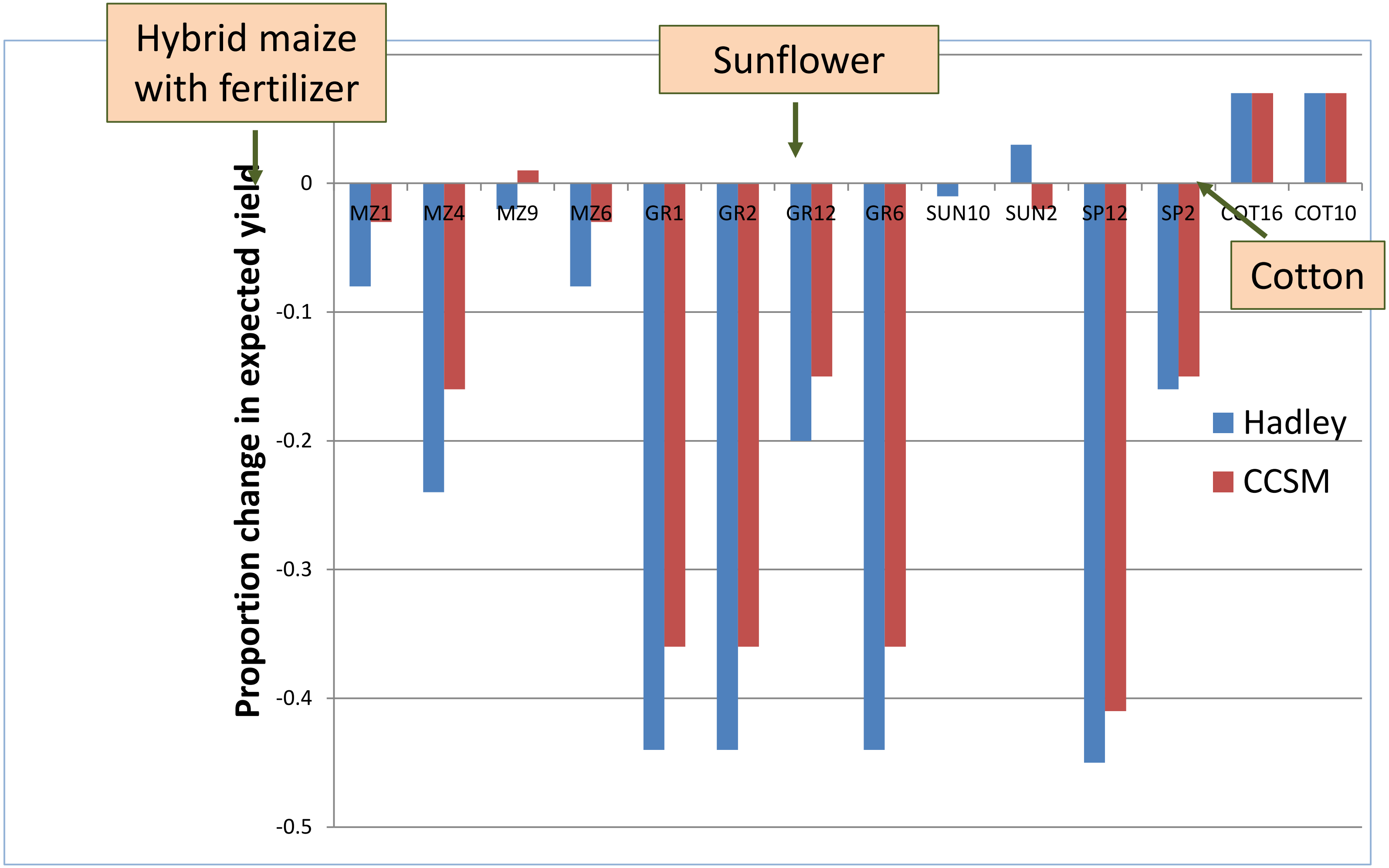
Hadley: ↓ 76 mm (-8%); ↑ 2.41 °C (+10%)
CCSM: ↑ 38 mm (+4%); ↑ 2.17 °C (+9%)

Hadley: ↓ 50 mm (-7%); ↑ 2.31 °C (+10%)
CCSM: ↑ 28 mm (+4%); ↑ 2.31 °C (+10%)

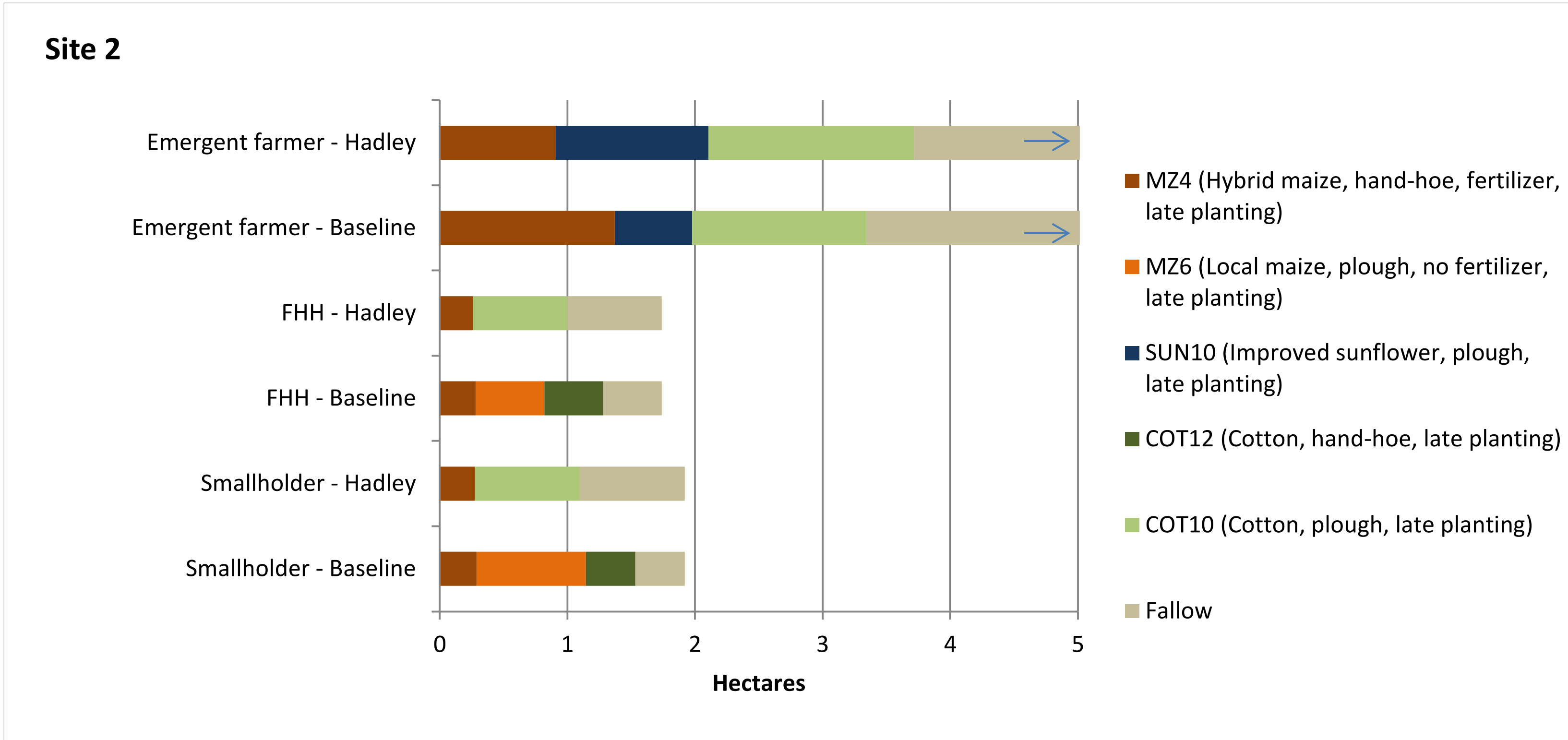
Future yield predictions for Eastern Province based on statistical yield analysis



Future yield predictions for Eastern Province based on statistical yield analysis

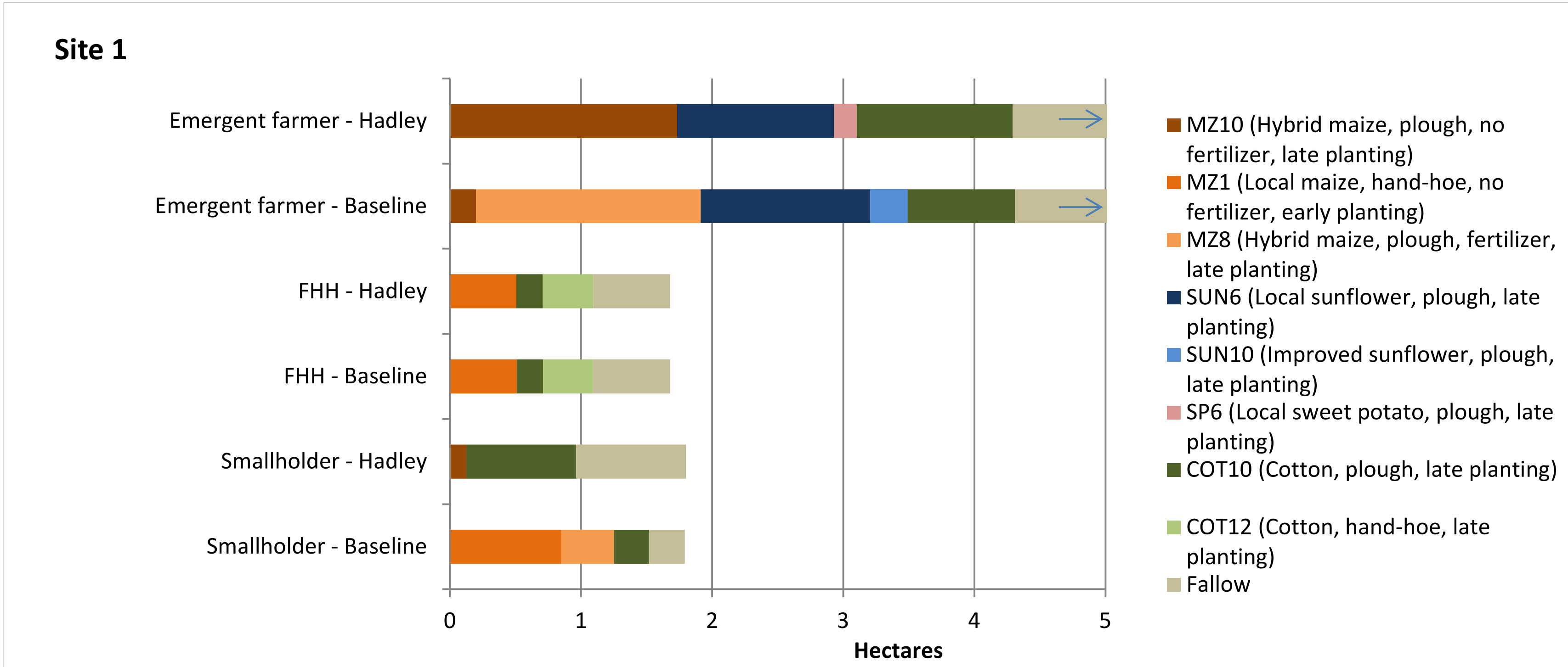


Effects of adaptation in Eastern Province



	Smallholder	**Female-headed household**	**Emergent farmer**
Baseline	4,938 cal/AE/day	5,967	10,995
	↓	↓	↓
No adaptation	4,584	5,614	10,082
	↓ +4.97%	↓ +3.57%	↓ +2.22%
With adaptation	4,829	5,827	10,326

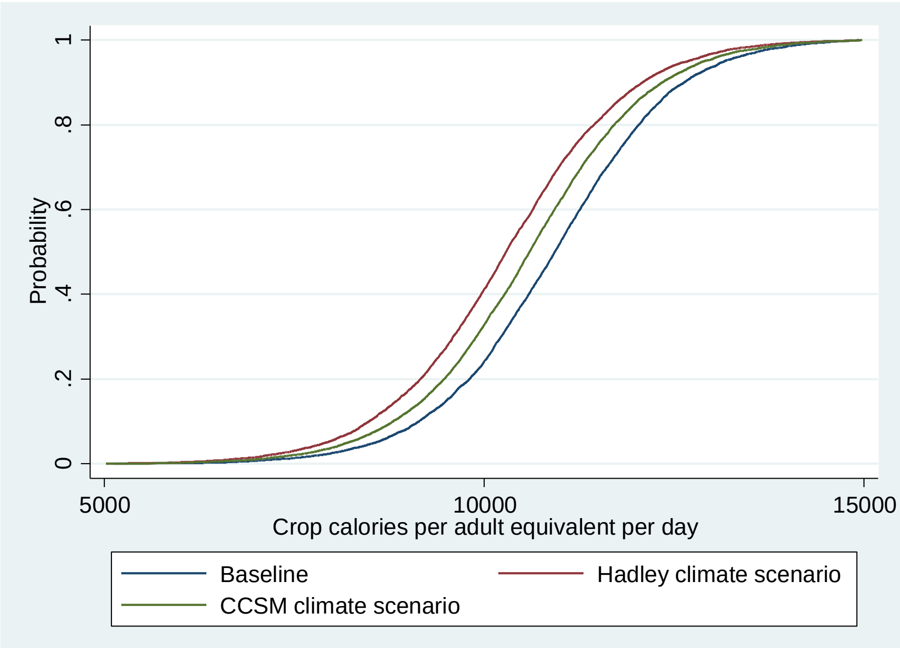
Effects of adaptation in Southern Province



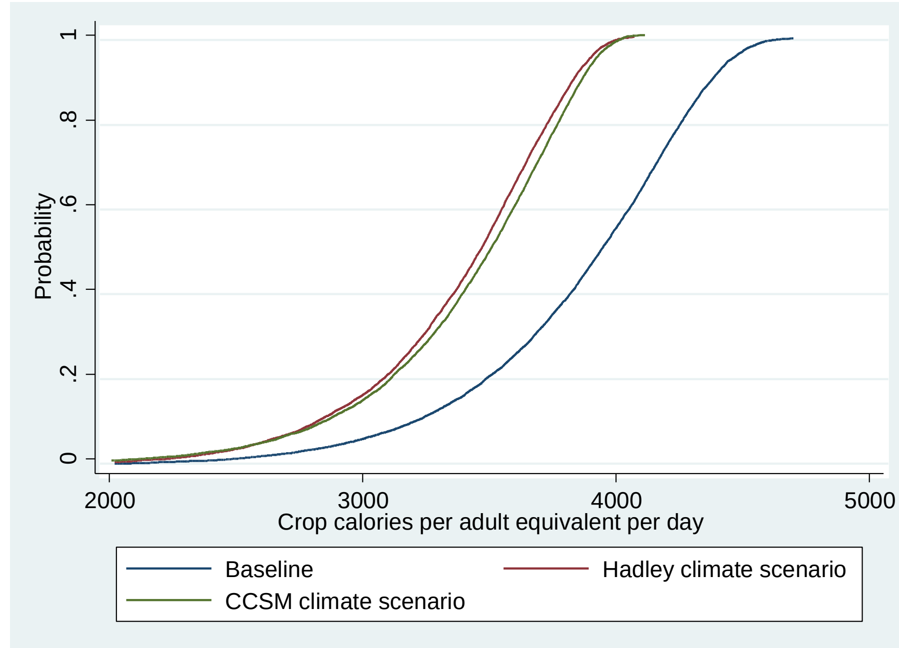
	Smallholder	Female-headed household	Emergent farmer
Baseline	3,227 cal/AE/day	3,581	8,124
↓	↓	↓	↓
No adaptation	3,154	3,915	7,418
↓	↓ +7.39%	↓ +0%	↓ +10.14%
With adaptation	3,392	3,915	8,241

Vulnerability analysis: Monte Carlo simulations

Emergent farmer, Eastern Province



Smallholder, Northern Province



Baseline=blue (right curve); CCSM=green (middle curve); Hadley=red (left curve)

Probability of falling below 3,000 calories/AE/day, given optimum farm plan (North Prov):

At baseline: 6.6% → 15.9% under CCSM scenario

→ 20.3% under Hadley scenario

Main findings and conclusions

- Crops have different levels of sensitivity to climate change → implications for agricultural policy.
- Farmers will choose different crops (cotton, sunflower) and technologies (less fertilizer) under climate change.
- This on-farm adaptation is likely to mitigate (but not necessarily offset) the negative effects of climate change.
- The household types modeled are expected to meet consumption requirements even under climate change, but smallholder farmers are most vulnerable to consumption shortfalls in a bad production year.
- Larger-scale adaptation measures are needed (e.g. heat-tolerant seed varieties, and agricultural investments and policies to reduce risk for small farmers).

Analysis of minimum tillage*

- Motivation:
  - Conservation agriculture (CA) is promoted as an effective adaptation to climate variability.
  - Minimum tillage (MT) is the most commonly adopted component of CA.
  - Dis-adoption rates of MT are high while overall use of MT remains low. Why?
  - Math programming models can capture the trade-offs farmers make when allocating resources.

*Drawn from Wineman (2014), "Modeling Minimum Tillage among Smallholders in Eastern Zambia."

Expanding the model

- 3 new maize regimes added to the household models for Eastern Province

Local seed – ***Basins*** – Early tillage – No fertilizer

Hybrid seed – ***Basins*** – Early tillage – Fertilizer

Hybrid seed – ***Ripping*** – Early tillage – Fertilizer

- Yields and labor requirements taken from CFS. Yields increase and labor requirements decrease over time.
- Crop budgets alternately assume:

Free equipment + subsidized inputs

Equipment purchases + commercially priced inputs

- Sometimes assistance is removed after two years.

Labor requirements for conventional and MT maize regimes

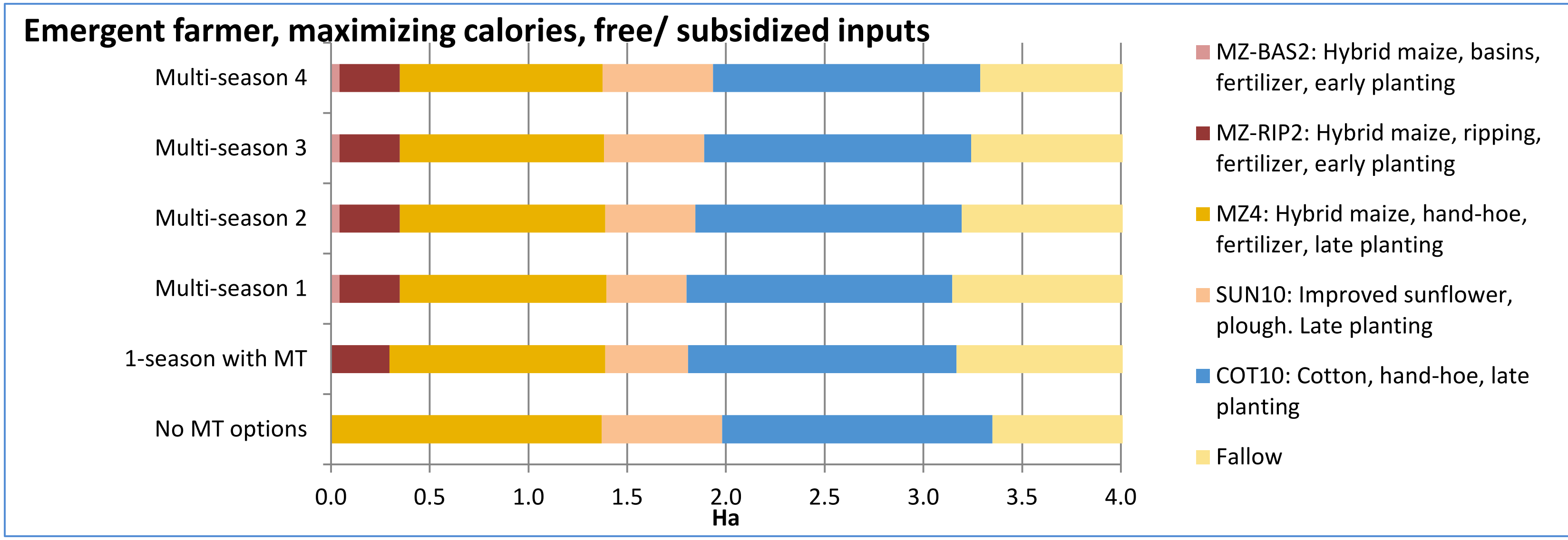
	MZ1: Local maize, hand-hoe, no fertilizer, early planting	MZ4: Hybrid maize, hand-hoe, fertilizer, late planting	MZ6: Local maize, plough, No fertilizer, late planting	MZ-BAS1: Local maize, planting basins, no fertilizer, early planting	MZ-BAS2: Hybrid maize, basins, fertilizer, early planting	MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
Land preparation	29.63	11.43	14.81	45.34	46.29	9.13
Planting	10.58	7.94	11.29	12.18	8.72	5.95
Weeding	44.44	33.86	44.44	53.79	35.05	48.43
Fertilizer application	--	5.13	--	--	5.78	8.58
Guarding	10.00	11.00	10.00	10.00	10.00	10.00
Harvest	19.75	17.64	24.69	17.87	23.79	15.15
Post-Harvest activities	21.87	23.78	23.28	27.33	35.33	23.81

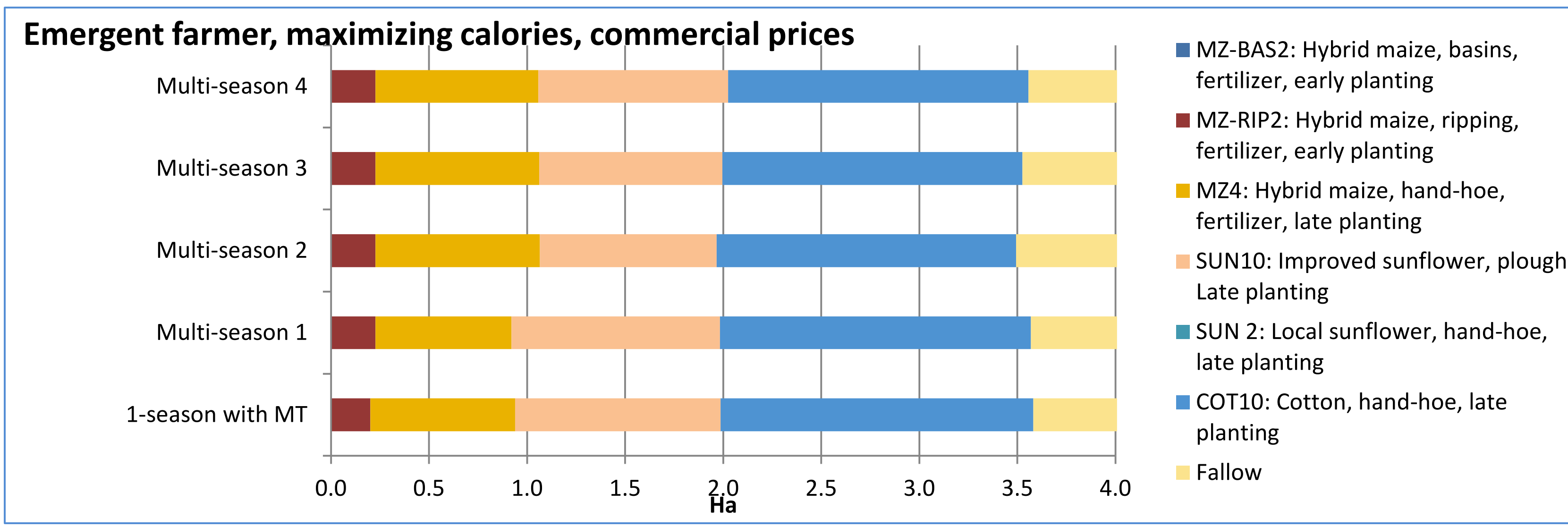
Unit = 7-hour workday

Source: Requirements estimated from CFS 2010 and 2011

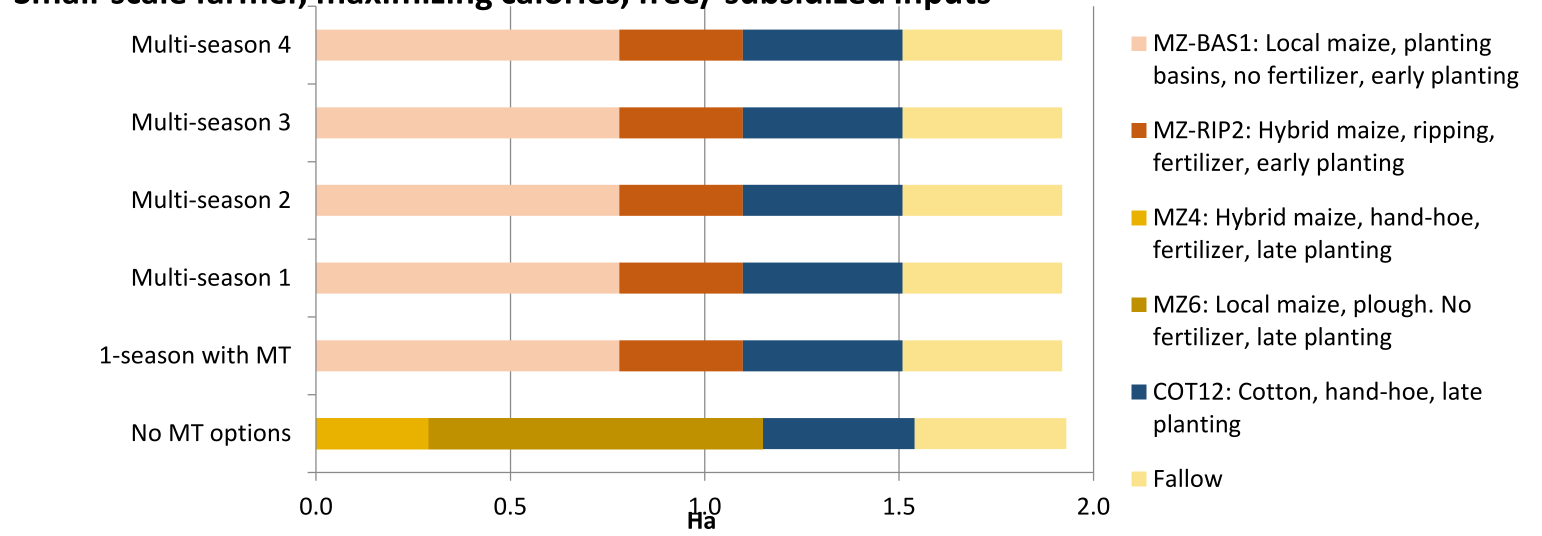
Results: Emergent farmer maximizing profit

Costs:	Free equipment + subsidized inputs				
No. seasons:	1	4			
Season:		1	2	3	4
Net revenue (ZMK)	5,440.86	5,424.20	5,605.63	5,772.60	5,939.54
Returns/ AE/ day (ZMK)	2.75	2.74	2.83	2.91	3.00
Cash spent on inputs	1,159.52	1,174.71	927.79	975.23	1,022.62
Calories/ AE/ day	10,903.13	10,111.35	10,412.33	10,757.06	11,101.68
Land cultivated (ha)	3.61	3.73	3.78	3.80	3.82
Total labor days	301.51	294.26	296.28	297.45	298.62
Labor binding?	May, June				
Hectares					
MZ-RIP2	0.19	0.42	0.42	0.42	0.42
MZ4	0.72	0.00	0.00	0.05	0.09
GR1	0.00	0.00	0.00	0.00	0.00
SUN10	1.09	1.65	1.70	1.70	1.69
SUN2	0.00	0.00	0.00	0.00	0.00
COT10	1.61	1.65	1.65	1.64	1.62
Fallow	2.87	2.75	2.70	2.68	2.66

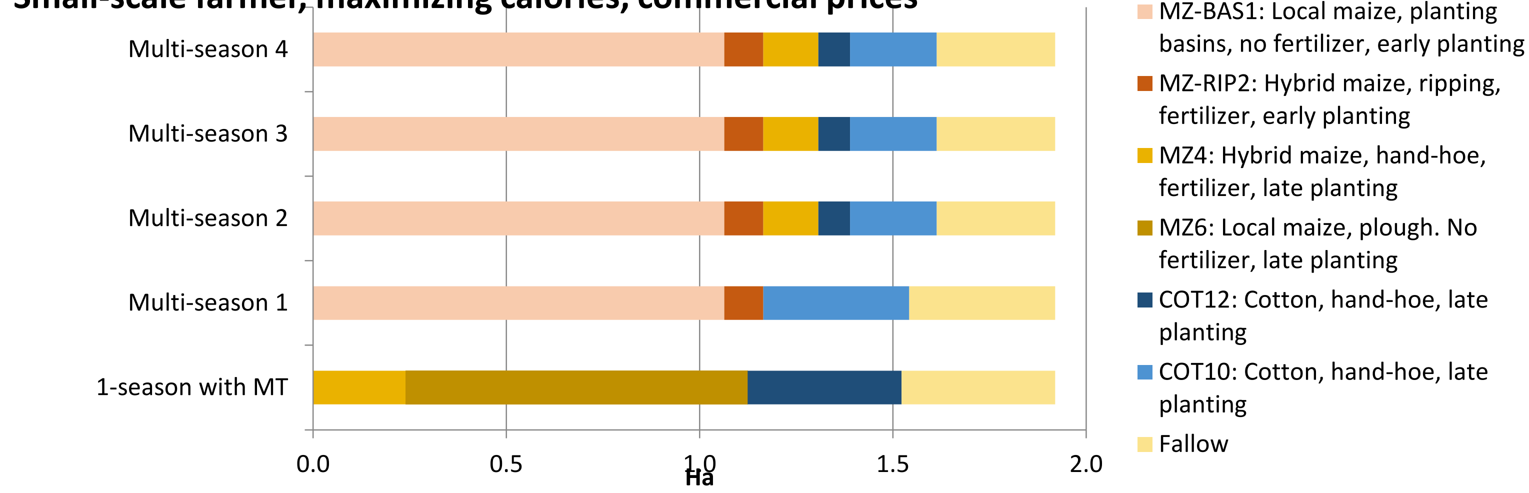

Emergent farmer, maximizing calories, free/ subsidized inputs
Multi-season 4
Multi-season 3
Multi-season 2
Multi-season 1
1-season with MT
No MT options
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Ha
MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
SUN10: Improved sunflower, plough. Late planting
COT10: Cotton, hand-hoe, late planting
Fallow


Emergent farmer, maximizing calories, commercial prices
Multi-season 4
Multi-season 3
Multi-season 2
Multi-season 1
1-season with MT
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Ha
MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
SUN10: Improved sunflower, plough. Late planting
SUN 2: Local sunflower, hand-hoe, late planting
COT10: Cotton, hand-hoe, late planting
Fallow

Small-scale farmer, maximizing calories, free/ subsidized inputs



Small-scale farmer, maximizing calories, commercial prices



Conclusions on min. tillage analysis

- MT requires more labor for planting and weeding, but less than expected, hence may not a big constraint to MT adoption.
- Models with four-year time frame include partial adoption of MT, but less so for models with one-year time frame (where long-run benefits aren’t fully incorporated).
- Question then about whether farmers are willing and able to take a long-term perspective on investing in minimum tillage.
- Important to incorporate risk into this analysis and to compare MT with other climate risk-reducing options.

Farmer perceptions vs empirical climate records*

- Generally, farmer accounts are consistent with met. data on rising temperature.
- Farmer perceptions of rainfall diverge from empirical records
- Rainfall records indicate a mixed picture, with a recent uptick in rainfall levels in Eastern Province and a shorter rainy season in Northern Province.
- Farmers in all study areas perceive the rainfall season to be growing shorter, highly variable, and with declining seasonal rainfall amounts.
- Empirical records on the other hand show relatively less variability in rainfall amounts, and no significant change in rainfall onset and cessation dates.

*Drawn from Mulenga and Wineman (2014), "Climate Trends and Farmers' Perceptions of Climate Change in Zambia."

Possible explanations for the divergence

- Our analysis may be too coarse—use of dekad (10-day) instead of daily rainfall records
- Farmer recollections may be incorrect
- Farmers may focus on climate-related parameters that are salient in their lives but difficult to document with only meteorological data.
- Farmers may fail to differentiate yield impacts of weather from yield impacts of changes in farming systems, and other confounding factors such as soil degradation.

Adaptation measures used by farmers

- Use of conservation agriculture practices, mainly minimum tillage–in Eastern and Southern Provinces
- Staggered planting—planting in phases to deal with uncertainty of the onset of the rains
- Diversification into other crops (e.g., cotton, sorghum), off-farm wage income, trading, and migration

Summary on farmer perceptions

- Our comparison suggests that the study of climate change should incorporate farmer perceptions and not be left to expert judgment or scientific observation alone.
- A lack of correlation between farmers' perceptions and observed weather does not imply that farmers' perceptions are invalid.
- Local systems of knowledge contribute different parameters and offer a more contextual interpretation of these climate parameters.
- Farmer knowledge should be considered complementary rather than contradictory.

Overall next steps and possible extensions

- Next steps:
  - Complete the report on sensitivity of field crops to climate shocks
  - Finalize and disseminate/publish other reports
- Possible extensions:
  - Improved analysis of risk and vulnerability
  - Improved analysis of minimum tillage; dependent on better estimates of input/output coefficients
  - Analysis of government crop promotion policies, considering which crops are apparently sensitive to climate change or not

Reports available

- Wineman and Crawford, “Climate Change and Crop Choice in Zambia: A Mathematical Programming Approach.”
- Mulenga and Wineman, “Climate Trends and Farmers’ Perceptions of Climate Change in Zambia.”
- Mulenga, “Climate Change Impact on Agricultural Production and Adaptation Strategies: Farmers’ Perceptions and Experiences.”
- Wineman, “Modeling Minimum Tillage among Smallholders in Eastern Zambia.”
- Wineman, “Maize Production in the Future.”
- Wineman, “Multidimensional Household Food Security Measurement in Rural Zambia.”
- Wineman, “Sensitivity of Field Crops to Climate Shocks in Zambia” (Draft available soon)

Questions?

Extra slides

Mathematical structure of model

$$max\ calories = \sum_{j=1}^{n} K_j\, X_j$$

Where K_j=calories per ha and X_j = ha, for activity j

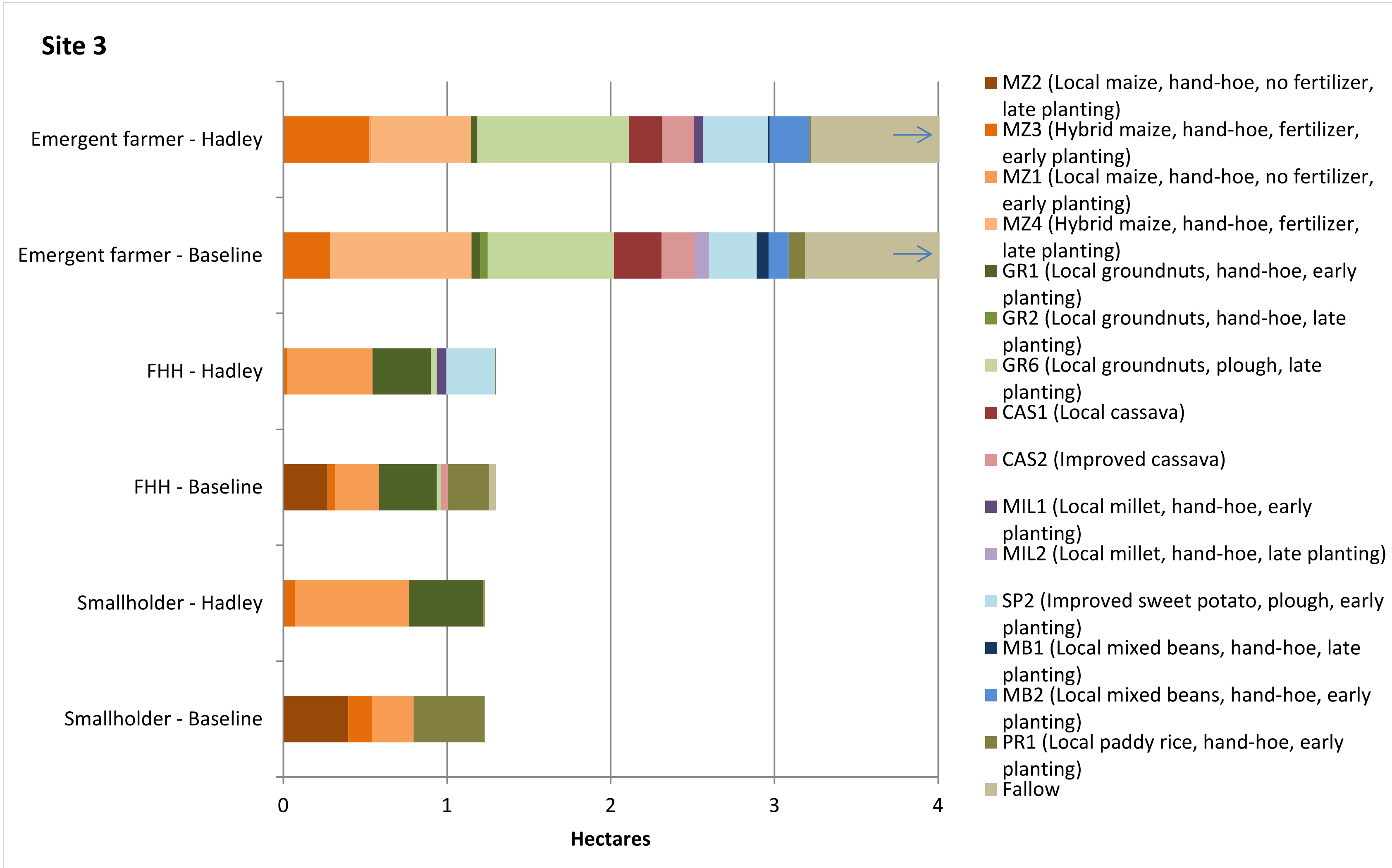
Subject to:

- Input requirements for each crop activity
- Resource constraints: $\sum_{j=1}^{m} a_{ij}\, X_j \ \leq\ b_i$
  - → For land and biweekly labor
- Budget constraint: $\sum_{j=1}^{n} C_{ij}\, X_j \leq\ \omega$
- Household calorie requirement: $K_j X_j \geq\ \theta$
- Non-negativity constraint: $X_j\ \geq 0$
- Flexibility constraints (sometimes): $K_j X_j \geq\ \varphi$

Crop budgets by site & crop regime

	Basal Fert	Top Fert	Seed/ planting material	Plough	Basal Fert	Top Fert	Seed/ planting material	Plough	Total Variable Costs
	Kg/Ha	Kg/Ha	Kg/Ha	Yes/No	ZMK/Kg	ZMK/Kg	ZMK/Kg	ZMK/Ha	ZMK/Ha
MZ1			28.08				1.07		30.00
MZ4	123.46	133.33	28.64		2.67	2.82	6.90		929.29
MZ9	123.46	133.33	23.11		2.67	2.82	1.07		756.45
MZ6			26.96	Yes			1.07	40.00	68.81
GR1			39.01				3.16		123.46
GR2			39.01				3.16		123.46
GR12			39.51				4.22		166.69
GR6			39.01	Yes			3.16	40.00	163.46

Effect of adaptation in Northern Province



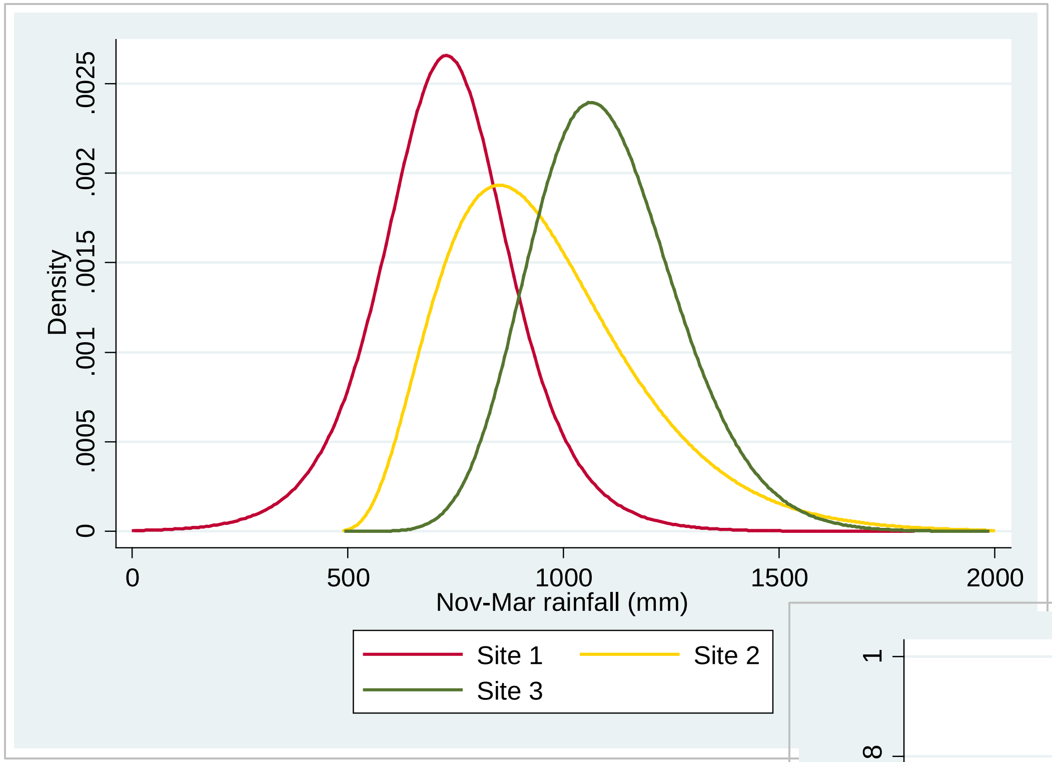
Effect of adaptation in Northern Province, cont.

Hadley

	Smallholder	Female-headed household	Emergent farmer
Baseline	3,869 cal/AE/day	4,477	9,740
	↓	↓	↓
No adaptation	3,154	3,905	8,024
	↓ +4.92%	↓ +2.21%	↓ +0.23%
With adaptation	3,344	4,004	8,046

CCSM

	Smallholder	Female-headed household	Emergent farmer
Baseline	3,869 cal/AE/day	4,477	9,740
	↓	↓	↓
No adaptation	3,301	4,050	8,466
	↓ +4.07%	↓ +1.51%	↓ +0.12%
With adaptation	3,458	4,117	8,478



Fitted distributions of rainfall at study sites

Average temperature