Modeling Climate Change Impacts on Farm Households in Kenya

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Outline of presentation

- Objectives addressed
- Model design and data sources
- Study sites and household types
- Illustrative model results
- Limitations, conclusions and implications

Objectives of farm household modeling

- Connect the science of climate change impacts on agriculture with the specificities of smallholder systems ([1], [2]).
- Connect relatively coarse climate models with the spatial scales at which adaptation information is most helpful ([3]).
- Fill a gap in literature regarding adaptation at the farm-household level ([4]).

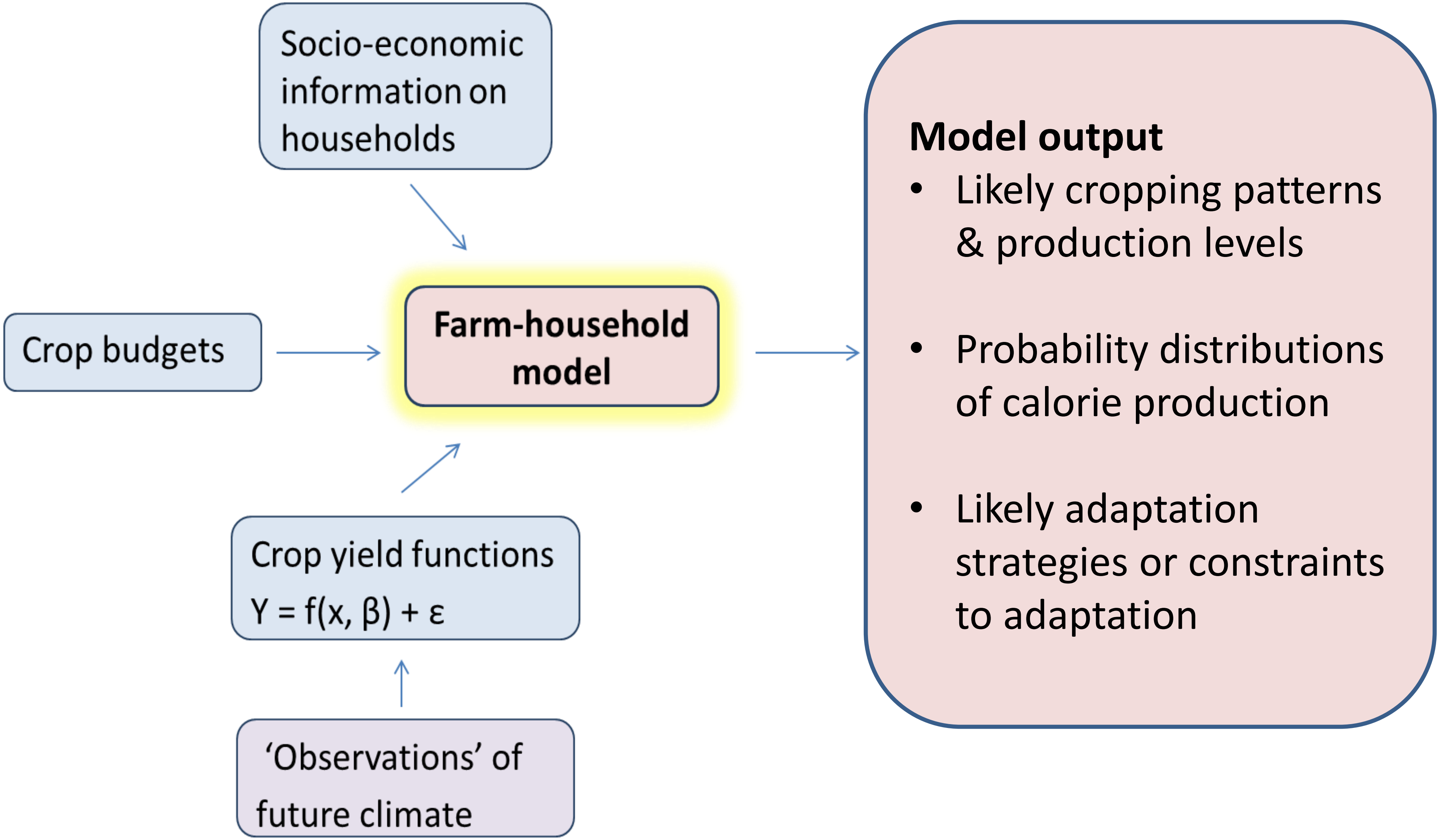
Research questions

1. How will representative farm households in Kenya 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?

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

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

Mathematical structure of model

Max calories = $\sum_{j=1}^{n} KjXj$ *or*

Max profit = $\sum_{j=1}^{n}(PjXj - \sum_{j=1}^{m} AijXj)$

Subject to:

- Input requirements for each crop activity
- Resource constraints: $\sum_{j=1}^{m} AijXj \leq Bi$

  → For land and biweekly labor
- Budget constraint: $\sum_{j=1}^{n} CijXj \leq \omega$
- Household calorie constraint: $KjXj \geq \theta$
- Non-negativity constraint: $Xj \geq 0$

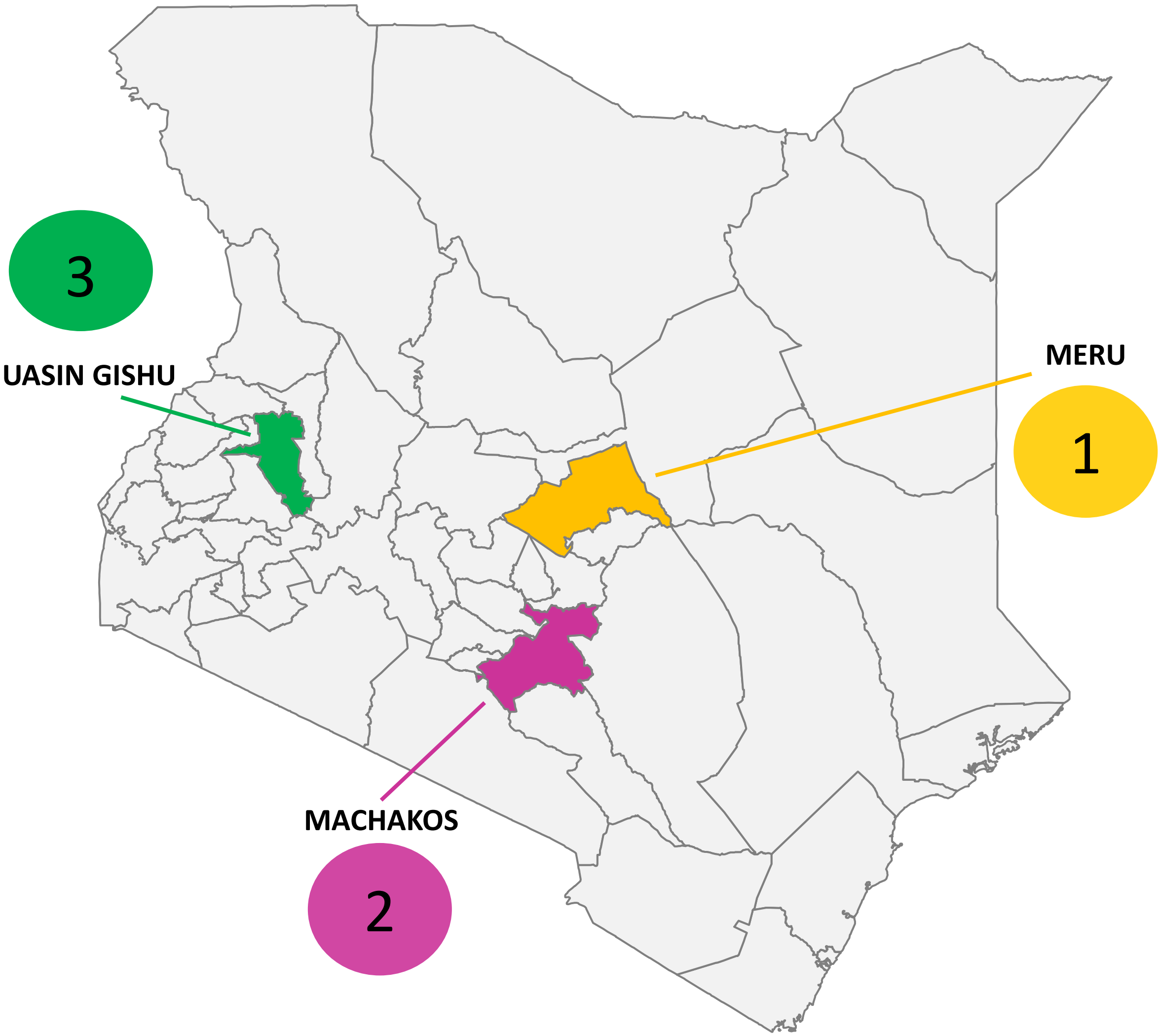
Data sources

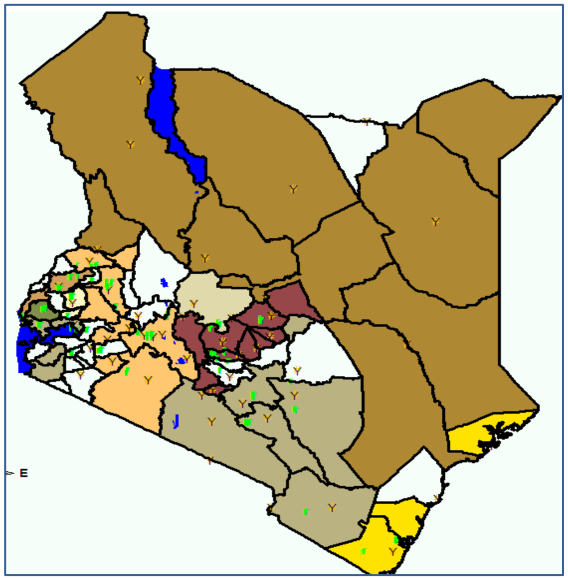
- 5-wave panel household data set collected by the Tegemeo Institute of Agricultural Policy and Development, with support of MSU
- Focus group input (EcoDym)
- FEWSNET (historical rainfall) & NASA POWER (historical temperature)
- IPCC GCM climate predictions

Climate scenarios

- Hadley (HadCM3) – Drier during main season
- CSIRO - Wetter

Study sites


3
UASIN GISHU
MERU
1
MACHAKOS
2


Eastern lowlands zone
Central highlands zone
High potential maize zone

Characteristics of sites (mean values per household)

Variable	Meru	Machakos	Uasin Gishu
Land owned (acres)	2.3	5.0	11.3
Land cultivated (main season)	1.8	2.7	6.1
Adult equivalents	3.7	5.5	6.0
Tropical Livestock Units	1.5	2.0	4.2
Equipment value (‘000 KSh)	37.9	30.5	38.4
Income per capita (KSh)	340.8	198.2	153.8

Household types (Machakos)

Small-scale

- 3.4 acres
- 4.3 working-age members
- ~9,600 KSh cash available

Medium-scale

- 12.5 acres
- 4.0 working-age members
- ~20,400 KSh cash available

Crops + management regimes (example)

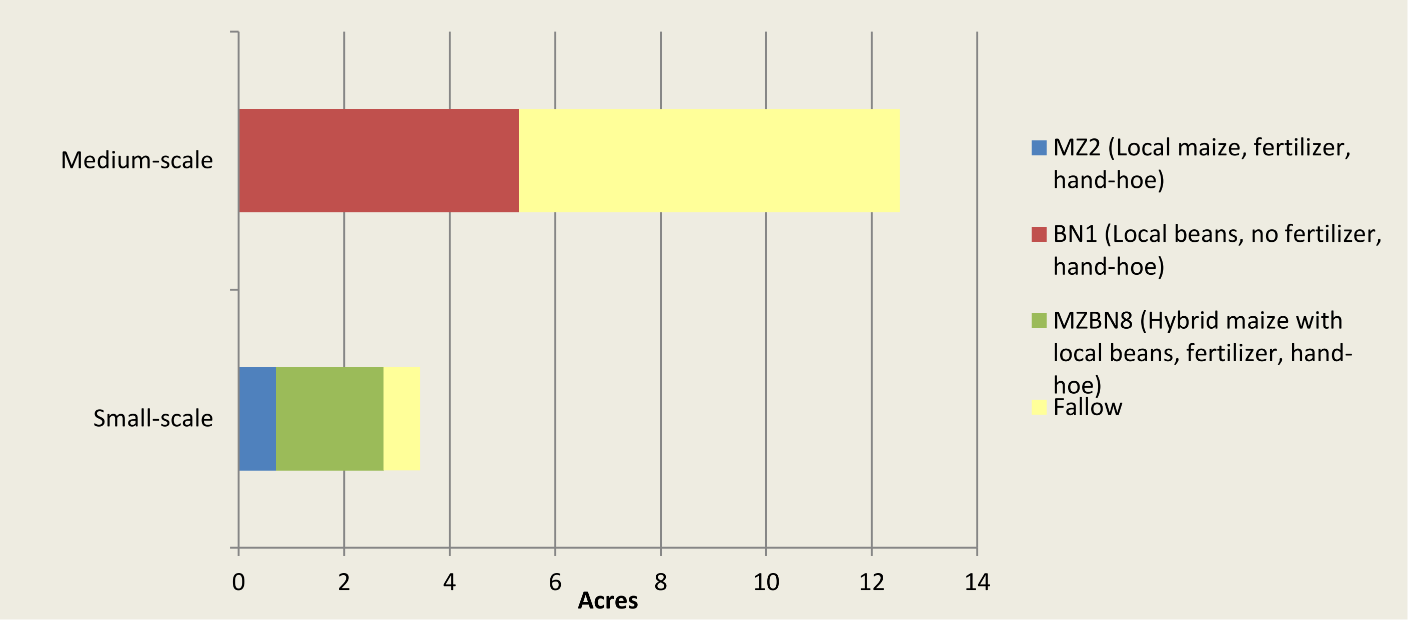
Crop	Local seed	Fertilizer	Hand-hoe	Regime Code
Maize	Y	N	Y	MZ1
Maize	N	Y	Y	MZ8
Beans	Y	N	Y	BN1
Maize and beans	N (maize)	N	Y	MZBN7
Sweet potato	Y	N	Y	SPOT1

Profit margins by crop (Meru)

Regime	Var cost/acre	Yield (kg/ac)	Sales P / kg	Gross Rev	Net Rev
MZ8	3,895	900	20.7	18,644	14,749
IPOT2	14,069	3,640	13.5	49,230	35,161
IPOT8	12,775	3,467	13.5	46,884	34,110
MZBN7-MZ	1,246	360	20.7	7,458	6,211
MZBN7-BN	897	72	41.6	2,998	2,101
MZBN8-MZ	3,365	720	20.7	14,915	11,550
MZBN8-BN	798	144	41.6	5,996	5,199
SPOT1	9,487	1,960	11.0	21,645	12,158

MZ=maize; IPOT=Irish potatoes; SPOT=sweet potatoes; MZBN7-MZ=maize & beans (mostly maize), local seed, no fert., hand hoe cultivation; MZBN8-BN=maize & beans (mostly beans), local seed, fert., hand hoe cultivation.

Baseline crop choices, Machakos



Medium-scale – Max profit
Cash spent: 17,784 KSh
Profit: 40,587 KSh
Land binding? No
Budget binding? No
Labor binding? Yes

Small-scale – Max calories
Cash spent: 9,658 KSh
Calories: 3,610/ AE/ day
Land binding? No
Budget binding? Yes
Labor binding? Yes

Statistical crop yield models

- Yield (kg/acre) of each crop in a crop mix is a function of:
  - Rainfall (amount and intra-season variability)
  - Temperature (average across growing season)
- Stepwise variable selection procedure:

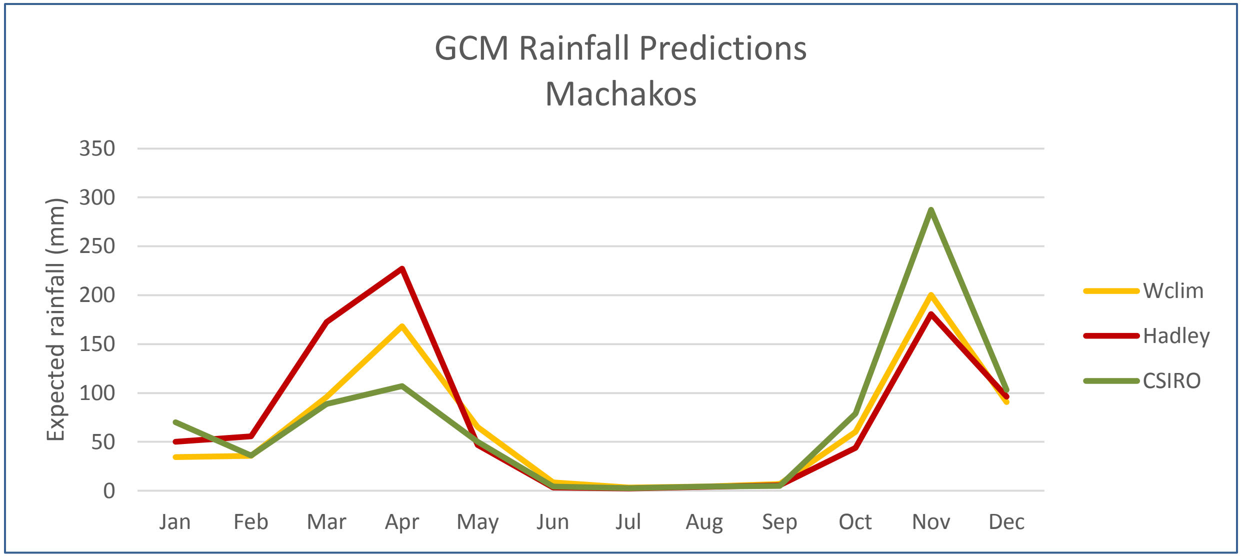
$$ln(mean\ yield_{dcsf}) = f(rain, rain^2, avg\ temp,\ temp^2, CV_{rain}, counties)$$

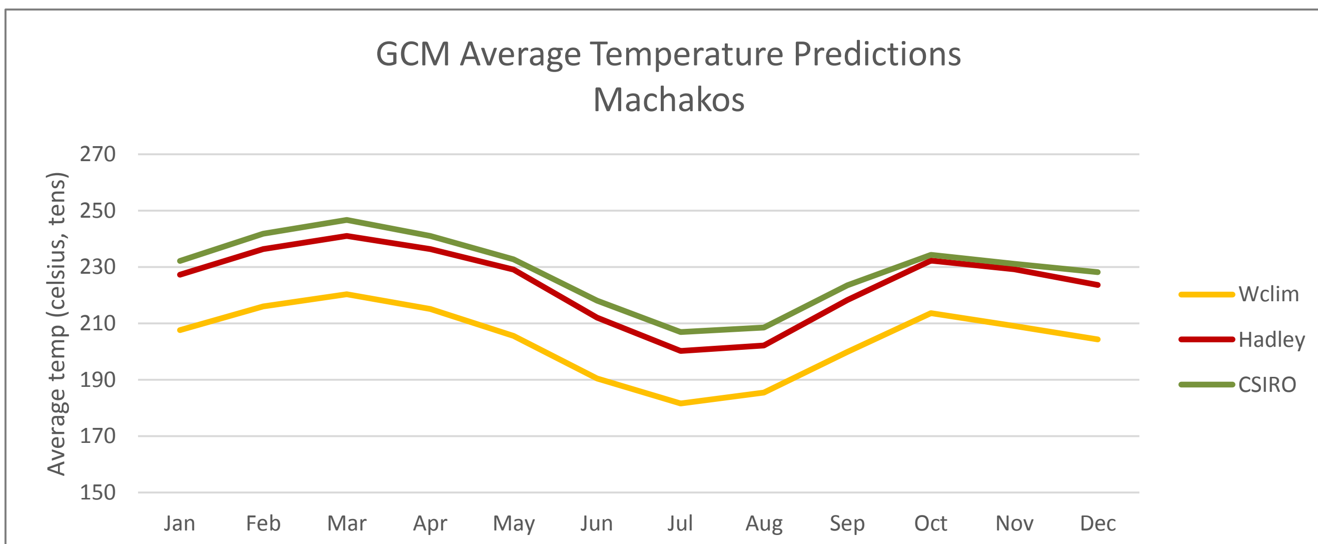
Where d = county c = crop, s = seed type, f = fertilizer use

Example of results

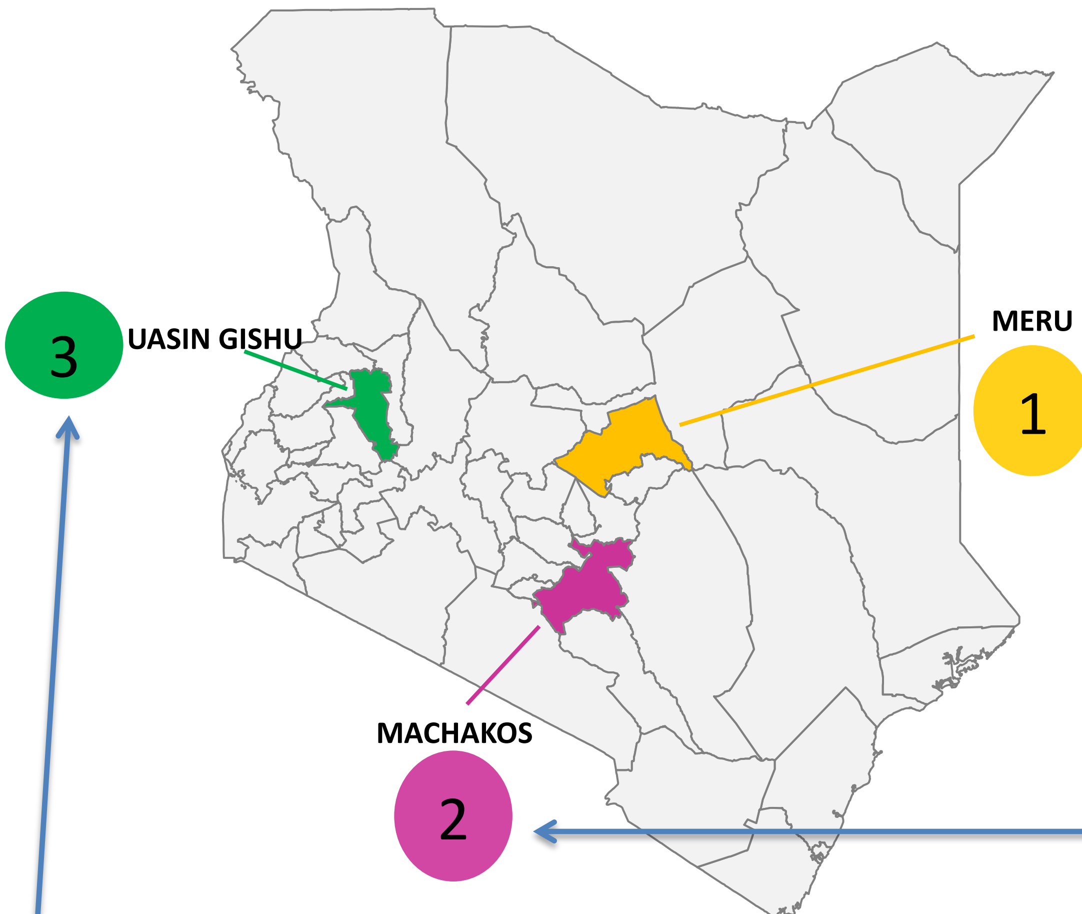
Machakos		
	Expected proportional Δ	
Regime	Hadley	CSIRO
MZ1	0.06	0.08
MZ2	-0.14	0.11
MZ8	-0.01	-0.13
BN1	0.01	-0.16
BN3	0.01	-0.16
MZBN7-MZ	-0.02	-0.04
MZBN7-BN	0.03	-0.11

Future climate change predictions ("2050") Machakos





Assumptions used to predict future yields ("main" season only)

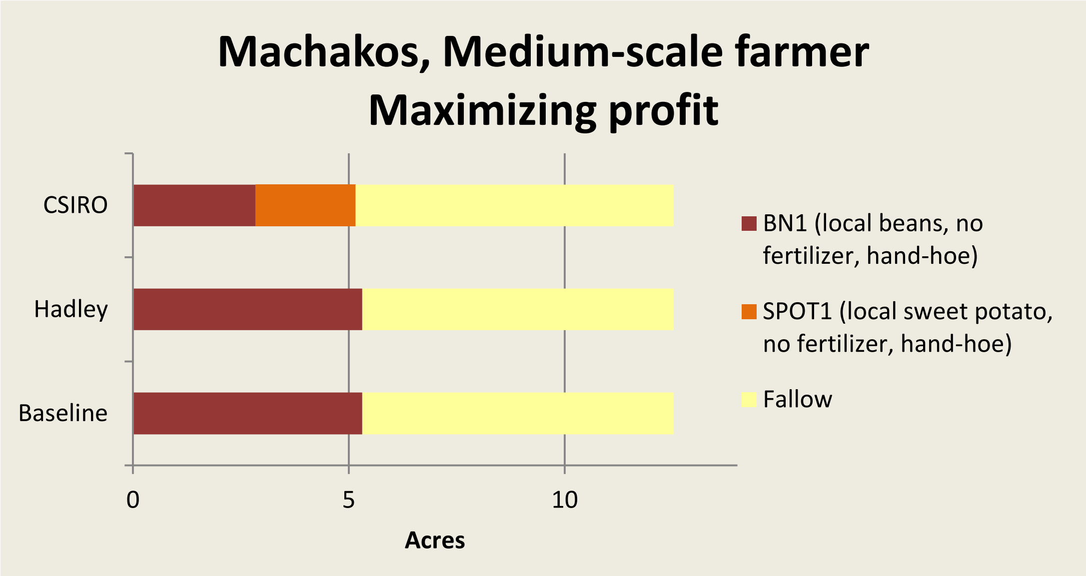


Hadley: ↓ 63 mm (-11.3%);
↑ 2.02 °C (+10.4%)
CSIRO: ↑ 197 mm (+35.3%);
↑ 2.33 °C (+11.9%)

Hadley: ↓ 30 mm (-8.6%);
↑ 1.98 °C (+9.4%)
CSIRO: ↑ 118 mm (+33.6%);
↑ 2.33 °C (+11.3%)

Hadley: ↓ 28 mm (-6.8%); ↑ 2.13 °C (+13.4%)
CSIRO: ↓ 69 mm (-16.8%); ↑ 2.50 °C (+15.7%)

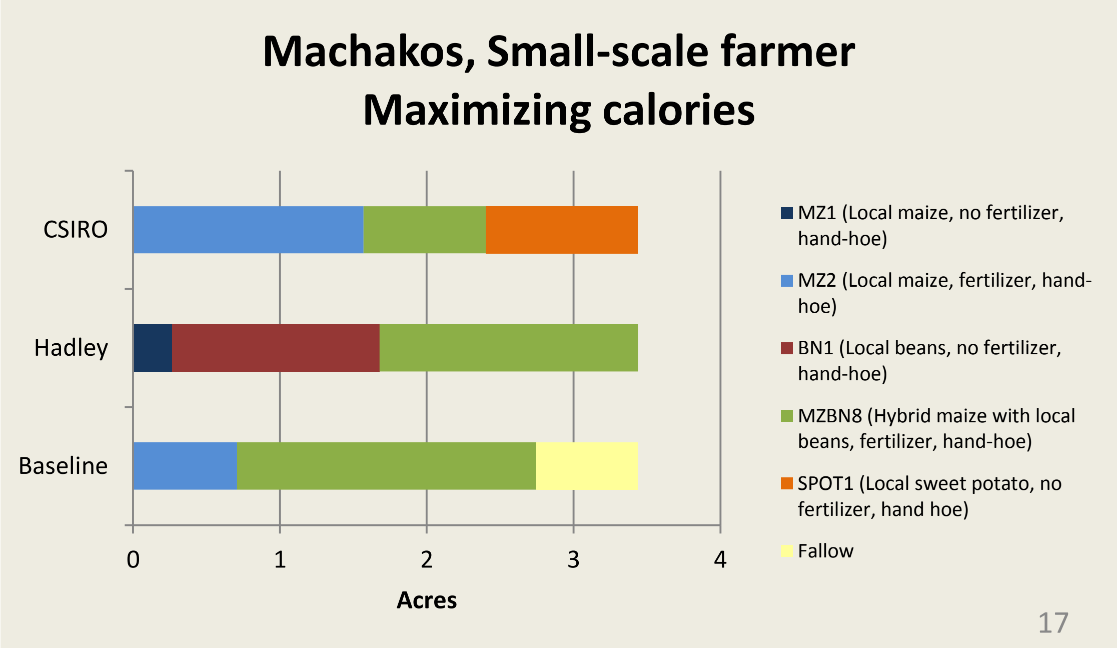
Crop choices under climate change scenarios



Under CSIRO

- Shift to sweet potato
- Net revenue falls
- Less land is cultivated
- Still labor-constrained

- Shift to sweet potato (CSIRO) or beans (Hadley)
- More land is cultivated
- Land is now binding
- Calories fall (Hadley) or increase (CSIRO)

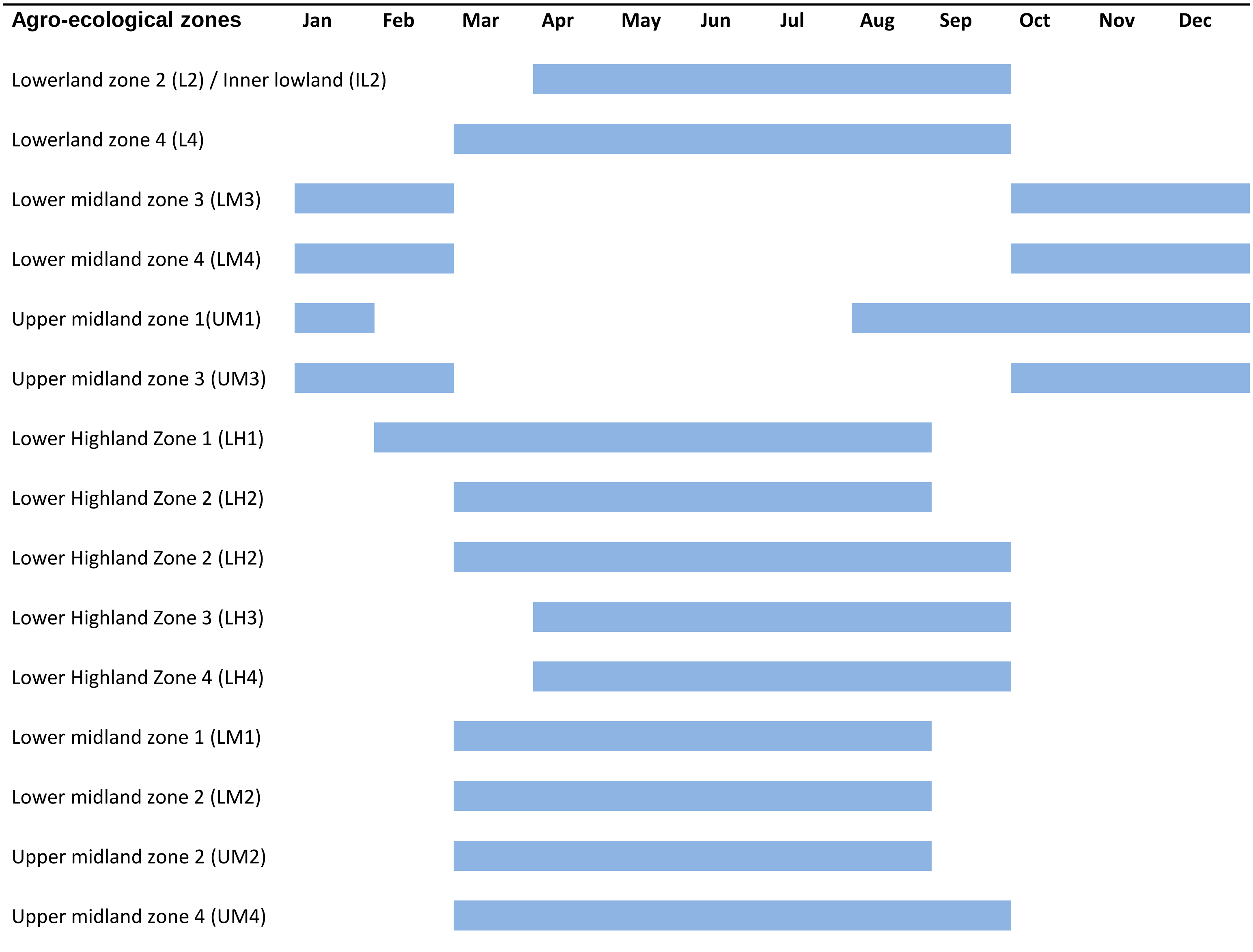


Impact of climate change on net revenue and calories produced*

	Net Revenue		Calories Produced
Site	Per Adult/day	Total	**Per Adult/day**
Meru			
Baseline	23.7	27,123	5,635
Climate change (Hadley)	25.8	29,552	6,000
Climate change (CSIRO)	30.7	35,132	5,182
Machakos			
Baseline	18.5	32,232	3,840
Climate change (Hadley)	17.8	30,950	3,696
Climate change (CSIRO)	19.4	33,700	4,713
Uasin Gishu			
Baseline	46.1	83,571	9,561
Climate change (Hadley)	54.8	99,203	11,060
Climate change (CSIRO)	57.1	103,455	11,465

* Small-scale farmers, assuming calorie-maximization objective.

Main season (maize production)



Limitations of study

- Shortcomings of available data for modeling purposes
  - For intercropped fields, area by crop not measured → reduces quality of estimated per-acre yields, inputs used, and returns
  - Few management distinctions (only fertilizer use, hoe vs. mechanized land preparation)
  - Only main season modeled; no tree crops
  - No survey data on family labor requirements
  - Female-headed households not modeled

Conclusions

- No significant negative effect of climate change on household welfare
  - Farmers able to shift crop choices to compensate for yield reductions
  - In some cases, climate change actually benefits crop yields
- But these results are preliminary and subject to significant model limitations

Implications

- Implications of shifts in rainfall from one growing season to another? (Short rainy season not included in modeling.)
- Implications of geographic shifts in agricultural potential for location of investment in agricultural infrastructure?
- Payoff to investment in better data and stronger local modeling/analytical capacity
  - Include perennial crops
  - Better estimates of yield and labor inputs per acre
  - Incorporation of risk preferences

References

[1] Morton, J. 2007. The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences* 104 (50):19680-5.

[2] Webber, H., T. Gaiser, and F. Ewert. 2014. What role can crop models play in supporting climate change adaptation decisions to enhance food security in Sub-Saharan Africa? *Agricultural Systems* 127:161-177.

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[4] Van Wijk, M. T., M. C. Rufino, D. Enahoro, D. Parsons, S. Silvestri, R. O. Valdivia, and M. Herrero. 2014. Farm household models to analyse food security in a changing climate: A review. *Global Food Security* 3(2):77-84.

Thanks for your attention…
Questions?