In the Weeds:
Effects of Temperature on Agricultural Input Decisions in Moderate Climates

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Motivation

- Agricultural livelihoods in developing countries are especially fragile in the face of climate change (e.g. Rosenzweig and Parry, 1994; Mendelsohn, 2008)
  - Greatest increases in temperatures (Harrington et al., 2016)
  - Limited know-how and resources to engage in adaptation
- Effects of climate change on agriculture, however, may be spatially heterogeneous (e.g., World Development Report, 2010; Zhao et al., 2017)
- Does heat affect agriculture in moderate temperature zones, especially in regions that cultivate heat-resistant crops, like maize?
  - If heat forces farmers to adjust their suite of inputs, there might exist indirect non-physiological pathways

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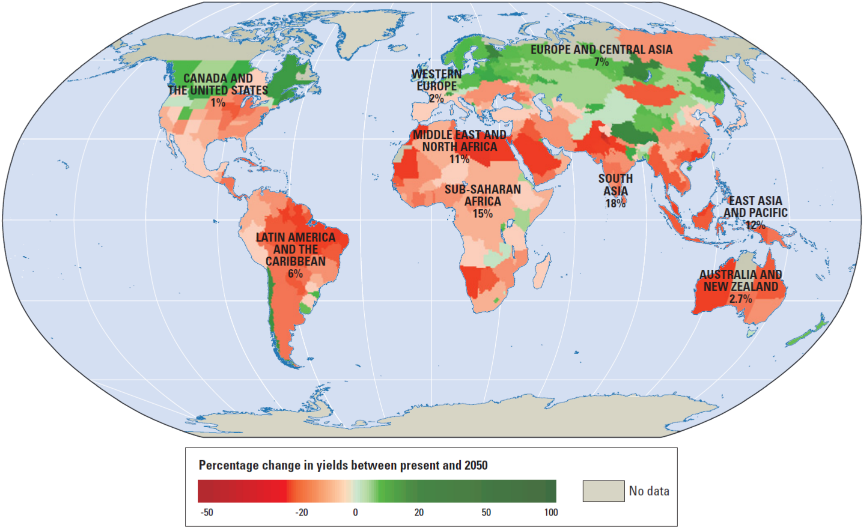
Map 1 Climate change will depress agricultural yields in most countries in 2050, given current agricultural practices and crop varieties



Sources: Müller and others 2009; World Bank 2008c.

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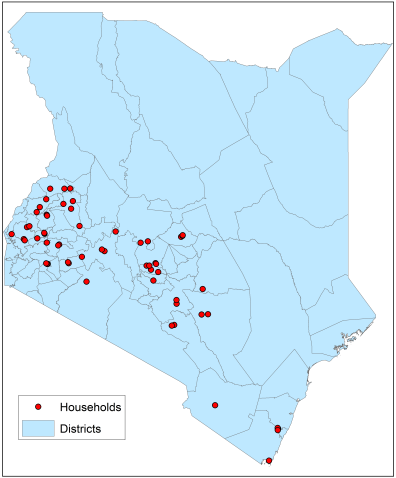
This Paper

- We use a household-level panel representative of maize farmers in Kenya's maize cultivating provinces



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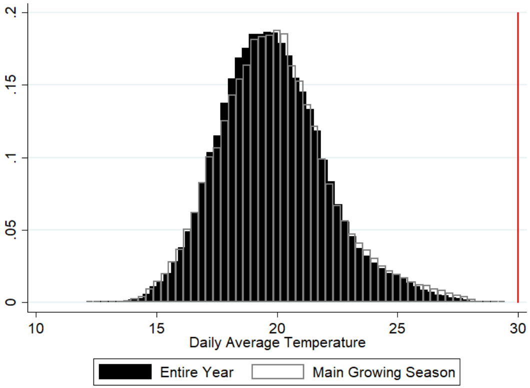
- **Daily average** temperatures in maize-growing regions of Kenya range from 12-29C

- Maize yields only decline above 29-30C (Lobell et al., 2011; Schlenker and Roberts, 2009)



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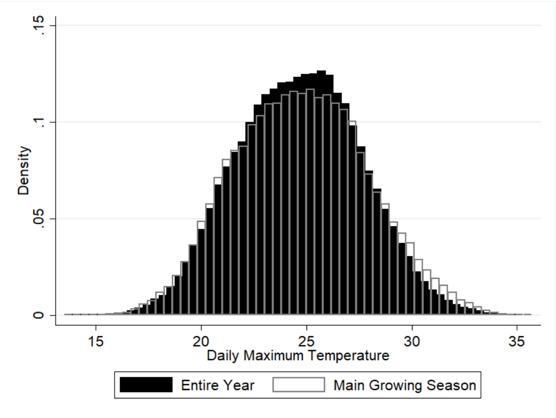
- In fact, 95th percentile of the distribution of **daily maximum** temperatures is 30C



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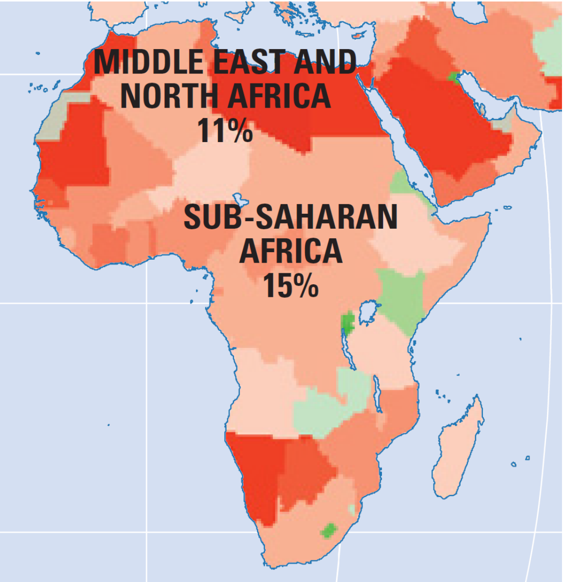

Source: World Development Report, 2010

This Paper

Table: Climate Change in Kenya?

	(1) Farmer Noticed Change in Temperature?	(2) Famer Affected by Changes in Temperature?
2009		
No	53.14	17.70
Yes	46.86	82.30

Notes: Sample includes 1242 households, balanced over 5 survey rounds, in the 2009-10 TAMPA survey.

This Paper

Table: How was farming affected by this change in temperature?

	(1) Affected by Changes in Temperature, How?
2009	
Decline in Yields	44.68
Decrease in Land Quality	4.38
Difficult to Time Seasons	6.89
Increase in Yields	5.43
Other	1.88
Weeds/Pests/Diseases	36.74

Notes: Sample includes 1242 households, balanced over 5 survey rounds, in the 2009-10 TAMPA survey.

This Paper

Table: Why Didn't You Use Fertilizer?

	(1) Why No Fertilizer?
2009	
Fertilizer Not Available	0.92
Lack of Advice	3.06
No Money/Too Expensive	57.80
No Need To Use Fertilizer	38.23

Notes: Sample includes 1242 households, balanced over 5 survey rounds, in the 2009-10 TAMPA survey.

This Paper

- Households are unlikely to experience physiological heat stress in maize
- Do higher than normal temperatures increase pesticide use?
  - Are there 'spillover' effects on productivity-enhancing inputs like fertilizer?

Preview of Results

- Result #1: Heat increases use of loss-reducing adaptive inputs like pesticides
  - Suggestive evidence for an ecological mechanism: temperature –> pests, weeds and crop diseases –> pesticides
  - Heat increases days spent weeding
- Result #2: Heat reduces use of productivity enhancing inputs like fertilizer
  - Suggestive evidence for a binding liquidity constraint hypothesis: wealth-differentiated effects, with poorer farmers bearing a greater cost of higher temperatures

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Our Contribution

- Existing studies have focused on the relationship between temperature and agricultural output or yield (e.g., Deschênes and Greenstone, 2007; Guiteras, 2008; Schlenker and Lobell, 2010)
    - Establish that high temperatures can also affect use of agricultural inputs
- Dependence of pests, weeds and plant diseases on weather has been well-known amongst plant pathologists and entomologists (e.g., Coakley, Scherm and Chakraborty, 1999; Patterson et al., 1999; Garrett et al., 2006)
    - Provide evidence for an ecological channel while examining the temperature-agriculture relationship in economics

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- Existing literature *infers* agricultural adaptation using 1) cross-sectional variation to compare outcomes, 2) comparing estimates from annual fluctuations for a given area under hotter versus cooler conditions, or 3) using long-difference models, and aggregate data at the county-year level (e.g., Mendelsohn, Nordhaus and Shaw, 1994; Deschênes and Greenstone, 2011; Burke and Emerick, 2016)
  - Using household-level data, and disaggregating temperatures in the growing season by different stages of the agricultural cycle, we observe adaption strategies in the short-run
- Large literature in development economics has examined the determinants of agricultural technology adoption (e.g., Conley and Udry, 2010; Dercon and Christiaensen, 2011; Marenya and Barrett, 2009; Suri, 2011)
  - Additional evidence for the liquidity constraint hypothesis
  - Demonstrate that farmers adjust their suite of inputs after observing temperatures pre-planting or early in the growing season

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  - Additional evidence for the liquidity constraint hypothesis
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Background: Temperature and Farmers' Input Decisions

- Large body of evidence on the relationship between maize-specific pests and crop diseases, weeds, and temperature (e.g., Paul and Munkvold, 2005; Cairns et al., 2012; Dukes et al., 2009)
- Likely that farmers adjust their suite of inputs due to higher than normal temperatures
  - Farmers can make their decisions sequentially, adapting to new information as it emerges (e.g. Fafchamps, 1993; Dillon, 2014)

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Background: Temperature and Farmers' Input Decisions

- Fungicide treatment for gray leaf spot, insecticide application for stem borers, and herbicides for weeds initiated early in the growing season (Ward, Laing and Rijkenberg, 1997; Orr, Mwale and Saiti, 2002; Gianessi, 2014)
- Two types of fertilizer for maize: basal and topdressing fertilizer; basal fertilizer is applied at planting; topdressing fertilizer is seldom applied if basal fertilizer is not applied (NAFIS, 2011)
- Pesticide and fertilizer adoption decisions are likely influenced by temperatures during pre-planting or early vegetative growth phase
- Labor inputs can be adjusted later in the growing season; effects on weeding labor might extend deeper into the growing season

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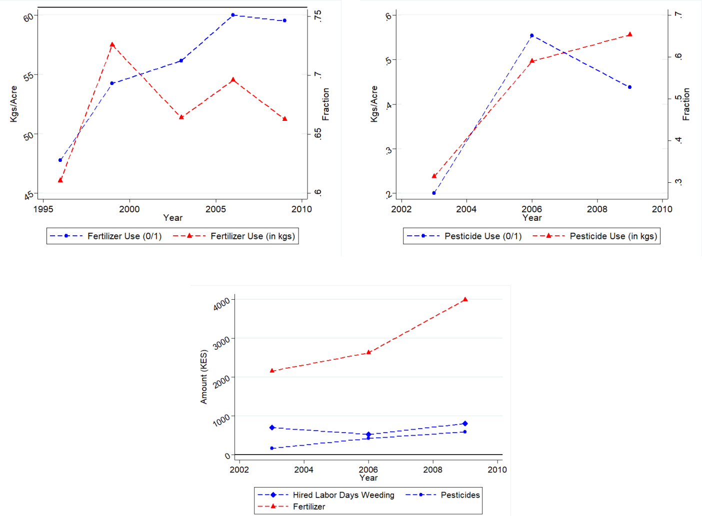
Data

- Tegemeo Agricultural Monitoring and Policy Analysis Project (TAMPA)
  - Balanced panel of 1242 maize-growing households collected over five rounds: 1996-97, 1999-00, 2003-04, 2006-07, and 2009-10
  - Outcomes of interest: pesticide use, fertilizer use, and weeding labor
- Kenya Maize Calendar
  - Food and Agriculture Organization (FAO)
  - Calendar for each agro-ecological zone (AEZ) in Kenya
- Kenya Weather Data
  - Gridded and satellite data sets
  - Daily weather data at the village level: temperature, precipitation, relative humidity and soil moisture

Data: Summary Statistics

Figure: Fertilizer Adoption (top left), Pesticide Use and Weeding Labor Days (top right), Expenditure on Agricultural Inputs by Adopters (bottom)



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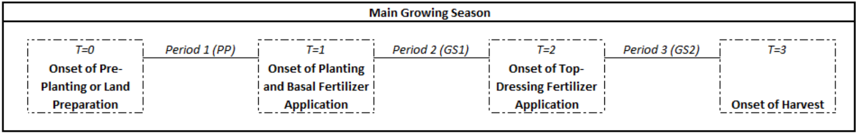

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Data: Daily Average Temperature (1990-2012)

Table: Growing Degree Days: Mean and Standard Deviations – Rounds 1-5

	All	1997	2000	2004	2007	2010
CY PP DD >21C	47.58	37.86	46.79	38.16	70.93	44.17
	(74.61)	(68.55)	(73.81)	(81.04)	(81.95)	(60.63)
CY GS1 DD >21C	30.03	24.60	23.04	38.17	24.08	40.25
	(49.28)	(44.84)	(42.70)	(61.47)	(39.35)	(52.03)
CY GS2 DD >21C	16.46	17.73	12.28	21.46	14.37	16.44
	(42.88)	(40.89)	(33.21)	(50.92)	(41.24)	(45.63)
Observations	6210	1242	1242	1242	1242	1242

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10). Temperature data was generated at the village level, so the table reports mean and standard deviations for degree days (DD) over 21C for each survey round. CY: current year; PP: pre-planting or land preparation - onset of planting; GS1: planting or basal fertilizer application - onset of top dressing fertilizer; GS2: top dressing fertilizer application - onset harvest. Standard deviations are in parentheses.

Research Design

We estimate the following model:

$$Y_{ijqt} = \beta_1(CDD_{PP} > 21C)_{jqt} + \beta_2(CDD_{GS1} > 21C)_{jqt} + \beta_3(CDD_{GS2} > 21C)_{jqt} + f(Rain_{jqt}) + \alpha_i + \mu_{qt} + \varepsilon_{ijqt} \quad (1)$$

- Y_{ijqt} is outcome of interest, for household i in village j in province q in round t
- Fixed effects: village (α_j) and province-by-year (μ_{qt})
- Standard errors: clustered by village
- $(CDD > 21C)_{jqt}$ is the sum of degree days over 21C during each stage of the main growing season

Main Results

Table: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Ln Weeding Days/Acre β / SE
CY PP DD >21C	0.0019	0.0084	-0.0003	-0.0054	0.0017
	(0.0014)	(0.0090)	(0.0005)	(0.0055)	(0.0021)
CY GS1 DD >21C	0.0063**	0.0450***	-0.0018**	-0.0180**	-0.0004
	(0.0026)	(0.0159)	(0.0008)	(0.0087)	(0.0048)
CY GS2 DD >21C	-0.0004	-0.0108	0.0003	0.0005	0.0084***
	(0.0015)	(0.0079)	(0.0004)	(0.0044)	(0.0031)
Village FE	Yes	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210	3726
R^2	0.336	0.354	0.594	0.656	0.177

Notes: The table presents the effects of temperature (captured via degree days (DD) over 21C) on agricultural input use. CY: current year; PP: pre-planting or land preparation - onset of planting; GS1: planting or basal fertilizer application - onset of top dressing fertilizer; GS2: top dressing fertilizer application - onset harvest. Standard errors are in parentheses, clustered by village. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Robustness Checks

- Household fixed effects
- District-by-year fixed effects
- Clustered standard errors at the district-year level
- Honoré semi parametric fixed effect tobit estimator
- Sensitivity to the choice of lower bound used to calculate cumulative degree days
- Alternative explanations:
  - Humidity and soil moisture
  - Direct effect of heat on maize yields

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Robustness Checks

Table: Log Total Maize Output, Agricultural Input Use and Temperature

	(1) Log Maize Yield/Acre (Kg.) β / SE	(2) Log Maize Yield/Acre (Kg.) β / SE
CY PP DD >21C	0.0037	0.0038
	(0.0041)	(0.0035)
CY GS1 DD >21C	-0.0027	0.0093
	(0.0066)	(0.0068)
CY GS2 DD >21C	0.0029	-0.0048
	(0.0028)	(0.0039)
Ln Pesticide/Acre		0.0507***
		(0.0091)
Ln Fertilizer/Acre		0.0309***
		(0.0088)
Ln Weeding Days/Acre		0.1067***
		(0.0169)
Village FE	Yes	Yes
Prov-by-Year FE	Yes	Yes
Rainfall Controls	Yes	Yes
Observations	6210	3726
R^2	0.374	0.406

Notes: The table presents the effects of temperature (captured via degree days (DD) over 21C) on total maize output. CY: current year; PP: pre-planting or land preparation - onset of planting; GS1: planting or basal fertilizer application - onset of top dressing fertilizer; GS2: top dressing fertilizer application - onset harvest. Standard errors are in parentheses, clustered by village. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Heterogenous Effects - by Wealth

- Exploit exogenous changes in temperature over time across 'poor' and 'wealthy' households; average land ownership as a proxy for wealth
- Are households with different abilities to accommodate ex-ante risk or absorb income shocks (i.e., through higher wealth) differentially influenced by an increase in pest and disease pressure?
- Add an interaction term between degree days in each phase, and a 0-1 binary variable, where an household i take value 1 if average land holding for i is <33p (2.5 acres), 0 otherwise

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- Add an interaction term between degree days in each phase, and a 0-1 binary variable, where an household i take value 1 if average land holding for i is $<$33p (2.5 acres), 0 otherwise

Heterogenous Effects - by Wealth

Table: Pesticides, Weeding Labor and Fertilizer Use, by Wealth (Round 1-5)

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer β / SE	(4) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0263	0.1261	-0.0007	-0.0354
	(0.0172)	(0.1110)	(0.0060)	(0.0616)
CY GS1 DD >21C	0.0713**	0.4958**	-0.0139	-0.1547*
	(0.0309)	(0.1899)	(0.0090)	(0.0924)
CY GS2 DD >21C	-0.0107	-0.1421	0.0033	0.0128
	(0.0199)	(0.1139)	(0.0042)	(0.0437)
CY PP DD >21C*Bottom Wealth Tercile	-0.0148**	-0.0877**	-0.0059	-0.0487
	(0.0061)	(0.0378)	(0.0041)	(0.0386)
CY GS1 DD >21C*Bottom Wealth Tercile	-0.0142	-0.0731	-0.0085	-0.0577
	(0.0112)	(0.0767)	(0.0061)	(0.0573)
CY GS2 DD >21C*Bottom Wealth Tercile	0.0250	0.1379	-0.0011	-0.0320
	(0.0185)	(0.1633)	(0.0080)	(0.0761)
Household FE	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210
R^2	0.588	0.589	0.740	0.788

Notes: The table presents the heterogeneous effects of temperature (captured via degree days (DD) over 21C) on agricultural input use, by wealth. CY: current year; PP: pre-planting or land preparation - onset of planting; GS1: planting or basal fertilizer application - onset of top dressing fertilizer; GS2: top dressing fertilizer application - onset harvest. Average landholding of the 33rd percentile is 2.5 acres. Standard errors are in parentheses, clustered by village. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Conclusion

- Heat can affect agriculture even in regions where temperatures are not high enough to directly, adversely affect crop growth

- Agricultural inputs decisions are sensitive to heat stress due to an ecological relationship between temperature and prevalence of pests, weeds and crop diseases

- Estimate the impact of temperatures during each stage of the agricultural cycle; demonstrate that farmers are quick to adapt to temperature variation in the short-run

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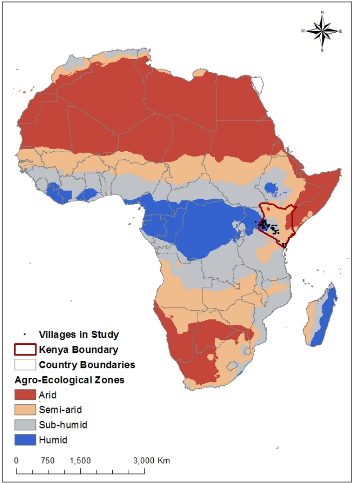
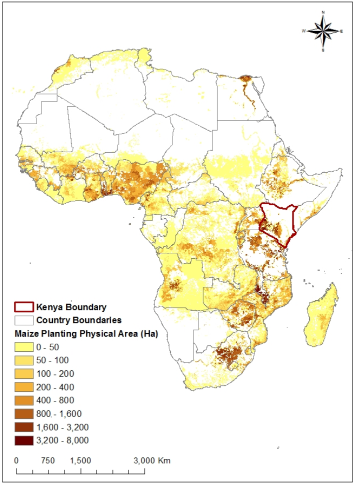
Figure: Agro-Ecological Zones and Maize Production in Africa





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