# Within-Season Producer Response to Warmer Temperatures:
## Defensive Investments by Kenyan Farmers

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# Motivation

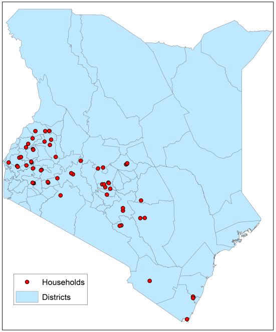
- Research Question: *How* do farmers in low-income countries adjust to changes in the temperature?
  - Agricultural livelihoods in developing countries are especially fragile in the face of climate change (e.g., Rosenzweig and Parry, 1994)
  - Developing countries will see the greatest increases in temperatures (Harrington et al., 2016)
  - Farmers in low-income countries have limited resources to engage in adaptation and avoid permanent damage

# Motivation

- Existing literature often *infers* agricultural adaptation:
  - Cross-sectional variation to compare outcomes in hot versus cold areas (e.g., Mendelsohn, Nordhaus and Shaw, 1994)
  - Comparing estimates from annual temperature fluctuations for a given area under hotter versus cooler conditions (e.g., Deschênes and Greenstone, 2011)
  - Differentiating estimates from annual temperature fluctuations with long-run impacts of higher than normal temperatures (e.g., Burke and Emerick, 2016)
- What are the mechanisms behind farmer adaptation?
  - Role of direct heat stress on plant physiology versus biotic stresses arising from broader agroecological response to warmer weather
  - Seasonal or annual data may miss within-season producer responses

# This Paper

- Use a household-level panel representative of maize farmers in Kenya's maize cultivating provinces and temperature disaggregated across different stages of the crop growth cycle
- Investigate how farmers adjust agricultural inputs within the growing season in response to temperature variation

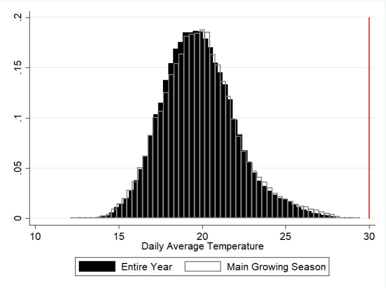


# Preview of Results

- We show that farmers respond promptly to temperature shocks
  - Result #1: Increase pesticide use in response to higher temperatures early in the growing season, responding to heat-induced increased biotic stress from diseases and pests that are most effectively addressed soon after emergence
  - Result #2: Increase household weeding effort throughout the season in response to higher temperatures that promote weed growth
  - Result #3: Reduce inorganic fertilizer use early in the growing season, contemporaneously with increased pesticide use; binding financial liquidity constraints plausibly induce trade-offs among input expenditures

# Context

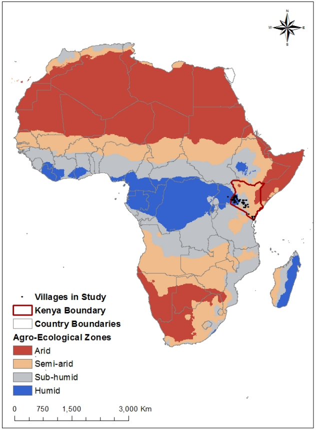
- **Daily average** temperatures in maize-growing regions of Kenya range from 12-29C
- Maize yields only decline above 29-30C (Lobell et al., 2011; Schlenker and Roberts, 2009)

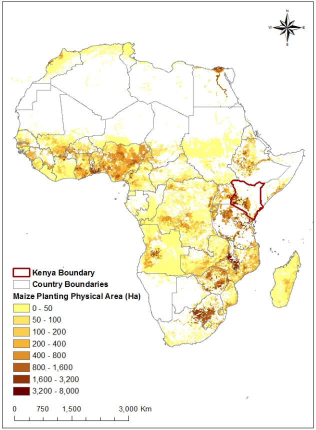



- Any adverse yield effects in this context are almost surely result from indirect, biotic stresses arising from the temperature response of pests and pathogens

# Context

Figure: Agro-Ecological Zones and Maize Production in Africa



# Background: Temperature, Pests, Weeds and Pesticides

- 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)
- Fungicide treatment for gray leaf spot, insecticide application for stem borers, and herbicides for weeds initiated early in the growing season (e.g., Ward, Laing and Rijkenberg, 1997; Orr, Mwale and Saiti, 2002; Gianessi, 2014)
- Effects on weeding labor might extend deeper into the growing season as labor inputs can be adjusted later in the growing season

# Background: Fertilizer Use Under Financial Constraints

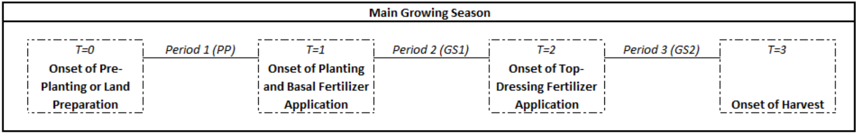
- Farmers facing binding financial constraint may reduce fertilizer use in favor of pesticides (e.g. Rosenzweig and Binswanger, 1993; Dercon and Christiaensen, 2011)
  - Warmer temperatures may increase risk of future harvest or induce input trade-offs due to liquidity constraints
- Moreover, like pesticides, fertilizer use decisions are likely influenced by temperatures during the early vegetative growth phase
  - Basal fertilizer is applied at planting; topdressing fertilizer is seldom applied if basal fertilizer is not applied
  - Kenyan agricultural markets are relatively well-developed compared to other countries in sub-Saharan Africa (Sheahan and Barrett, 2017); Kenyan farmers usually buy fertilizer just before applying it (Duflo, Kremer and Robinson, 2011)
- Farmers can make their decisions sequentially, adapting to new information as it emerges (Antle, 1983; Fafchamps, 1993; Dillon, 2014)

# 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 Weather Data
  - Gridded and satellite data sets
  - Daily weather data at the village level: temperature, precipitation, relative humidity and soil moisture

# Kenya Maize Calendar

- We use calendar for each agro-ecological zone (AEZ) in Kenya from the Food and Agriculture Organization (FAO)



# Qualitative Evidence

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.

# Qualitative Evidence

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

| | (1)<br>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.

# Qualitative Evidence

Table: Why Didn't You Use Fertilizer?

| | (1)<br>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.

# 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 ($\alpha_j$) and province-by-year ($\mu_{qt}$)
- 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 (Per Acre)

| | (1) Pesticides 0/1 $\beta$ / SE | (2) Ln Pesticide $\beta$ / SE | (3) Fertilizer 0/1 $\beta$ / SE | (4) Ln Fertilizer $\beta$ / SE | (5) HH Weeding Days $\beta$ / SE |
|---|---|---|---|---|---|
| CY PP DD >21C | 0.0019 | 0.0084 | -0.0003 | -0.0054 | 0.0323** |
| | (0.0014) | (0.0090) | (0.0005) | (0.0055) | (0.0149) |
| CY GS1 DD >21C | 0.0063** | 0.0450*** | -0.0018** | -0.0180** | 0.0375 |
| | (0.0026) | (0.0159) | (0.0008) | (0.0087) | (0.0271) |
| CY GS2 DD >21C | -0.0004 | -0.0108 | 0.0003 | 0.0005 | 0.0392* |
| | (0.0015) | (0.0079) | (0.0004) | (0.0044) | (0.0219) |
| 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 | 0.165 |

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
- Honoré semi parametric fixed effect tobit estimator (Honoré, 1992)
- Conley standard errors to reflect spatial dependence (Conley, 1999; Hsiang, 2010)
- Sensitivity to the choice of lower bound used to calculate cumulative degree days
- Accounting for within-day temperature variations (Snyder, 1985; Roberts, Schlenker and Eyer, 2013)
- Robust to inclusion of daily humidity and soil moisture

# 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

# Heterogenous Effects - by Wealth

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

| | (1) Pesticides 0/1 β / SE | (2) Ln Pesticide β / SE | (3) Fertilizer 0/1 β / SE | (4) Ln Fertilizer β / SE |
|---|---|---|---|---|
| CY PP DD >21C | 0.0026 | 0.0126 | -0.0001 | -0.0035 |
| | (0.0017) | (0.0111) | (0.0006) | (0.0062) |
| CY GS1 DD >21C | 0.0071** | 0.0496** | -0.0014 | -0.0155* |
| | (0.0031) | (0.0190) | (0.0009) | (0.0092) |
| CY GS2 DD >21C | -0.0011 | -0.0142 | 0.0003 | 0.0013 |
| | (0.0020) | (0.0114) | (0.0004) | (0.0044) |
| CY PP DD >21C*Bottom Wealth Tercile | -0.0015** | -0.0088** | -0.0006 | -0.0049 |
| | (0.0006) | (0.0038) | (0.0004) | (0.0039) |
| CY GS1 DD >21C*Bottom Wealth Tercile | -0.0014 | -0.0073 | -0.0009 | -0.0058 |
| | (0.0011) | (0.0077) | (0.0006) | (0.0057) |
| CY GS2 DD >21C*Bottom Wealth Tercile | 0.0025 | 0.0138 | -0.0001 | -0.0032 |
| | (0.0018) | (0.0163) | (0.0008) | (0.0076) |
| 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

- We show that farmers in a low-income country can quickly adjust agricultural input use to within-season temperature variation
- Greater heat compels farmers to divert investment from productivity-enhancing technologies like fertilizer to adaptive, loss-reducing, defensive inputs like pesticides and weeding labor
- Warmer temperatures can affect agriculture due to temperature-induced biotic stresses even in regions where temperatures are not high enough to directly, adversely affect crop growth

Thank you!

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