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

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Abstract

We present evidence that farmers adjust agricultural inputs in response to within-season temperature variation, undertaking defensive investments to reduce the adverse agroecological impacts of warmer temperatures. Using panel data from Kenyan maize growing households, we find that higher temperatures early in the growing season increase the use of pesticides, while reducing fertilizer use. Warmer temperatures throughout the season increase household weeding effort. These adjustments arise because greater heat increases the incidence of pests, crop diseases and weeds, compelling farmers to divert investment from productivity-enhancing technologies like fertilizer to adaptive, loss-reducing, defensive inputs like pesticides and weeding labor.

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1 Introduction

How do farmers in low-income countries adjust to temperature variation in the short-run? Agricultural livelihoods in developing countries are especially fragile in the face of global climate change, and understanding how farmers might adapt to warming temperatures could inform allocation of scarce public resources to build resilience and avoid permanent damage (Rosenzweig and Parry, 1994). Existing studies, predominantly from the United States, have often inferred agricultural adaptation either by using cross-sectional variation to compare outcomes in hot versus cold areas, or by comparing estimates from annual temperature fluctuations for a given area under hotter versus cooler conditions, or by differentiating estimates from annual temperature fluctuations with long-run impacts of higher than normal temperatures (e.g., Mendelsohn, Nordhaus and Shaw, 1994; Schlenker, Hanemann and Fisher, 2006; Deschênes and Greenstone, 2007; Deschênes and Greenstone, 2011 Schlenker and Roberts, 2009; Dell, Jones and Olken, 2012; Taraz, 2017; Burke and Emerick, 2016). Such approaches rely on aggregate data, usually at the state- or district-year level, and typically fail to unpack the mechanisms behind farmer adaptations or yield effects. In particular, the literature has largely overlooked farmer defensive investments to avert crop losses, especially those arising not due to heat stress but rather due to biotic stresses arising from broader agroecological response to warmer weather.[1] Furthermore, if farmers adapt input applications within season in response to temperature shocks that differentially affect crop growth across different stages in the agricultural cycle, then studies based on seasonal or annual data may miss important behavioral responses to shifting climate. In this paper, we use household-level panel data from maize farmers in Kenya, and temperature and other weather data disaggregated across different stages of the crop growth cycle, to investigate how farmers adjust agricultural inputs within the growing season in response to temperature variation.

We show that farmers respond promptly and appropriately to temperature shocks. They 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. And farmers increase household weeding effort

[1] A small number of papers within this literature have examined how farmers adjust irrigation choice and crop mix in response to higher temperature (Kurukulasuriya and Mendelsohn, 2007, 2008; Kurukulasuriya, Kala and Mendelsohn, 2011; Seo and Mendelsohn, 2008*a*,*b*). These studies too, for the most part, use cross-sectional variation in climate to identify impacts.

throughout the season in response to higher temperatures that promote weed growth. Meanwhile, farmers reduce inorganic fertilizer use early in the growing season, contemporaneously with increased pesticide use. That could be a response to increased yield risk, but appears most consistent in the data with binding financial liquidity constraints inducing trade-offs among input expenditures.

More precisely, we find that a 10% increase in growing degree days (GDD) during the initial vegetative growth stage increases the proportion of farmers using pesticides by around 10%, and reduces the proportion using inorganic fertilizer by approximately 2%, compared to the baseline. Similarly, a 10% increase in GDD increases pesticide application rates per acre by 15%, while reducing fertilizer application rates by over 5%. And an extra GDD during the post-planting phase increases weeding labor by 0.04 days. Qualitative data indicate that these farmers recognize that higher temperatures increase the incidence of pests, weeds and crop diseases, and most of them report financial liquidity constraints limit their purchase of inputs. So temperature shocks confront farmers with a trade-off between defensive investments in pesticides and weeding labor, versus yield-increasing fertilizers. Farmers' responsiveness also appears positively associated with wealth, as reflected in land holdings. Overall, our results are consistent with a model in which farmers make production decisions sequentially, promptly adjusting to new information as it arrives within season, subject to financial and labor availability constraints (Antle, 1983; Dillon, 2014; Fafchamps, 1993).

These findings are noteworthy as well because the maize growing regions of Kenya fall in temperate zones in which warming temperatures are widely anticipated to boost staple crop yields. Average daily temperatures in the villages we study range from 12-29C, but maize yields only decline physiologically due to heat stress above 29-30C (Lobell et al., 2011; Schlenker and Roberts, 2009) (Figure 1). Importantly, large swaths of maize farms in Africa fall in similar agro-ecological zones (Figure 2). Because these households' maize crops are unlikely to experience direct, abiotic heat stress from modest warming, any adverse yield effects almost surely result from indirect, biotic stresses arising from the temperature response of pests and pathogens. Our setting permits us to isolate this mechanism behind farmer adaptation to temperature in a way that prior studies have not.

In investigating the relationship between temperature and agricultural input decisions, this paper also contributes to the development economics literature that studies the determinants of agricultural technology adoption in low-income countries.[2] This literature provides a number of explanations for low adoption of modern agricultural inputs: learning, insurance or credit constraints, heterogeneity in returns and behavioral anomalies (e.g., Foster and Rosenzweig, 1995; Conley and Udry, 2010; Moser and Barrett, 2006; Dercon and Christiaensen, 2011; Cole et al., 2013; Marenya and Barrett, 2009; Suri, 2011; Duflo, Kremer and Robinson, 2011). Our findings suggest that temperature increases might also reduce adoption of productivity-enhancing technologies like fertilizer in favor of loss-reducing, defensive technologies like pesticides, plausibly due to the financial constraints and/or production risk faced by poor farmers in developing countries. Thus, incomplete or imperfect financial markets in agrarian economies may impede households' ability to insure or borrow to manage increased biotic stress on crops.

The remainder of the paper proceeds as follows. In Section 2 we provide background on relevant ecological and agronomic literatures, and briefly discuss the role of credit and insurance markets in agricultural technology adoption in poor countries. Section 3 describes the data. In Section 4 we outline the empirical strategy and our main results for the effects of temperature on agricultural input decisions. Finally, in Section 5 we provide concluding remarks.

2 Background

2.1 Temperature, Pests, Weeds and Pesticides

The dependence of plant diseases and pests on weather is well-known amongst plant pathologists and entomologists (e.g., Chakraborty, 2008; Coakley, Scherm and Chakraborty, 1999; Garrett et al., 2006). For that reason, the broader ecological literature concludes that climate change will increase challenges to agriculture from pests, weeds and diseases, in part due to higher than normal temperatures (e.g., Patterson et al., 1999; Rosenzweig et al., 2001).

[2] Feder, Just and Zilberman (1985) and Foster and Rosenzweig (2010) provide a comprehensive overview of this literature.

For instance, grey leaf spot is a major maize fungal disease in Kenya. It was first reported in Kenya during 1995, and small-scale farmers have continued to experience considerable yield losses from grey leaf spot (Simons, 2006). Infection and growth of grey leaf spot are most likely to occur following a humid and warm period. Specifically, at 100% relative humidity, the optimum temperature for sporulation is between 25-30C. Similarly, the highest rates of lesion expansion were observed at 25C and 30C (Paul and Munkvold, 2005). Experiments indicate that fungicide treatment should be initiated after the disease was observed but before high levels were present (Ward, Laing and Rijkenberg, 1997). So higher temperatures could increase gray leaf spot incidence and induce early season adaptive responses by farmers. Delayed response to fungal infection is typically ineffective and thus a poor use of scarce resources.

Similarly, insect behavior, distribution, development and survival are strongly coupled with environmental conditions, especially temperature, since insects do not use their metabolism to control their body temperature, but rather depend on ambient air temperature. Global warming will favor insect proliferation and increase the incidence and severity of insect-related damages in maize (Cairns et al., 2012).

The most common insect maize pest in Kenya is the stem borer. Damage caused by stem borers is one of the main causes of low maize yields (Songa, Guofa and Overholt, 2001). Female stem borer moths lay eggs on maize leaves. The newly emerged larvae enter into the whorls of young maize plants and feed actively on the tender leaves. Later, the larvae bore into the stem and start tunneling. Stem borers can be controlled by applications of insecticides to the leaf whorl early in crop growth cycle to kill early larval instars; this method has limited effectiveness once the larvae bore into the stem (Gianessi, 2014). So as with gray leaf spot disease, the stem borer pest pressure on maize in Kenya should increase with higher temperatures, inducing early season response through pesticide application.

Weeds compete with crops for nutrients, moisture, light and space, adversely affecting crop yields. Weed growth is also influenced by abiotic conditions such as temperature and humidity (Dukes et al., 2009; Peters, Breitsameter and Gerowitt, 2014; Singer, Travis and Johst, 2013). For instance, milder winters are likely to increase the survival of some winter annual weeds, whereas warmer summers may allow other type of weeds to grow in previously inhospitable regions (Bloomfield et al., 2006; Hanzlik and Gerowitt, 2012; Walck et al., 2011). Weed control during the first weeks after planting is crucial because weeds compete vigorously with the maize crop for nutrients and water during this crucial period of plant growth (du Plessiss, 2003). Extension recommendations call for maize fields to be kept weed-free for the first 56 days after planting to achieve maximum yields (I. O Akobundu, 1987). One week's delay in first weeding may reduce maize yields by as much as one-third (Orr, Mwale and Saiti, 2002). Very early in the season, weed control among small farmers in Kenya is typically accomplished with household labor. But if weed growth is aggressive, farmers might use herbicides - a pesticide targeted specially at weeds before planting or in the early post-planting stage as a substitute for weeding labor (Gianessi, 2010). Once the crop is established, however, any further weed control requires additional labor effort, which continues nearly until harvest. As with maize disease and pests, higher temperatures are thus expected to induce greater weed competition with crops, forcing farmers to devote more labor and pesticides to combating weeds. The effects of warmer temperatures on manual weeding may extend deeper into the growing season as farmers can adjust labor inputs later in the season. These predictions from the agro-ecological literature mirror what we find in the data.

2.2 Fertilizer Use Under Financial Constraints

Higher than normal temperatures increase the prevalence of pests and diseases, plausibly forcing farmers to increase defensive investments on loss-reducing inputs like pesticides (e.g., herbicides, insecticides, fungicides) and diverting resources from productivity-enhancing technologies like fertilizer. Such effects on fertilizer uptake might be driven by ex ante credit constraints that compel poor farmers to trade off expenditures in one area for another; alternatively, farmers might anticipate increased risk of crop losses due and reduce the capital they put at risk through fertilizer purchases. These two effects can be difficult to fully disentangle. For instance, Rosenzweig and Binswanger (1993) show that poor farmers facing increased rainfall variability tend to hold a portfolio that is less influenced by rainfall, although wealthier farmers facing varying exposure to risk do not exhibit changing portfolios of investments. More recently and nearby, Dercon and Christiaensen, 2011, find that both ex ante credit constraints and the possibility of low consumption outcomes when harvests fail discourage the application of fertilizer in Ethiopia.

Farmers usually apply fertilizer twice on maize: basal and top dressing fertilizer applications. Basal fertilizer applications occur at planting, and top dressing fertilizer seldom occurs without basal fertilizer application. But if fertilizer is used at planting, top dressing often occurs post-germination, roughly 4-6 weeks into the growing season. Thus, if farmers promptly adjust to new information (Antle, 1983; Dillon, 2014; Fafchamps, 1993), these effects should respond primarily to temperature shocks during the pre-planting or early vegetative growth phase. This is particularly true in our context, as agricultural input markets in Kenya are relatively well-developed compared to other countries in sub-Saharan Africa (Sheahan and Barrett, 2017), and because Kenyan farmers usually buy fertilizer just before applying it (Duflo, Kremer and Robinson, 2011).

3 Data

We use a qualitatively rich, household level panel data set, representative of farmers in Kenya's main maize cultivating provinces. We augment these with detailed village level data with daily weather variables including temperature, rainfall, humidity and soil moisture.

3.1 Household Data

The household panel survey data are representative of the main maize-growing areas in Kenya. The survey was designed and implemented under the Tegemeo Agricultural Monitoring and Policy Analysis (TAMPA) project, a collaboration among Tegemeo Institute of Egerton University, Michigan State University, and the Kenya Agricultural Research Institute. Figure A.1 maps the survey villages across Kenya. These villages were selected randomly from each of eight predetermined agro-economic zones and then households were sampled randomly from each selected village. We use data from a balanced panel of 1242 households collected over five rounds: 1996-97, 1999-00, 2003-04, 2006-07, and 2009-10. The survey includes detailed agricultural input and output data, demographics, credit and infrastructure information. The 2009-10 round collected rich subjective data on farmers perceptions of the impacts of changes in temperature, as well as reasons for non-adoption of fertilizer. Villages were geo-referenced, allowing us to merge the household data with daily temperature, precipitation, relative humidity and soil moisture data at the village level as well as agro-ecological zone crop calendars.

Table A.1 presents summary statistics for our balanced sample from 1997-2010. 'Pesticide 0/1' and 'Pesticide/Acre(kgs)' capture the uptake rate and application intensity of pesticide use (irrespective of take-up) during the main growing season, respectively.[3] These detailed data were only collected in 2003-04, 2006-07, and 2009-10. While answering questions on inputs, respondents often used pesticides and specific pests, weeds and disease repellents (e.g., herbicide, insecticide, fungicide) interchangeably. Therefore, our measure of pesticide use: takes the binary value of 1 if a farmer uses any chemical or biological agent that protects crops from pests, weeds or crop diseases, 0 otherwise. Almost 30% of households in our balanced panel adopted some variety of pesticides in 2003, use then increased to 65% in 2006, before somewhat dropping to 50% in 2009. The average maize farmer used 0.25 kg/acre of pesticides in 2003, increasing to over 0.5 kg/acre by 2009. 'Own Weeding Days/Acre' indicates the average number own (household) labor days spent in weeding activities. 'Fertilizer 0/1' depicts the uptake of inorganic fertilizer in the main growing season, 1997-2010. Fertilizer use is high amongst maize farmers in rural Kenya. In 1997, almost 65% of households used fertilizer, while the corresponding figure is 75% for 2010. The average maize farmer used around 45 kgs/acre in 1997, average quantity use then increased to over 55 kgs/acre in 1999, before dropping to 50 kgs/acre in 2009. Lastly, 'Maize Output/Acre(kgs)' captures average maize yields over time.

Finally, Tables A.2 and A.3 show household-level transitions of pesticide and fertilizer use in the data, with 30% (60%) of households switching into or out of fertilizer (pesticide) use across survey rounds. So there is clearly considerable across round variation in input use patterns by Kenyan maize farmers around the broader trend of expanding purchased input use over time. We exploit the inter-temporal variation in household-specific input use to identify the causal effects of temperature shocks within specific periods of the growing

[3] We assume all pesticides to have the same density and convert all units to kilograms (kgs).

season on farmer defensive investments in preventing crop loss due to biotic stresses and any contemporaneous adjustment in productivity-enhancing fertilizer investments.

3.2 Kenyan Maize Calendar

To uncover the underlying mechanisms that influence farmer climate adaptation strategies, and plausibly related spillover effects on productivity-enhancing inputs, we need to disaggregate the main growing season. So as to parse the information set available to farmers as they make sub-season-specific input use choices. We use maize crop calendars specific to each agro-ecological zone (AEZ) in Kenya, broken into three distinct stages of the agricultural cycle.[4] This calendar gives the usual start and end dates of the planting period and harvest period for each AEZ and for long and short rainy seasons. We use the calendar for the long rainy season, which is the main growing season. We define as the 'pre-planting' period the two months right before planting begins, with or without basal fertilizer application. Land preparation occurs during this pre-planting period, sometimes including clearing weeds.[5] We define the four to six weeks right after planting as the initial post-planting period. This is the recommended period for top dressing application of fertilizer. Thus, the three phases of the main agricultural cycle are: 1) 'PP': land preparation period (from onset of pre-planting to onset of planting) 2) 'GS1': planting and basal fertilizer application period (the initial post-planting period from onset of planting to onset of top dressing fertilizer application), and 3) 'GS2': post-planting top dressing fertilizer application period (after top dressing fertilizer to onset of harvest) (Figure A.2).

3.3 Weather Data

Because of the incomplete coverage of ground weather stations in Kenya, we use daily temperature, precipitation, relative humidity and soil moisture data from various gridded and satellite data sets. Daily temperature data are the land surface temperature from the Noah 2.7.1 model in Global Land Data Assimilation System (GLDAS).[6] The data are in 0.25 de-

[4] The maize calendar was downloaded from http://www.fao.org/agriculture/seed/cropcalendar/welcome.do.

[5] Please see http://nafis.go.ke/agriculture/maize/establishment-of-maize/ for recommendation on land preparation and http://www.nafis.go.ke/agriculture/maize/field-management-practices/ for recommendation on fertilizer application.

[6] The data are located on the OPENDAP NASA web server as GRIB and netcdf files.

gree resolution, from 1990. The temporal resolution is three-hour (Rodell et al., 2004). A point shapefile for each village in the TAMPA sample was used to generate the value of each point for each daily temperature pixel it intersects with. We generated a table of every date and the temperature values of the points for each village coordinate point for every day each year. Similarly, we generated daily precipitation data from the Climate Hazards Group InfraRed Precipitation Station (CHIRPS) data set of daily 0.5 degree resolution gridded data for all of Africa.[7] Daily relative humidity data came from NASA.[8] These satellite and model derived solar and meteorological data cover the global surface at 1 by 1 degree resolution. Lastly, daily soil moisture data are sourced from the European Space Agency. This global soil moisture data set has been generated using active and passive microwave spaceborne instruments and covers the 37 year period from 1978 to 2015. It provides daily surface soil moisture with a spatial resolution of 0.25 degrees.[9]

From daily data, we generate aggregate weather indicators for each stage of the crop growth cycle, across five rounds of the TAMPA data. For our primary variable of interest, temperature, we use the concept of cumulative growing degree days (GDD). GDD measures the intensity of daily exposure to temperatures above a lower bound, beneath which cold stress might impede plant growth, and below an upper bound at which heat stress might begin, to estimate the effects of temperature on fertilizer and pesticide use, as well as weeding labor days. Past literature has demonstrated the relationship between temperature and agricultural outcomes using GDDs (e.g., Lobell et al., 2011; Schlenker and Lobell, 2010; Schlenker and Roberts, 2009; Schlenker, Hanemann and Fisher, 2006). We use daily average temperatures to calculate the number of days each village is exposed to temperatures above a lower bound (21C), and then sum these daily exposures for each of the three phases during the main growing season for those bounds.[10] Figure A.4 shows the distribution of daily average temperatures in each phase of the agricultural cycle during the main growing season for all villages in TAMPA data. Table present summary statistics for GDD above 21C in each

[7] CHIRPS was downloaded from http://chg.geog.ucsb.edu/data/chirps/

[8] The relative humidity data are from https://power.larc.nasa.gov/cgi-bin/agro.cgi?na

[9] The soil moisture data are downloaded from http://www.esa-soilmoisture-cci.org/node/145

[10] We have a pre-determined upper bound, since average daily temperatures in the data are less than 30C (Figure 1). In fact, the 99th percentile of the distribution of *maximum* daily temperatures for villages in our sample is 32C (Figure A.3). This is significant since optimum maize growth occurs at temperatures of 24-30C (Pingali, 2001). Relatedly, Schlenker and Roberts (2009) and Lobell et al. (2011) find that maize yields only decline physiologically due to heat stress above 29-30C.

phase of the agricultural cycle for all five rounds of the household survey. For each phase of the agricultural cycle, there exists substantial variation in degree days across households in each round, as well as significant round-on-round variation in GDD for all households in the TAMPA data.

4 Temperature and Agricultural Input Use Response

Almost 50% of households in this sample noticed a change in temperature in the last 10 years, and over 80% of those households indicated that they were affected by said change (Table A.5). If higher temperatures increase the incidence of pests, weeds and diseases, then farmers may incur greater adaptive expenditures on pesticides and weeding labor, and simultaneously reduce use of productivity enhancing fertilizer due to financial constraints, as just explained. Indeed, the qualitative evidence from the TAMPA data set supports such an explanation: almost 40% of maize-farmers affected by changes in temperature pointed to an increase in incidence of pests, weeds and crop diseases as one of the primary consequences of changes in temperature (Table A.6). And close to 60% of all non-adopters of fertilizer pointed to financial constraints as the reason for non-adoption (Table A.7).

In this section, we formally test the hypotheses that temperature variation during the growing season induces prompt agricultural input adjustments among maize farmers in Kenya. We rule out alternative mechanisms in Appendix A.

4.1 Research Design

To examine the effect of temperature on agricultural input use, we estimate the following model:

$$\begin{aligned} Y_{ijdqt} = \beta_1(GDD_{PP} > 21C)_{jdqt} + \beta_2(GDD_{GS1} > 21C)_{jdqt} + \\ \beta_3(GDD_{GS2} > 21C)_{jdqt} + f(Rain_{jdqt}) + \alpha_j + \mu_{qt} + \epsilon_{ijdqt} \end{aligned} \quad (1)$$

Y_{ijdqt} is fertilizer or pesticide use (a binary variable equal to one if used) for household i in village j, in district d in province q in round t. We control for cumulative rainfall using upper and lower terciles indicators calculated for each period in the agricultural cycle using daily data, and include village fixed effects (α_j). We also include province-by-round fixed effects (μ_{qt}) to control for unobservables that vary by province over time, such as input prices or seasonal climate forecasts. $(GDD > 21C)_{jdqt}$ is the sum of degree days over 21C during each stage of the main growing season in Kenya.[11] Thus, β_1 is the marginal effect of an extra growing degree days during the pre-planting phase, and so on for other coefficients. We cluster standard errors at the village level. The identifying assumption is that changes in the number of degree days experienced by a village during each phase of the agricultural cycle is exogenous to household or village level unobservable characteristics that vary over time. The assumption is plausible given the randomness of weather fluctuations and the inability of rural households to predict such fluctuations beyond common spatial features such as season climate forecasts for which we control with province-by-round fixed effects (μ_{qt}). As robustness checks, we also control for time invariant household level characteristics (e.g., farming skill, access to groundwater, education, relationship with input suppliers), as well as district level attributes that vary over time (e.g., local elections), and provide plausibly causal estimates for the effects of temperature on agricultural input use.

4.2 Results

4.2.1 The Response of Pesticides Use and Weeding Days to Temperature

We estimate Equation (1) and find that an extra 1 degree day above 21C in the initial growth period (GS1) increases the proportion of households using pesticides by over 0.6 percentage points (Table 1: Column 1). In 2003, almost 30% of maize-farmers in the TAMPA data adopted pesticides. Thus our point estimates imply that an extra 1 DD in GS1 leads to an approximately 2% increase in pesticide users. Similarly, an extra DD in GS1 leads to a 5% increase in the intensity of pesticide use (Table 1: Column 2). Note that since pesticide application is most effective - and thus most commonly applied - soon after pests are found on germinated crop, the effect should be most pronounced in GS1, not PP or GS2. This is precisely what we find.

[11] 21C is the 75th percentile of the distribution of average daily temperatures for villages in our sample, between 1990-2010. In Section 4.2, we demonstrate that our results are robust to the choice of lower bound used to calculate growing degree days.

If greater heat increases the incidence of weeds, we should also observe an increase in manual weeding labor. Indeed, we find that an extra degree day in the pre-planting period (PP) is associated with a 0.03 days (0.3%) increase in own (household) weeding labor per acre (Table 1: Column 5).[12] In fact, the effects on weeding labor start during pre-planting (PP), when increased weeding during land preparation would be a natural response to more robust weed growth in warmer weather, and continues throughout the growing season. An extra degree day in the post-planting period (GS2) increases own weeding effort by 0.04 days. The effect is of comparable magnitude, but imprecisely estimated, during the GS1 period when herbicides might plausibly substitute for weeding labor. Since crop-weed competition continues after top dressing, these results are exactly what one would expect.

Combined with the qualitative evidence presented in Table A.6, these results strongly suggest that early growing season temperatures, in the pre-planting and initial vegetative growth stages, increase the incidence of pests and diseases, driving use of adaptive inputs like pesticides in the early crop growth stages, with no significant impact of heat during latter stages of the growing season, by which time farmer response to crop diseases and pests, excluding weeds, is likely unproductive. Effects on weeding labor start early, but is equally pronounced deeper into the growing season as the ability to reverse the adverse effects of weed competition persists longer as well. Household labor can clear weeds manually if they survive initial application of herbicides, or to tackle encroachment of weeds that arises later in the growing season, due to higher than normal temperatures.

4.2.2 The Effects of Temperature on Fertilizer Use

Next, we examine effects on productivity-enhancing inputs like inorganic fertilizer. We find that an extra DD above 21C in the initial planting or basal fertilizer application period (GS1) decreases the proportion of households applying fertilizer by 0.2 percentage points (Table 1: Column 3). These effects coincide temporally with the pesticide effects observed, entirely consistent with a liquidity constraint mechanism, moreso than with a risk response, which should begin pre-planting. Almost 65% of the households in our balanced panel

[12] Only 20% of households in the TAMPA data set hired labor for manual weeding for just over a day per acre on average. However, we also examine the effects of higher temperatures on hired weeding labor both on the intensive and extensive margin. We find small positive effects on the probability of hiring labor for manual weeding (Table A.8).

applied fertilizer in 1997, so a 0.2 percentage point decrease translates into a 0.35% decrease from adoption levels in Round 1. Similarly, an extra DD over 21C in GS1 reduces fertilizer application rates per acre by around 2% (Table 1: Column 4). These effects are driven by early growing season temperatures, coinciding with the basal fertilizer application period, and by which time financial constraints typically begin to bind.

Back of the envelope estimates indicate a roughly one-to-one correspondence between increase in defensive expenditures and reduction in expenditure on fertilizer: An extra degree day in the initial planting period (GS1) increases expenditure of pesticides by KES 9.38, and reduces fertilizer expenditure by KES 23.38. Additionally, an extra degree day in GS1 increases the cost of own weeding labor (opportunity cost) by KES 18.51.[13,14] This suggests that as liquidity constraints begin to bind for farmers, expenditure on loss-reducing adaptive inputs necessitates reduction in fertilizer use.[15]

4.2.3 Robustness Checks

We exploit plausibly random round-by-round variation in temperature at the village level beyond time invariant village level characteristics and time varying spatial or administrative features, for which we control with province-by-round fixed effects, to provide plausibly causal estimates for the effects of temperature on agricultural input use.[16] After removing village and province-by-round fixed effects, any remaining temperature variation pertains only to within-province-round deviations from village means, as for example, the amount by which western parts of Nyanza province, are warmer than normal in a given survey round compared to how much eastern Nyanza is warmer than normal in the same round.

If provinces are large enough, it is plausible that we can control for time varying administrative features at a much smaller spatial unit like district, and still have enough variation

[13] 1 United States Dollar (USD) = 100 Kenyan Shilling (KES).

[14] We compute the average price/kg for both pesticides and inorganic fertilizer using the shilling amount spent by users of each input per acre divided by the kilogram quantity used per acre across rounds. We use the cost of hired weeding labor/day for households who hired weeding labor to impute the cost of own weeding labor/day. On average 52.14 kg/acre of fertilizer is used across rounds, and a kilogram of fertilizer costs KES 24.91 on average. So, using coefficients from Table 1, an extra degree day decreases fertilizer expenditure by (0.02*52.14)*24.91. Similarly, pesticide expenditure increased by (0.05*0.43)*484.77, while cost of own weeding labor increased by (0.04*4.88)*101.08.

[15] However, an alternative mechanism might be that increased ex ante maize yield risk due to an increase in the prevalence of pests and weeds could also adversely affect fertilizer uptake. We cannot rule out such an explanation.

[16] Including household fixed effects doesn't affect our estimates since the treatment (temperature) is at the village level (Table A.9).

to precisely estimate our coefficients of interest. However, generally whenever eastern Migori, a district in Nyanza province, is warmer than normal, so is western Migori, because temperatures vary smoothly in space due to thermodynamics. Thus, it is unlikely that we have sufficient identifying variation in temperature after removing household and district-by-year fixed effects. We report within-province and within-district temperature variation in Table A.10. The entries report the percentage of households by round observations with deviations at least as large as 5 or 10 degrees, averaged over the five survey rounds. For example, the "Removed Province*Round Effects" degree-days column indicate that 29% and 10% of households by round observations had deviations larger than 5 and 10 degree-days in the planting period (GS1), respectively. The corresponding percentages for the "Removed District*Round Effects" degree-days column are only 11% and 3%, respectively. Indeed, when we estimate Equation (1) with district-by-round fixed effects instead of province-by-round effects we lose precision for 'Pesticides' and 'Own Weeding Days/Acre', although the point estimate remains relatively unchanged (Table A.11).

A sizable proportion of households, across rounds, did not use fertilizer or pesticides. Thus, limited (specifically, censored) dependent variable models might be appropriate for estimating the effect of temperature on intensity of input use. However, fixed effects in tobit models based on the normal distribution yield inconsistent estimates, as fixed effects cannot be treated as incidental parameters without biasing the other model coefficients, so long as N>T (Hsiao, 1986). Thus, for consistent estimation, we provide regression estimates using the Honoré semi-parametric fixed effect tobit estimator (Honoré, 1992).[17] As before, the effects on pesticide and fertilizer use are driven by early growing season temperatures. Moreover, early growing season estimates are statistically significant as well. Similarly, we provide regression estimates for weeding labor as well. Table 2 shows the effects of temperature on intensity of pesticide and fertilizer use based on Honoré household fixed effects tobit. For comparison, the standard tobit is also presented in Table 3. Qualitative conclusions drawn from our main results presented in Table 1 remain unchanged with either censored dependent variable estimator.

In Table A.12, we adjust standard errors to reflect spatial dependence as modeled in

[17] We use Honoré's Pantob program, accessible here: http://www.princeton.edu/ honore/stata/

Conley (1999), and implemented by Hsiang (2010). We allow errors to be spatially autocorrelated within a distance of 500 km. Our point estimates remain precisely estimated. In Table A.13 we demonstrate that effects of temperature on agricultural input decisions are robust to the choice of lower bound used to calculate cumulative growing degree days (GDDs). Next, we employ a sinusoidal interpolation between the daily minimum and maximum temperature (Snyder, 1985). We follow Roberts, Schlenker and Eyer (2013), and generate growing degree days accounting for within-day temperature variations, not just the daily mean temperature, and estimate the effects on agricultural input response. The core story line remains, although the effects on pesticide use and weeding labor are relatively smaller (Table A.14).

Lastly, we examine the relationship between growing degree days over 21C and agricultural yields amongst maize farmers in the data. Almost 45% of maize-growers in the TAMPA data set indicated that variation in temperature reduced crop yields (Table A.6). Yet the warmer temperatures experienced in these temperate zones should not weaken maize growth physiologically.[18] So farmers' responses most likely reflect the biotic stresses we have emphasized.

To unpack this a bit, we estimate a reduced form relationship between temperatures in the growing season and maize yields; that is, we observe the net effect of at least the following channels of impact: an increase in incidence of pests, weeds and crop diseases, consequent increase in pesticide use and manual weeding, decrease in fertilizer use, and an unlikely direct effect of higher temperatures on maize yields. We find that an extra degree day over 21C in the initial growth stage (GS1) reduces maize yields by 0.3%, although the estimate is not statistically significant (Table A.15, Column 1). However, when we account for within-day temperature variations, we find a statistically significant effect of -0.8% from the initial planting period temperatures, consistent with our prior results (Table A.15, Column 2).

Overall, the estimation results are consistent with predictions from the agronomic literature and with farmers qualitative comments, and stand up to various robustness tests.

[18]Maize yields only decline above 29-30C (Lobell et al., 2011; Schlenker and Roberts, 2009), while average daily temperatures for villages in our sample are well below 30C (Figure 1).

4.2.4 Hetereogenous Effects by Wealth

Precisely disentangling the effects of credit constraints and ex ante risk falls outside the scope of this paper, especially because we lack good measures of farmer risk aversion or liquidity constraints.[19] We can nonetheless provide suggestive empirical evidence of an association between farmer input response and farmer wealth that suggests plausibly heterogeneous effects of rising temperatures due to farmers' differential ability and willingness to cope with temperature-induced increased incidence of pests and diseases. To examine such a mechanism, the key thought experiment involves the question of whether, ceteris paribus, changes in ex ante income or income risk affect input use. We exploit plausibly exogenous changes in temperature over time across relatively 'poor' and 'wealthy' households under the maintained hypotheses that poor households are more likely to face binding financial liquidity constraints and will be more risk averse for a given increase in biotic risk exposure (i.e., preferences exhibit decreasing absolute risk aversion). We show suggestive evidence that household wealth differences are associated with different responses to higher within-season temperatures, consistent with a story of heterogeneous effects among farmers.

We use average land ownership across all five rounds as a proxy for wealth. We separate the balanced sample by terciles, and denote households in the bottom tercile as relatively 'poor'. We then estimate the relationships between heat and agricultural input use, now adding interaction terms between degree days in each phase of the crop cycle (PP, GS1 and GS2), and a 0-1 binary wealth variable which takes value 1 if wealth for household i is in the bottom tercile, that is if the 1995-2010 average land holding is less than 2.5 acres, 0 otherwise. We find that poorer households are less likely to adapt to higher temperatures via pesticide use. These effects are consistent with the binding liquidity constraints hypothesis, but less so with a risk aversion story if pesticide purchases reduce risk and farmers exhibit constant or decreasing absolute risk aversion. We also examine the relationship between GDDs and fertilizer use by household wealth. We find that poorer households use less fertilizer due to higher temperatures (Tables A.16, A.17 and A.18).[20]

[19] We would have liked to at least test the liquidity constraints hypothesis by looking for within-season adjustments in other expenditures, but the data set does not include temporally disaggregated (monthly) consumption expenditures, so we are unable to do a test like Behrman, Foster and Rosenzweig (1997).

[20] In Tables A.19, A.20 and A.21, we use baseline (Round 1) land ownership as a proxy for wealth for all rounds. The point estimates remain largely unchanged.

These results suggest that not only do wealthier farmers adapt more through increased pesticide use than their poorer neighbors do to a temperature-induced increase in incidence of pests, weeds and diseases, the wealthier farmers also seem to reduce their expenditure on fertilizer less in face of higher temperatures. These associations suggest that higher temperatures may lead to regressive distributional yield and income effects within low-income agrarian communities. Limited financial resources constrain uptake of loss-reducing inputs and aggravates the reduction in fertilizer application as temperature increases.

5 Conclusion

In this paper, we show that farmers in a low-income country can quickly adjust agricultural input use to within-season temperature variation. We find that maize farmers in Kenya increase pesticide use and household weeding labor in response to higher temperatures, and reduce fertilizer use. We present suggestive evidence that these effects are driven by pests, weeds and crop diseases that are sensitive to temperature, and confront farmers with a trade-off. Financially constrained households are induced to reduce spending on productivity-enhancing fertilizer and to increase defensive expenditure on loss-reducing pesticides and on weeding labor.

Yields are the joint product of crop physiological response to higher temperatures holding input use constant, and the effects of induced change in input application patterns on crop yields. Our findings indicate that warmer temperatures, by influencing input application patterns, may affect agricultural production even in regions where temperatures are not high enough to directly, adversely affect crop growth. The defensive investments farmers quickly undertake within a growing season in response to temperature-induced biotic stresses affect patterns of uptake of modern agricultural technologies in low-income agrarian communities. And farmer responsiveness appears uneven across the landholding, and thus wealth, distribution in these communities.

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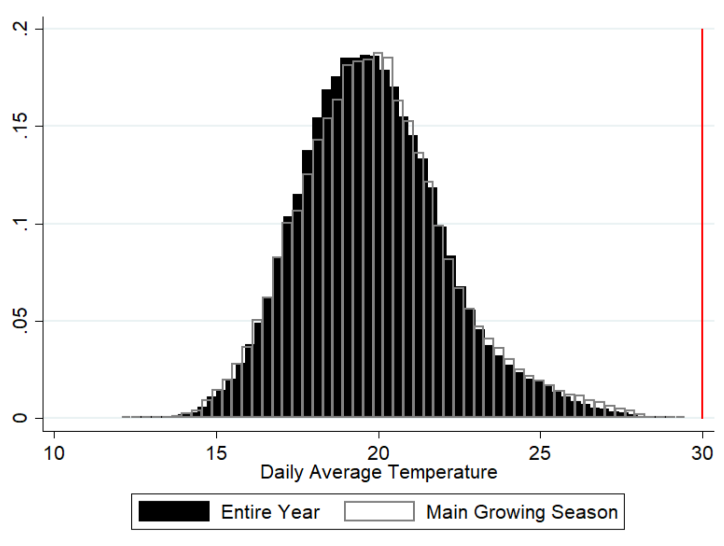
Tables and Figures

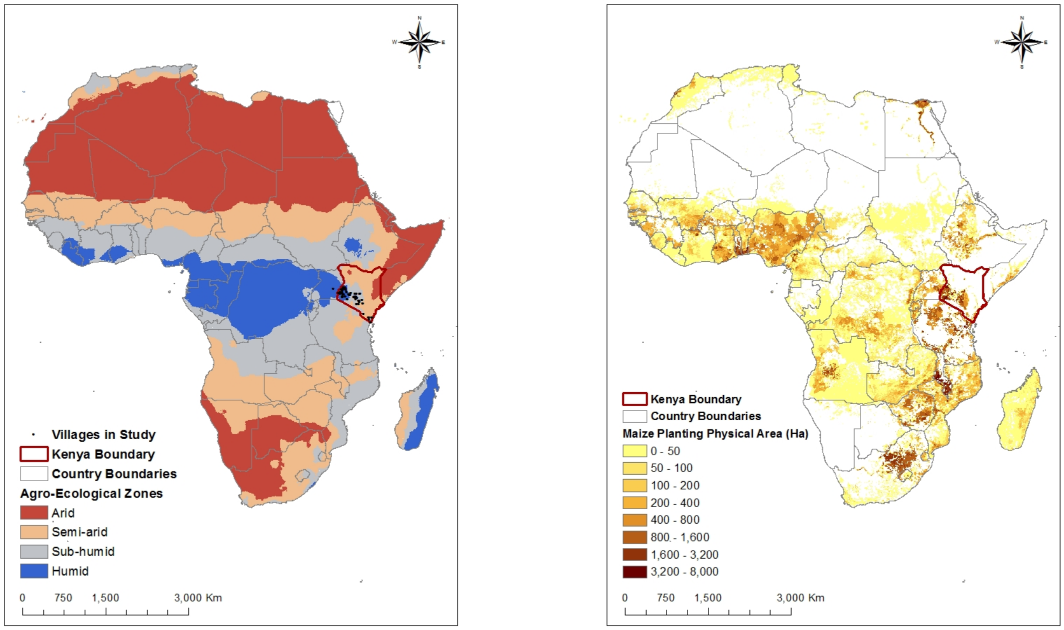
Figures

Figure 1: Daily Average Temperature in TAMPA Sample (1990-2012)



Notes: Distribution of average daily temperatures in villages in TAMPA from 1990-2012. According to existing literature, temperature affects maize yields only after 30C, represented by the red line (Lobell et al., 2011; Schlenker and Roberts, 2009).

Figure 2: Agro-Ecological Zones and Maize Production in Africa



Source: Agro-ecological zones - IFPRI Harvest Choice (www.harvestchoice.org.); Maize Production in Africa: Spatial Production Allocation Model (SPAM), 2005 (www.mapSPAM.info)

Agro-Ecological Zones (AEZs): Agro-ecological zones (AEZs) are geographical areas sharing similar climate characteristics (e.g., rainfall and temperature) with respect to their potential to support (usually rain-fed) agricultural production. Because of the general similarity of production conditions, many agricultural technologies, practices and production systems tend to behave or respond consistently within a specific AEZ. AEZs therefore provide a useful spatial framework for identifying the potential area extent of applicability of given innovations and, futhermore, the likely potential for production related innovations to "spillover" from one country (or continent) to another. AEZs provide an ecology-based division of geographic space as opposed to administrative or political boundaries within which environmental conditions could vary significantly. The tabulation of rural population by AEZ for Sub-Saharan Africa indicates that almost 23% of the rural population lives in more humid highland regions.

Tables

Table 1: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer 0/1 β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Own Weeding Days/Acre β / 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: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. 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%.

Table 2: Honoré Fixed Effects Tobit: Temperature, Fertilizer and Pesticide Use

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE	(3) Own Weeding Days/Acre β / SE
CY PP DD >21C	0.0259*	-0.0041	0.0810**
	(0.0144)	(0.0075)	(0.0356)
CY GS1 DD >21C	0.0899***	-0.0375***	0.0581
	(0.0265)	(0.0140)	(0.0583)
CY GS2 DD >21C	-0.0054	0.0014	0.0920**
	(0.0126)	(0.0058)	(0.0412)
Village FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	6210	3726
R^2			

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. 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%.

Table 3: Standard Tobit Estimates: Temperature, Fertilizer and Pesticide Use

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE	(3) Own Weeding Days/Acre β / SE
CY PP DD >21C	0.0349*	-0.0038	0.0320**
	(0.0183)	(0.0074)	(0.0162)
CY GS1 DD >21C	0.1081***	-0.0317**	0.0250
	(0.0365)	(0.0129)	(0.0308)
CY GS2 DD >21C	-0.0064	0.0001	0.0474**
	(0.0190)	(0.0054)	(0.0217)
Village FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	6210	3726
R^2			

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. The table presents the effects of temperature (captured via degree days (DD) over 21C) on weeding labor. 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

A Appendix

Alternative Explanations

In this section, we rule out some alternative channels that could potentially explain the observed relationship between temperature and agricultural input use. Specifically, we consider two alternative explanations: (1) influence of humidity on the incidence of pests and crop disease, and (2) higher than normal temperatures can affect soil moisture, in turn reducing fertilizer uptake.

Humidity

Grey leaf spot is a major maize disease in Kenya. Empirical results suggest that moderate to high temperatures and prolonged periods of high relative humidity are both favorable for the development of gray leaf spot (Latterell and Rossi, 1983; Rupe, Siegel and Hartman, 1982). Similarly, relative humidity is also a main factor affecting the distribution of stem borers, the main insect pest affecting maize in Kenya (Mwalusepo et al., 2015). Thus, given the correlation between heat and humidity, it is possible that our estimates actually capture the influence of relative humidity on pests and crop diseases. To rule out this explanation, we control for relative humidity at the village level, and find that our estimates are relatively unchanged (Table A.22, Columns 1-3). Even holding humidity constant, temperature exerts an independent effect on agricultural input use.

Soil Moisture

Higher than normal temperatures could reduce the stock of water in the soil, and thereby reduce fertilizer effectiveness, inducing lower farmer uptake. Water and soil nutrients (such as nitrogen and phosphorus) are essential for crop growth. Fertilizer use adds to soil nutrients. In rain-fed agriculture, where soil moisture depends on rainfall, temperature, and soil quality, the effectiveness of fertilizer can be seriously affected inadequate soil moisture (cite agronomy paper). When moisture deficiency is the primary factor limiting crop growth, yield is less responsive to fertilizer use, in line with von Liebig's law of the minimum which states that yield is determined by the amount of the most limiting nutrient (Marenya and Barrett, 2009; Paris, 1992). In addition, soil nutrients are taken up by plant roots in a water solution, so water availability affects how efficiently applied fertilizer can be used by crops. Farmers are less likely to adopt fertilizer in zones where soil moisture supply is deficient (at least partially) due to low yield response to fertilizer (Jha and Hojjati, 1995; Lele and Stone, 1989; Matlon, 1990; Thompson P. and Baanante, 1989).

Moreover, both air temperature and soil temperature affect soil moisture through the evapotranspiration process, the predominant water cycle in the absence of precipitation (Longobardi and Khaertdinova, 2015). Temperature plays a critical role in evapotranspiration. Higher temperature increases transpiration of water in the surface soil, just like in the plants. Komuscu, Erkan and Oz (1998) assess the implications of climate change for soil moisture availability in southeast Turkey, finding substantial reductions in availability during summer. Also, local effects of heat stress on soil moisture will vary with soil characteristics. Boix-Fayos et al. (1998), for example, show that infiltration and the water-holding capacity of soils on limestone are greater with increased frost activity and infer that increased temperatures could lead to increased surface or shallow runoff.

Since we include household fixed effects in our model, we control for time invariant qualities of the soil. We also control already for time varying attributes of soil at province level. However, if changes in heat across years are correlated with changes in soil moisture within a province, the estimated relationship between temperature and fertilizer use may be susceptible to the soil moisture channel. To rule out this explanation, we control for daily soil moisture at the village level. Our findings remain unchanged when we hold soil moisture constant (Table A.22, Columns 4-5).[21]

[21]Unfortunately, we do not have daily soil moisture data for the entire sample. Columns 1 and 3 presents results using our baseline specification for the subset of observations for which we could find matching soil moisture estimates, while Columns 2 and 4 control for soil moisture.

Figures

Figure A.1: Location of Sample Villages

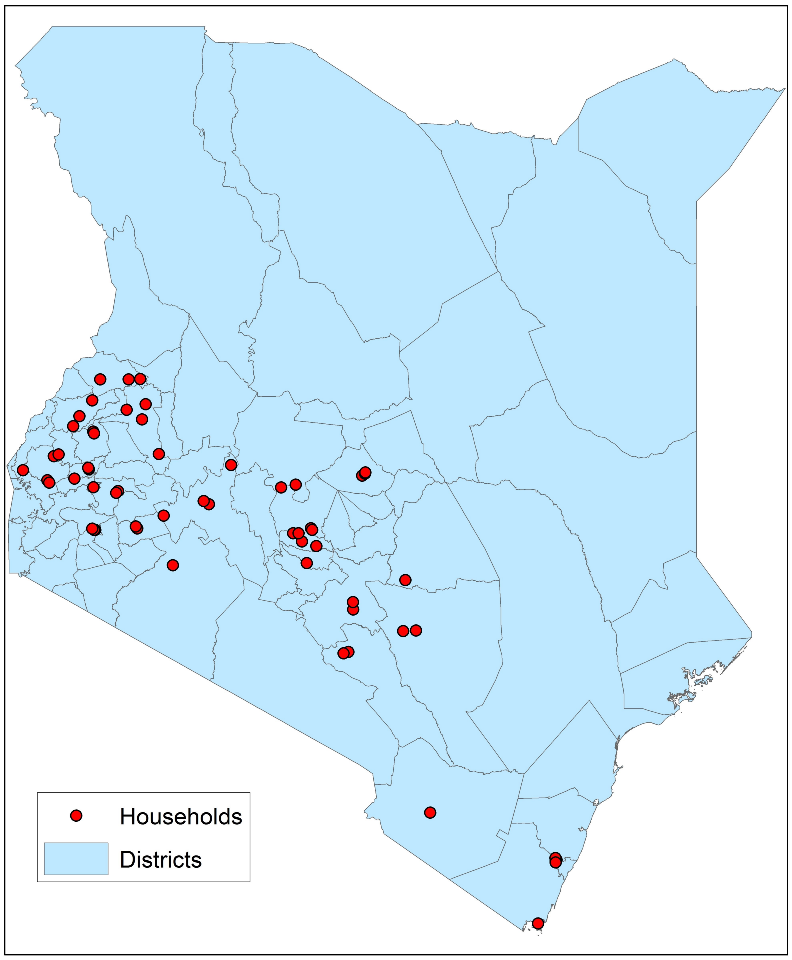


Figure A.2: Kenyan Maize Calendar

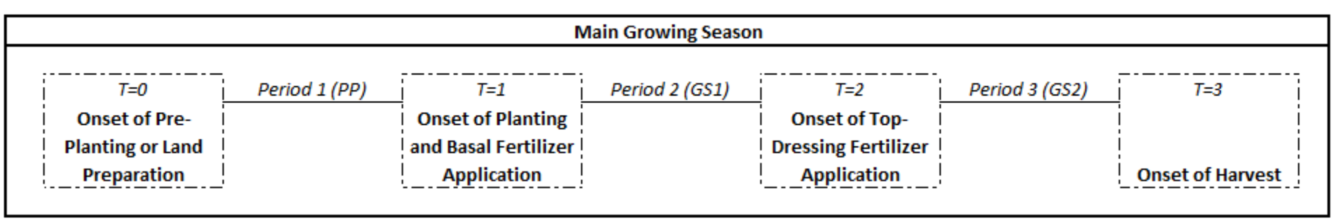


Figure A.3: Daily Maximum Temperature in TAMPA Sample (1990-2013)

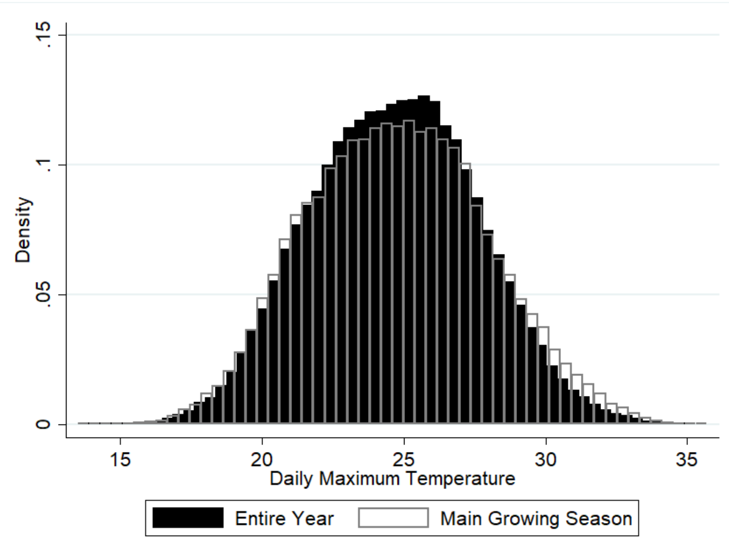
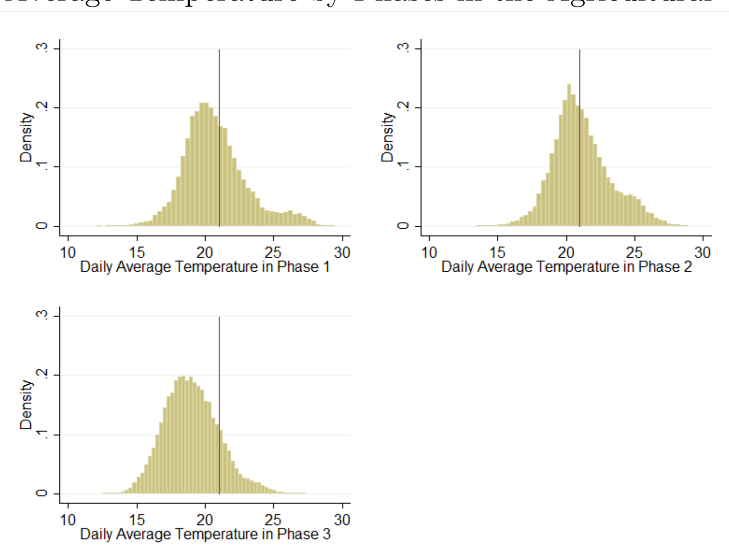


Figure A.4: Daily Average Temperature by Phases in the Agricultural Cycle (1990-2012)



Notes: Distribution of average daily temperatures from 1990-2012 for three phases of the agricultural cycle. Phase 1: pre-planting or land preparation - onset of planting; Phase 2: planting or basal fertilizer application - onset of top dressing fertilizer; Phase 3: top dressing fertilizer application - onset harvest. We calculate cumulative growing degree days from a lower bound of 21C (represented by red vertical line)

Tables

Table A.1: Summary Statistics

	1997	2000	2004	2007	2010
Pesticides 0/1			0.27	0.65	0.53
			(0.45)	(0.48)	(0.50)
Pesticide/Acre(kgs)			0.24	0.50	0.56
			(1.68)	(1.01)	(3.96)
Total Weeding Days/Acre			9.59	4.67	4.56
			(11.64)	(6.94)	(6.43)
Own Weeding Labor 0/1			0.92	0.80	0.77
			(0.27)	(0.40)	(0.42)
Own Weeding Days/Acre			7.86	3.64	3.16
			(11.11)	(6.13)	(5.35)
Hired Weeding Labor 0/1			0.25	0.21	0.20
			(0.43)	(0.41)	(0.40)
Hired Weeding Days/Acre			1.73	1.04	1.41
			(4.80)	(3.75)	(4.08)
Fertilizer 0/1	0.63	0.69	0.71	0.75	0.75
	(0.48)	(0.46)	(0.45)	(0.43)	(0.44)
Fertilizer/Acre(kgs)	46.07	57.48	51.37	54.53	51.25
	(76.02)	(91.09)	(70.20)	(63.80)	(57.05)
Maize Output/Acre(kgs)	292.33	355.18	406.68	489.37	394.87
	(333.03)	(908.16)	(424.91)	(445.54)	(353.66)

Notes: Standard deviations are given in parentheses. Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10). Detailed data on pesticides and weeding labor days was only collected in 2003-04, 2006-07 and 2009-10.

Table A.2: Pesticide Use Transitions

	Fraction of Households
NNN	0.22 (0.42)
NYY	0.26 (0.44)
NNY	0.08 (0.27)
NYN	0.16 (0.37)
YNY	0.02 (0.15)
YNN	0.02 (0.15)
YYN	0.07 (0.25)
YYY	0.17 (0.37)
Observations	1242

Notes: This table shows all possible three transitions in our sample of farmers and the fraction of our sample that experiences each of these transitions. The three periods correspond to the 2003-04, 2006-07 and 2009-10 survey rounds. In the first column, the three letters represent the transition history with respect to pesticide adoption, where "Y" represents the use of pesticides and "N" represents non-adoption of pesticides. These are ordered by survey round. For example, the transition "YYY" stands for farmers who used pesticides in all three periods; they make up about 17% of our sample. "YYN" represents the 7% of the sample that use pesticides in 2003-04 and 2006-07 but not in 2009-10.

Table A.3: Fertilizer Use Transitions

	Fraction of Households
NNNNN	0.16 (0.37)
NYYYY	0.06 (0.23)
NNYYY	0.03 (0.17)
NNNYY	0.02 (0.12)
NNNNY	0.03 (0.16)
NYN/YNY	0.14 (0.35)
YNNNN	0.00 (0.07)
YYNNN	0.01 (0.07)
YYYNN	0.00 (0.04)
YYYYN	0.02 (0.12)
YYYYY	0.54 (0.50)
Observations	1242

Notes: This table shows all possible five transitions in our sample of farmers and the fraction of our sample that experiences each of these transitions. The three periods correspond to the 1996-97, 1999-00, 2003-04, 2006-07 and 2009-10 survey rounds. In the first column, the five letters represent the transition history with respect to fertilizer adoption, where "Y" represents the use of pesticides and "N" represents non-adoption of fertilizer. For example, the transition "YYYYY" stands for farmers who used fertilizer in all five periods; they make up about 54% of our sample. "NYN/YNY" stands for farmers who transitioned both in and out of fertilizer use within these five rounds of data. All other sequences are unidirectional.

Table A.4: Growing Degree Days: Mean and Standard Deviations – Rounds 1-5

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

Table A.5: 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.

Table A.6: 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 in the 2009-10 TAMPA survey.

Table A.7: 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 in the 2009-10 TAMPA survey.

Table A.8: Temperature and Hired Weeding Labor

	(1) Hired Weeding Labor 0/1 β / SE	(2) Hired Weeding Days/Acre β / SE	(3) Hired Weeding Days/Acre β / SE	(4) Hired Weeding Days/Acre β / SE
CY PP DD >21C	0.0004	-0.0079	-0.0521	0.0056
	(0.0004)	(0.0066)	(0.0443)	(0.0306)
CY GS1 DD >21C	0.0018*	-0.0104	-0.0170	0.1057*
	(0.0010)	(0.0151)	(0.0762)	(0.0584)
CY GS2 DD >21C	0.0004	0.0018	0.0118	0.0369
	(0.0008)	(0.0073)	(0.0511)	(0.0281)
Village FE	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes
Observations	3726	3726	3726	3726
R^2	0.485	0.416		

Notes: Sample includes 1242 households balanced over 3 survey rounds (1996-97, 1999-00, 2003-04, 2006-07. The table presents the effects of temperature (captured via degree days (DD) over 21C) on hired weeding labor. Columns 3 and 4 present Honoré Fixed Effects Tobit and Standard Tobit estimates, respectively. 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.9: Household FE: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer 0/1 β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Own Weeding Days/Acre β / SE
CY PP DD >21C	0.0019	0.0084	-0.0003	-0.0054	0.0323*
	(0.0017)	(0.0109)	(0.0006)	(0.0062)	(0.0181)
CY GS1 DD >21C	0.0063**	0.0450**	-0.0018*	-0.0180*	0.0375
	(0.0031)	(0.0192)	(0.0009)	(0.0096)	(0.0327)
CY GS2 DD >21C	-0.0004	-0.0108	0.0003	0.0005	0.0392
	(0.0018)	(0.0095)	(0.0005)	(0.0049)	(0.0264)
Household 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	0.587	0.587	0.739	0.788	0.478

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. 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%.

Table A.10: Observed temperature variation: proportion of households with degree-days below/above average (degrees) after removing province*year effects and district*year effects

	Removed Prov*Round FE % HHs	Removed Dist*Round FE % HHs
CY PP DD >21C: DD below/above 5 degrees	0.37	
CY PP DD >21C: DD below/above 10 degrees	0.17	
CY GS1 DD >21C: DD below/above 5 degrees	0.29	
CY GS1 DD >21C: DD below/above 10 degrees	0.10	
CY GS2 DD >21C: DD below/above 5 degrees	0.13	
CY GS2 DD >21C: DD below/above 10 degrees	0.04	
CY PP DD >21C: DD below/above 5 degrees		0.18
CY PP DD >21C: DD below/above 10 degrees		0.08
CY GS1 DD >21C: DD below/above 5 degrees		0.11
CY GS1 DD >21C: DD below/above 10 degrees		0.03
CY GS2 DD >21C: DD below/above 5 degrees		0.06
CY GS2 DD >21C: DD below/above 10 degrees		0.03

Notes: Sample include 1242 balanced households over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10). The table presents the leftover variation in growing degree days (DD) after removing province-by-round and district-by-round fixed effects. 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.

Table A.11: District*Year FE: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer 0/1 β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Own Weeding Days/Acre β / SE
CY PP DD >21C	0.0009	0.0063	-0.0016**	-0.0194**	0.0304
	(0.0015)	(0.0088)	(0.0008)	(0.0082)	(0.0256)
CY GS1 DD >21C	0.0051	0.0480**	-0.0031**	-0.0323**	0.1015
	(0.0038)	(0.0229)	(0.0014)	(0.0136)	(0.0646)
CY GS2 DD >21C	0.0013	0.0037	-0.0011**	-0.0148***	0.0170
	(0.0016)	(0.0096)	(0.0005)	(0.0055)	(0.0297)
Village FE	Yes	Yes	Yes	Yes	Yes
District-by-Year FE	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210	3726
R^2	0.371	0.388	0.607	0.667	0.174

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. 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%.

Table A.12: Conley Standard Errors: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer 0/1 β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Own Weeding Days/Acre β / SE
CY PP DD >21C	0.0019*	0.0084	-0.0003	-0.0054	0.0323***
	(0.0010)	(0.0063)	(0.0004)	(0.0046)	(0.0035)
CY GS1 DD >21C	0.0063**	0.0450***	-0.0018**	-0.0180***	0.0375*
	(0.0024)	(0.0154)	(0.0008)	(0.0061)	(0.0195)
CY GS2 DD >21C	-0.0004	-0.0108	0.0003	0.0005	0.0392***
	(0.0032)	(0.0200)	(0.0008)	(0.0073)	(0.0069)
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210	3726
R^2	0.045	0.048	0.017	0.021	0.012

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. The table presents the effects of temperature 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 adjusted to reflect spatial dependence as modeled in Conley (1999). Spatial autocorrelation is assumed to linearly decrease in distance up to a cutoff of 500 km.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.13: Alternative GDD Lower Bounds: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides 0/1 β / SE	(2) Pesticides 0/1 β / SE	(3) Pesticides 0/1 β / SE	(4) Fertilizer 0/1 β / SE	(5) Fertilizer 0/1 β / SE	(6) Fertilizer 0/1 β / SE
CY PP DD >19C	0.0015			-0.0004		
	(0.0010)			(0.0004)		
CY GS1 DD >19C	0.0029**			-0.0014**		
	(0.0011)			(0.0006)		
CY GS2 DD >19C	-0.0006			-0.0000		
	(0.0006)			(0.0003)		
CY PP DD >20C		0.0017			-0.0004	
		(0.0012)			(0.0005)	
CY GS1 DD >20C		0.0034**			-0.0016**	
		(0.0016)			(0.0007)	
CY GS2 DD >20C		-0.0007			0.0001	
		(0.0008)			(0.0004)	
CY PP DD >22C			0.0018			-0.0008
			(0.0016)			(0.0007)
CY GS1 DD >22C			0.0078***			-0.0021**
			(0.0028)			(0.0009)
CY GS2 DD >22C			-0.0027			0.0006
			(0.0024)			(0.0006)
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	3726	6210	6210	6210
R^2	0.336	0.336	0.336	0.594	0.594	0.594

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides. The table presents the effects of temperature (captured via degree days (DD) over 19C, 20C, and 22C) 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%.

Table A.14: Accounting for Within-Day Temperature Variation: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer 0/1 β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Own Weeding Days/Acre β / SE
CY PP DD >21C II	0.0017	0.0096	-0.0008	-0.0093	0.0264**
	(0.0012)	(0.0078)	(0.0006)	(0.0059)	(0.0122)
CY GS1 DD >21C II	0.0017	0.0215***	-0.0022***	-0.0213***	-0.0192
	(0.0014)	(0.0082)	(0.0008)	(0.0074)	(0.0145)
CY GS2 DD >21C II	-0.0011	-0.0054	0.0001	0.0016	0.0080
	(0.0008)	(0.0060)	(0.0004)	(0.0045)	(0.0111)
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	0.335	0.352	0.595	0.657	0.164

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. 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%.

Table A.15: 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	
	(0.0041)	
CY GS1 DD >21C	-0.0027	
	(0.0066)	
CY GS2 DD >21C	0.0029	
	(0.0028)	
CY PP DD >21C II		0.0021
		(0.0043)
CY GS1 DD >21C II		-0.0083**
		(0.0033)
CY GS2 DD >21C II		0.0002
		(0.0029)
Village FE	Yes	Yes
Prov-by-Year FE	Yes	Yes
Rainfall Controls	Yes	Yes
Observations	6210	6210
R^2	0.374	0.375

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10). 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%.

Table A.16: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1-5)

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer 0/1 β / SE	(4) Ln Fertilizer/Acre 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: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides. 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%.

Table A.17: Standard Tobit Estimates: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1-5)

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0382**	0.0002
	(0.0189)	(0.0079)
CY GS1 DD >21C	0.1177***	-0.0260*
	(0.0364)	(0.0138)
CY GS2 DD >21C	-0.0025	0.0045
	(0.0196)	(0.0057)
CY PP DD >21C*Bottom Wealth Tercile	-0.0123	-0.0118*
	(0.0086)	(0.0068)
CY GS1 DD >21C*Bottom Wealth Tercile	-0.0105	-0.0192*
	(0.0163)	(0.0108)
CY GS2 DD >21C*Bottom Wealth Tercile	-0.0045	-0.0110
	(0.0200)	(0.0110)
Household FE	Yes	Yes
Prov-by-Year FE	Yes	Yes
Rainfall Controls	Yes	Yes
Observations	3726	6210
R^2		

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides. 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%.

Table A.18: Honoré Fixed Effects Tobit: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1-5)

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0282***	-0.0012
	(0.0086)	(0.0050)
CY GS1 DD >21C	0.0921***	-0.0293***
	(0.0174)	(0.0111)
CY GS2 DD >21C	-0.0049	0.0067
	(0.0104)	(0.0106)
CY PP DD >21C*Bottom Wealth Tercile	-0.0078	-0.0099*
	(0.0082)	(0.0056)
CY GS1 DD >21C*Bottom Wealth Tercile	-0.0085	-0.0195*
	(0.0131)	(0.0109)
CY GS2 DD >21C*Bottom Wealth Tercile	-0.0026	-0.0151
	(0.0196)	(0.0135)
Observations	3726	6210
R^2		

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides. 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%.

Table A.19: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1)

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer 0/1 β / SE	(4) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0025	0.0130	-0.0002	-0.0046
	(0.0017)	(0.0112)	(0.0006)	(0.0062)
CY GS1 DD >21C	0.0072**	0.0493**	-0.0014	-0.0165*
	(0.0031)	(0.0191)	(0.0009)	(0.0093)
CY GS2 DD >21C	-0.0009	-0.0128	0.0004	0.0027
	(0.0020)	(0.0113)	(0.0004)	(0.0044)
CY PP DD >21C*Bottom Wealth Tercile	-0.0013**	-0.0091**	-0.0003	-0.0022
	(0.0006)	(0.0038)	(0.0004)	(0.0038)
CY GS1 DD >21C*Bottom Wealth Tercile	-0.0016	-0.0070	-0.0008	-0.0037
	(0.0011)	(0.0073)	(0.0005)	(0.0049)
CY GS2 DD >21C*Bottom Wealth Tercile	0.0015	0.0072	-0.0003	-0.0073
	(0.0017)	(0.0146)	(0.0006)	(0.0055)
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	0.588	0.740	0.788

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides. 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%.

Table A.20: Standard Tobit Estimates: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1)

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0381**	-0.0018
	(0.0191)	(0.0079)
CY GS1 DD >21C	0.1193***	-0.0278**
	(0.0369)	(0.0140)
CY GS2 DD >21C	0.0010	0.0064
	(0.0189)	(0.0058)
CY PP DD >21C*Bottom Wealth Tercile	-0.0113	-0.0058
	(0.0090)	(0.0062)
CY GS1 DD >21C*Bottom Wealth Tercile	-0.0140	-0.0140
	(0.0161)	(0.0105)
CY GS2 DD >21C*Bottom Wealth Tercile	-0.0152	-0.0151*
	(0.0203)	(0.0083)
Household FE	Yes	Yes
Prov-by-Year FE	Yes	Yes
Rainfall Controls	Yes	Yes
Observations	3726	6210
R^2		

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides. 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%.

Table A.21: Honoré Fixed Effects Tobit: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1)

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0289***	-0.0025
	(0.0085)	(0.0050)
CY GS1 DD >21C	0.0919***	-0.0317***
	(0.0174)	(0.0115)
CY GS2 DD >21C	-0.0029	0.0077
	(0.0108)	(0.0112)
CY PP DD >21C*Bottom Wealth Tercile	-0.0085	-0.0054
	(0.0076)	(0.0053)
CY GS1 DD >21C*Bottom Wealth Tercile	-0.0074	-0.0130
	(0.0125)	(0.0112)
CY GS2 DD >21C*Bottom Wealth Tercile	-0.0087	-0.0163
	(0.0179)	(0.0140)
Observations	3726	6210
R^2		

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides. 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%.

Table A.22: Controls for Daily Humidity: Temperature, Pesticides and Weeding Labor Days

	(1) Pesticides 0/1 β / SE	(2) Ln Pesticide/Acre β / SE	(3) Own Weeding Days/Acre β / SE
CY PP DD >21C	0.0023	0.0093	0.0239
	(0.0014)	(0.0090)	(0.0181)
CY GS1 DD >21C	0.0068**	0.0470***	0.0223
	(0.0027)	(0.0165)	(0.0290)
CY GS2 DD >21C	0.0001	-0.0085	0.0261
	(0.0018)	(0.0097)	(0.0250)
Village FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Humidity Controls	Yes	Yes	Yes
Observations	3726	3726	3726
R^2	0.338	0.355	0.166

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use and 3 survey rounds (2003-04, 2006-07 and 2009-10) for pesticides and weeding labor days. 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%.

Table A.23: Controls for Soil Moisture: Temperature and Fertilizer Use

	(1) Fertilizer 0/1 β / SE	(2) Fertilizer 0/1 β / SE	(3) Ln Fertilizer/Acre β / SE	(4) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0009	0.0004	0.0062	-0.0007
	(0.0007)	(0.0008)	(0.0073)	(0.0083)
CY GS1 DD >21C	-0.0018	-0.0022	-0.0134	-0.0161
	(0.0013)	(0.0013)	(0.0138)	(0.0136)
CY GS2 DD >21C	0.0002	-0.0002	0.0010	-0.0041
	(0.0006)	(0.0004)	(0.0065)	(0.0047)
Village FE	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes
Soil Moisture Controls	No	Yes	No	Yes
Observations	2352	2352	2352	2352
R^2	0.587	0.588	0.644	0.645

Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10) for fertilizer use. 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%.