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

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Does heat affect agriculture in regions where temperatures are not high enough to directly, adversely affect crop growth? Combining daily weather data with a qualitatively rich, longitudinal survey of Kenyan agricultural households in rural maize-growing areas where daily average temperatures are well below 30C, we find that higher temperatures early in the growing season increase the use of pesticides, while reducing fertilizer use, with comparatively modest effects of temperature later in the growing season. Suggestive evidence indicates that 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 inputs like pesticides.

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Abstract

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1 Introduction

Agricultural livelihoods in developing countries are especially fragile in the face of climate change (e.g. Rosenzweig and Parry, 1994; Mendelsohn, 2008). The effects of climate change on agriculture, however, may be spatially heterogeneous (e.g., The World Bank, 2010; Zhao et al., 2017). An interesting issue in this context concerns whether global warming adds to the weather risk faced by agricultural households in moderate climates, where the likelihood of crop physiological stress from higher temperature is low–indeed modestly higher temperature might boost yields–especially in regions that have traditionally cultivated heat-resistant crops, like maize.[1] If, however, heat affects farmers' input use, there might exist indirect non-physiological pathways by which temperature increases associated with climate change will affect farmers. This paper tries to make progress on this issue by exploring a household-level panel of rural maize-growers in Kenya (Figure 1).

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 1). Such responses are significant since average daily temperatures in maize growing agro-ecological zones of Kenya range from 12-29C (Figure 2), and because maize yields only decline due to physiological stress above 29-30C (Lobell et al., 2011; Schlenker and Roberts, 2009). Large swaths of maize farms in Africa are in similar agro-ecological zones (Figure 3). Since these households are unlikely to experience physiological heat stress in maize itself, qualitative data suggests implications for agricultural livelihoods beyond the direct, physiological relationship between temperature and maize output, and illustrates the empirical questions that motivate this paper: might climate change affect smallholder farmer productivity via pathways other than crop physiology?

Qualitative data and significant ecological literature (e.g., Coakley, Scherm and Chakraborty, 1999; Garrett et al., 2006; Chakraborty, 2008; Patterson et al., 1999; Rosenzweig et al., 2001) suggest that higher temperatures increase the incidence of pests, weeds and crop diseases. Perhaps not coincidentally, we find that higher temperatures early in the growing season, in the pre-planting and initial vegetative growth stages, increase pesticide use. Moreover, we

[1]Heat-resistant or C4 crops have a greater ability for photosynthetic acclimation to heat stress than C3 crops, like rice, in which photosynthesis is inhibited even at moderately high temperatures. Other examples of C4 crops include sorghum, pearl millet, sugar cane, finger millet and pasture grasses.

show that higher temperatures early in the growing season reduce the uptake of fertilizer. Presumably this occurs due to binding financial constraints or changing risk profile of future harvest. High temperatures confront farmers with a trade-off, inducing them to divert spending from yield-increasing fertilizer to loss-reducing pesticides and weeding.[2]

Our analysis combines daily temperature data at the village-level with a household level panel survey of Kenya's maize growing regions. We find that a 10% increase in degree days over 21C during the initial vegetative growth stage increases pesticide use on the extensive margin by around 10 percent, and reduces uptake of fertilizer by approximately 2 percent, compared to the baseline. On the intensive margin, a 10% increase in degree days over 21C increases the intensity of pesticide use by 15 percent, while reducing quantity of fertilizer used by over 5 percent.

In this paper, we connect two distinct literatures. The first is an environmental and agricultural economics literature that examines the relationship between temperature and agriculture. We make three contributions to this literature. One, existing studies have almost exclusively focused on estimating the reduced form relationship between temperature and agricultural output or yield (e.g., Deschênes and Greenstone, 2007; Guiteras, 2008; Feng, Krueger and Oppenheimer, 2010; Welch et al., 2010). 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. The first effect is well established in environmental science (e.g., Lobell and Burke, 2008; Schlenker and Lobell, 2010; Lobell et al., 2011). We establish that high temperatures can also affect agricultural input use, both loss-reducing and productivity-enhancing.

Two, we document an ecological channel, beyond the physiological relationship between heat and crop growth. The dependence of plant diseases and pests on weather has been well-known amongst plant pathologists and entomologists (e.g., Coakley, Scherm and Chakraborty, 1999; Garrett et al., 2006; Chakraborty, 2008). In fact, 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). However, as far as we know, we are first to provide eco-

[2]Fungicides, herbicides and insecticides are all pesticides.

nomic evidence for such an ecological channel while examining the temperature-agriculture relationship.

Three, we estimate the impact of heat during each stage of the crop growth cycle separately, and highlight that farmers are extremely quick to adopt adaptation strategies in response to changing agro-ecology driven by higher temperatures. The existing literature has often *inferred* agricultural adaptation by using cross-sectional variation to compare outcomes in hot versus cold areas (e.g., Mendelsohn, Nordhaus and Shaw, 1994; Schlenker, Hanemann and Fisher, 2006), or by comparing estimates from annual temperature fluctuations for a given area under hotter versus cooler conditions (e.g., Deschênes and Greenstone, 2007; Deschênes and Greenstone, 2011 Schlenker and Roberts, 2009; Dell, Jones and Olken, 2012; Taraz, 2017), or by differentiating estimates from annual temperature fluctuations with long-run impacts of higher than normal temperatures (e.g., Burke and Emerick, 2016). Such approaches rely on aggregate data at the county- or district-year level, and fail to explicitly examine adaptive behavior. In this paper, using household-level data, and by disaggregating temperatures in the growing season by different stages of the crop growth cycle, we combine the intent of agroeconomic models with panel data analyses to observe adaptation strategies in the short-run. We demonstrate that farmers adjust purchased inputs after observing temperatures pre-planting or early in the growing season.[3]

The second literature to which we contribute is in development economics that studies the determinants of agricultural technology use.[4] This literature provides a number of explanations for low adoption of modern agricultural inputs: learning (e.g., Foster and Rosenzweig, 1995; Conley and Udry, 2010), insurance or credit constraints (e.g., Moser and Barrett, 2006; Dercon and Christiaensen, 2011; Cole et al., 2013), heterogeneity in returns (e.g., Marenya and Barrett, 2009; Suri, 2011) and behavioral anomalies (e.g., Duflo, Kremer and Robinson, 2011). Our findings suggest that increase in temperatures associated with global warming will also reduce adoption of productivity-enhancing technologies like fertil-

[3]Few papers have investigated how farmers adjust their inputs to adapt to higher temperatures. However, these studies either examined effects on irrigation (Kurukulasuriya and Mendelsohn, 2007; Kurukulasuriya, Kala and Mendelsohn, 2011; Oehninger, Lawell and Springborn, 2017; Seo and Mendelsohn, 2008*a*), or crop mix (Kurukulasuriya and Mendelsohn, 2008; Seo and Mendelsohn, 2008*b*). Furthermore, a small number of these use household or farm level data, but none of these papers disaggregate growing season temperatures by different stages of the crop growth cycle. Therefore, these studies only observe aggregate response to growing season, annual, or longer-run temperature.

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

izer, in favor of loss-reducing adaptive inputs like pesticides, presumably due to the financial constraints faced by poor farmers in developing countries.

2 Data

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

2.1 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 Project (TAMPA), a collaboration among Tegemeo Institute of Egerton University, Michigan State University, and the Kenya Agricultural Research Institute. Figure 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 'climate change', 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.

Figure 4 shows both uptake and intensity of pesticide use; 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. Figure 5 shows the average number of labor days spent in weeding activities. Figure 6 depicts fertilizer use 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.

Figure 7 shows average expenditure (cash or credit) on fertilizer, pesticides and hired labor for manual weeding, conditional on use, by adopters of each 'technology', respectively. The mean expenditure on pesticides and hired-labor for weeding by adopters is over 30% of the mean expenditure on fertilizer by fertilizer adopters.

Figure 8 shows average maize yields over time, while Figures 9 and 10 show the distribution of maize yields, pooled for all rounds, by technology. Ignoring possible selection bias, these suggest that maize yields are higher, and variance lower for fertilizer and pesticide users, indicating first order stochastic dominance of use of these modern purchased inputs. Table A.1 presents summary statistics for our balanced sample from 1997-2010. Finally, Tables 2 and 3 show household-level transitions of pesticide and fertilizer use in the data, with 30% (60%) of households switching in 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.

2.2 Kenyan Maize Calendar

To uncover the underlying mechanisms that influence farmer climate adaptation strategies, and 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 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.[5] This calendar gives the usual start and end dates of the planting period and harvest period for

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

each AEZ and for long and short rainy seasons. We use the calendar for long rainy season (main growing season). We define as the 'pre-planting' period the two months right before the start of the planting or basal fertilizer application during which land preparation occurs.[6] We define the four to six weeks right after the start of the planting period as the post-planting period; this is also 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 (from onset of planting to onset of top dressing fertilizer application), and 3) 'GS2': post-planting and top dressing fertilizer application period (after top dressing fertilizer to onset of harvest).

2.3 Weather Data

Because of 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).[7] The data are in 0.25 degree 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 in a year. Similarly, we generated daily precipitation data from the Climate Hazards Group InfraRed Precipitation Station (CHIRPS) data set of daily 0.05 degree resolution grided data for all of Africa.[8] Daily relative humidity data came from NASA.[9] 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

[6]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.

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

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

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

moisture with a spatial resolution of 0.25 degrees.[10]

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), which measures the intensity of daily exposure to temperatures above a lower bound 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.[11] We use daily average temperatures to calculate the number of days each village is exposed to temperatures above a lower bound and below an upper bound, and then sum these daily exposures for each of the three phases during the main growing season for those bounds.[12] Figure 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 4 present summary statistics for GDD above 21C in each 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.

3 Background

3.1 Temperature, Pests, Weeds and Pesticides

In the TAMPA survey, 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 such changes (Table 5). Furthermore, another almost 45% of survey respondents reported decline in yields, which is counterintuitive given that in these temperate AEZs, additional GDDs should increase not decrease maize yields physiologically. This suggests that some other mechanisms–such as disease, insects or weed pressure–was experienced, resulting in increased crop losses, that is, lower net yields. Unfortunately, our data do not

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

[11]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).

[12]We have a pre-determined upper bound, since average daily temperatures in the data are less than 30C.

contain information on incidence of specific crop diseases or pests. But the ecological literature broadly concurs that climate change will increase disease, pest and weed pressure. We look to existing studies that examine plant pathology and crop management to better understand the effects of heat stress on diseases and pests specific to maize.

Grey leaf spot is a major maize disease in Kenya. It was first reported in Kenya during 1995. Small-scale farmers have continued to experience considerable yield losses from grey leaf spot in Kenya (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). Moreover, 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 from the historical range in our sites should increase gray leaf spot incidence and induce early season adaptive responses by farmers.

Insect behavior, distribution, development and survival are strongly coupled with environmental conditions, especially temperature, since insects do not use their metabolism, but rather depend on ambient temperature to control their body 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 control during the first eight weeks after planting is crucial because weeds compete vigorously with the maize crop for nutrients and water during this period (du Plessiss, 2003). So weeding continues beyond the period of fertilizer top dressing. Specifically, maize fields should 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). Herbicides can be used before planting and during the growing season (Gianessi, 2010). 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 regions previously inhospitable (Bloomfield et al., 2006; Hanzlik and Gerowitt, 2012; Walck et al., 2011). 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. That would continue later in the season through disease and pest reduction efforts. These predictions from the agro-ecological literature mirror what we find in the data.

3.2 Fertilizer Use Under Liquidity Constraints

Almost 60% of all non-adopters of fertilizer pointed to financial liquidity constraints as the reason for non-adoption, while a little less than 40% claimed they didn't need to use fertilizer, which could reflect either highly fertile or poor, non-responsive soils (Table 6). Higher than normal temperatures increase the prevalence of pests and diseases, plausibly forcing farmers to divert resources from productivity-enhancing technologies like fertilizer, towards expenditure on adaptive loss-reducing inputs like pesticides (e.g., herbicides, insecticides, fungicides) or labor for manual weeding. Such effects on fertilizer uptake might be driven by ex ante credit constraints faced by poor farmers, or alternatively, farmers might anticipate increased risk of crop losses due to an increase in pest pressure, and opt for less risky technologies to avoid lasting damage. For instance, Binswanger and Rosenzweig (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. Marenya and Barrett (2007) find that enhanced financial liquidity due to non-farm employment boosts fertilizer uptake among Kenyan maize farmers.

Farmers usually apply fertilizer twice on maize. Basal fertilizer applications occur at planting. Top dressing fertilizer seldom occurs without basal fertilizer application. But if fertilizer is used at planting, top dressing often occurs post-germination. In high rainfall areas, topdressing fertilizer is applied in two splits. The first split is done 6 weeks after planting and the second split is done 10-15 days later or just before tasseling. In low rainfall areas fertilizer is applied only once, typically six or so weeks after planting (NAFIS, 2011).

Thus, higher than normal temperatures in moderate climates might be expected to increase use of pesticides and weeding labor, and reduce fertilizer use. Existing evidence indicates that farmers in Africa make their decisions sequentially, adapting to new information as it emerges (Dillon, 2014; Fafchamps, 1993). Duflo, Kremer and Robinson (2011) find that in Western Kenya, 96-98% of farmers who used fertilizer had bought it just before applying it. Moreover, fertilizer and pesticide adoption rates are quite high amongst maize farmers in Kenya, suggesting that agricultural input markets are relatively well-developed compared to other countries in Sub-Saharan Africa (Sheahan and Barrett, 2017). Thus, it is likely that the effects of increased temperatures on input decisions will be driven by changes during the pre-planting or early vegetative growth phase, only extending deeper into the growing season for manual weeding as farmers can adjust labor inputs later in the season.

4 Temperature and Agricultural Input Use Response

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, as just explained. In this section, we show that higher than normal temperatures indeed affect adoption of agricultural inputs in ways consistent with the just described ecological channel. We subsequently rule out alternative mechanisms.

4.1 Research Design

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

$$Y_{ijdqt} = \beta_1(30C > GDD_{PP} > 21C)_{jdqt} + \beta_2(30C > GDD_{GS1} > 21C)_{jdqt} + \beta_3(30C > GDD_{GS2} > 21C)_{jdqt} + f(Rain_{jdqt}) + \alpha_j + \mu_{qt} + \epsilon_{ijdqt} \quad (1)$$

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/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. $(30C > GDD > 21C)_{jdqt}$ is the sum of degree days over 21C and below 30C during each stage of the main growing season in Kenya.[13] [14] 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 household 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.

[13] 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.

[14] We have a pre-determined upper bound of 30C, since didn't observe a single day with an average temperature over 30C in the data.

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 pesticide use by over 0.6 percentage points (Table 7: Column 1). In 2003, almost 30% of maize-farmers in TAMPA adopted pesticides. Thus our point estimates imply that an extra 3 DDs in GS1 leads to an approximately 6 percent increase in pesticide use. Similarly, on the intensive margin, an increase in 3 DDs in GS1 leads to a 15 percent increase in quantity of pesticide used. Note that since pesticide application typically occurs 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.

If greater heat increases the incidence of weeds, we should also observe an increase in manual weeding. Indeed, we find that an extra degree day in the post-planting period (PP) is associated with a 1% increase in weeding labor (Table 7: Column 5). Since the most intense crop-weed competition typically occurs after top dressing, these results are precisely what one would expect.

Combined with the qualitative evidence presented in Table 5, these results strongly suggest an ecological mechanism beyond physiological heat stress, which should not be an issue in these data (which we confirm below). 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 is likely unproductive. Effects on weeding labor is pronounced deeper into the growing season as the ability to reverse the adverse effects of weed competition persists longer as well. Household or hired 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 fertilizer. Descriptive data indicate that pesticide adopters spend on pesticides the equivalent of 10-20% of the total amount spent on fertilizer by fertilizer adopters. Households hiring labor for manual weeding spend on hired labor around 25-45% of the total amount spent on fertilizer by fertilizer adopters (Figure 7). Thus, if credit constraints bind for farmers, expenditure on loss-reducing adaptive inputs may necessitate reduced fertilizer use. Alternatively, increased ex ante maize yield risk due to an increase in the prevalence of pests and weeds could also adversely affect fertilizer uptake.

We indeed find that an extra 3 DD above 21C in the initial planting or basal fertilizer application period (GS1) decreases fertilizer use by 0.6 percentage point (Table 7: Column 3). These effects coincide temporally with the pesticide effects observed, entirely consistent with a liquidity constraint mechanism, moreso than a risk response. Almost 65% of households in our balanced panel applied fertilizer in 1997, so a 0.6 percentage point decrease translates into a 1 percent decrease from adoption levels in Round 1. Similarly, an extra 3 DD over 21C in GS1 reduce fertilizer use by around 6 percent on the intensive margin. These effects are driven by early growing season temperatures, by which time financial constraints typically begin to bind. Higher temperatures before planting or late in the growing season, after fertilizer top dressing is usually finished, do not have a significant impact on fertilizer use. The associated point estimates are of both low magnitude and low confidence.

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.[15] After removing village and province-by-round fixed effects, remaining temperature variation pertains only to within-province-round deviations from village means, as for example, the amount by which

[15]Including household fixed effects doesn't affect our estimates since the treatment (temperature) is at the village level (Table A.2).

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 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.3. 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', although the point estimate remains relatively unchanged (Table A.4). In fact, our point estimates for fertilizer use increase for all three periods, although the effects are still largest for GS2. Lastly, for 'Log Weeding Days', we observe a substantial decrease in the GS2 DD point estimate, and a corresponding increase in GS1 DD point estimate. We have low confidence in our GS2 point estimates for fertilizer as well as weeding labor because there isn't sufficient variation in GS2 DD after removing district-by-round fixed effects. The "Removed Province*Round Effects" ("Removed District*Round Effects") degree days column indicates that 13% (6%) and 4% (3%) of households by round observations had deviations larger than 5 and 10 degree days in the post-planting period, respectively.

A sizable proportion of households, across rounds, did not use fertilizer, pesticides, or use weeding labor. Thus, limited 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 (as long as N>T) (Hsiao, 1986). Thus, for consistent estimation, first, we provide regression estimates using Honoré semi-parametric fixed effect tobit estimator (Honoré, 1992).[16] 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 log-level regression estimates for weeding labor as well. Table A.6 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 A.5. Qualitative conclusions drawn from our main results presented in Table 7 remain unchanged.

In Table A.7, we cluster standard errors at the level of district-round. Our main results allow for heteroskedasticity and autocorrelation of households within each village and across rounds, but assume that households are identically distributed across villages. Here, we allow for spatial correlation of villages (households) within a district in a round. The core story line remains, although the significance of the estimated effects on fertilizer use weakens appreciably. Lastly, in Table A.8 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). The estimation results are consistent with predictions from the agronomic literature and with farmers qualitative comments, and stand up to various robustness tests.

4.2.4 Hetereogenous Effects - by Wealth

Disentangling the effects of credit constraints and ex ante risk falls outside the scope of this paper. However, apart from the qualitative evidence presented earlier, we provide suggestive empirical evidence for a broader wealth channel driven by the relationship between rising temperatures and the 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. We show suggestive evidence that household wealth differences may confer different abilities to accommodate ex

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

ante risk or to absorb income shocks that are differentially influenced by an increase in pest and disease pressure arising due to higher temperatures.

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.9, A.10 and A.11).[17]

These results suggest that not only do wealthier farmers adapt more than their poorer neighbors to an increase in incidence of pests, weeds and diseases, through increased pesticide use, they also seem to reduce their expenditure on fertilizer less in face of higher temperatures. These associations suggest that higher than normal temperatures may lead to regressive distributional yield effects within communities in these moderate agro-ecological zones. Limited liquidity constrains uptake of loss-reducing inputs and aggravates the reduction in fertilizer application as temperature increases.

4.2.5 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 three alternative explanations: (1) the direct impact of temperature on agricultural yields, (2) influence of humidity on the incidence of pests and crop disease, and (3) higher than normal temperatures can affect soil moisture, in turn reducing fertilizer uptake.

[17]In Tables A.12, A.13 and A.14, we use baseline (Round 1) land ownership as a proxy for wealth for all rounds. The point estimates remain largely unchanged.

Temperature and Maize Yields: Temperature could affect agricultural input use by directly affecting agricultural production: heat stress during the growing season in the previous year could reduce agricultural yields through physiological mechanisms, affecting input use in the current growing season. In fact, 45% of maize-growers in our sample said that changes in temperature reduced crop yields (Table 5). However, it is likely that these answers indicate an indirect relationship between temperature and yields due to the aforementioned ecological channel rather than direct heat stress on maize plants.

We expect the link from higher temperatures to reduced maize yields is indirect for two reasons. First, optimum maize growth occurs at temperatures of 24-30C (Pingali, 2001). Schlenker and Roberts (2009) find that maize yields in the United States increase with temperature up to 29C. Average daily temperatures for villages in our sample are well below 30C, in fact, the 99th percentile of the distribution of *maximum* daily temperatures for villages in our sample is 32C (Figure 12).

Second, we directly examine the relationship between growing degree days over 21C and agricultural yields amongst maize farmers in the data. We observe 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 a possible direct effect of higher temperatures on maize yields. We find no statistically significant relationship between GDDs and maize yields when we control for key inputs, use of which responds to temperature change (Table A.15). Indeed, the point estimate is positive, consistent with a positive physiological effect of temperature on maize growth in this region, given its relatively moderate temperatures, offset by greater pest and weed pressures to which farmers respond adaptively, as we have already established, and reduced fertilizer inputs.[18]

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

[18]By employing a sinusoidal interpolation between the daily minimum and maximum temperature (Snyder, 1985), we follow Roberts, Schlenker and Eyer (2013), and also generate growing degree days accounting for within-day temperature variations, not just the daily mean temperature, and estimate the effects on maize yields. Again, we fail to find evidence for a negative effect of temperature on yields (Table A.16).

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.17, 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.17, Columns 4-5).[19]

5 Conclusion

The use of modern agricultural technologies is key to agricultural productivity growth, and a pathway out of poverty for agrarian households in poor economies. The dramatic growth in agricultural yields in Asia, the stagnation of yields in Africa, and subsequent effects on economic growth, may be partly explained by increased use of modern agricultural inputs in Asia and continued low use in Africa (e.g., McArthur and McCord, 2017; Morris et al., 2007; Sánchez, 2010).

In this paper, we find that higher than normal temperatures can affect agriculture even in regions where temperatures are not high enough to directly, adversely affect crop growth through physiological heat stress. Agricultural input decisions are sensitive to higher temperatures even in moderate climates due to an ecological relationship between temperature and the prevalence of pests, weeds and crop diseases. As far as we are aware, this is the first economic study to provide evidence for such indirect effects of temperature on agriculture, apparently due to a ecological mechanism underlying the relationship between climate and agriculture.

Moreover, because different crops and different stages in the agricultural cycle are affected by temperature in different ways, the underlying mechanisms of impact as well as

[19] 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.

the suitable adaptive responses, may differ too. This matters because farmers make their decisions sequentially, adapting to new information as it emerges. By separately estimating the impact of temperatures during each stage of the agricultural cycle, we are not only able to identify an ecological mechanism, but also demonstrate that farmers promptly adapt to temperature variation in the short-run.

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Tables and Figures

Figures

Figure 1: Location of Sample Villages

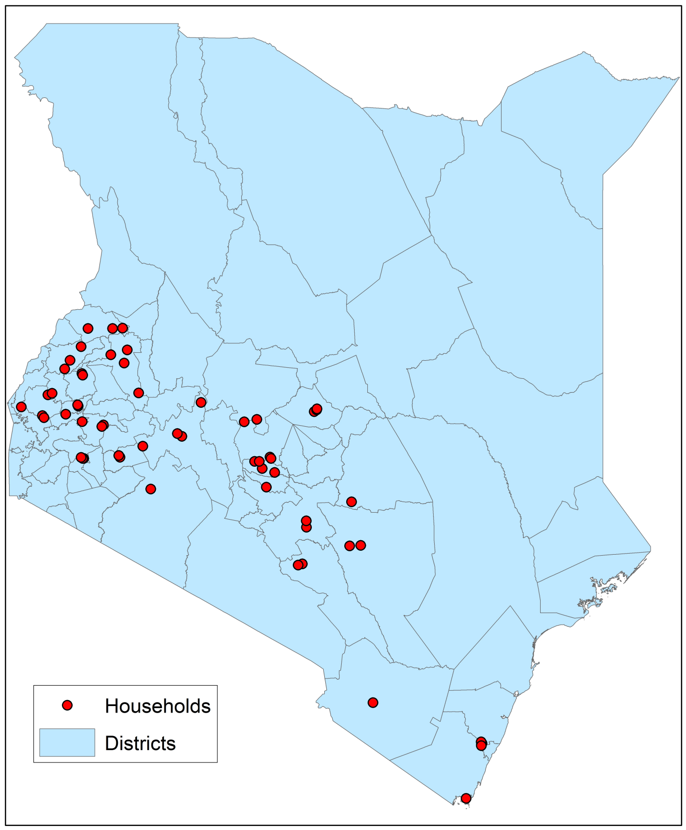
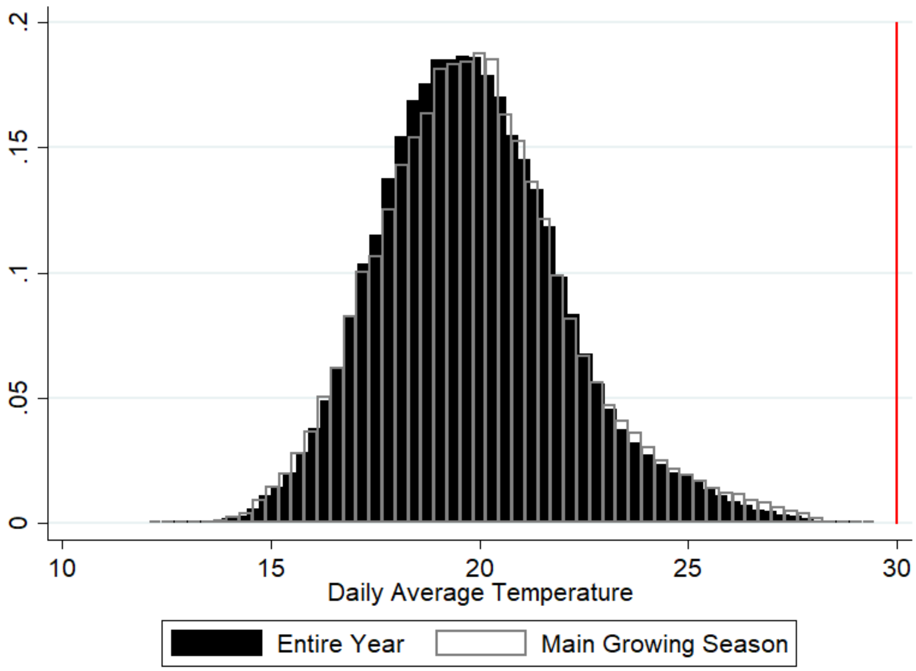
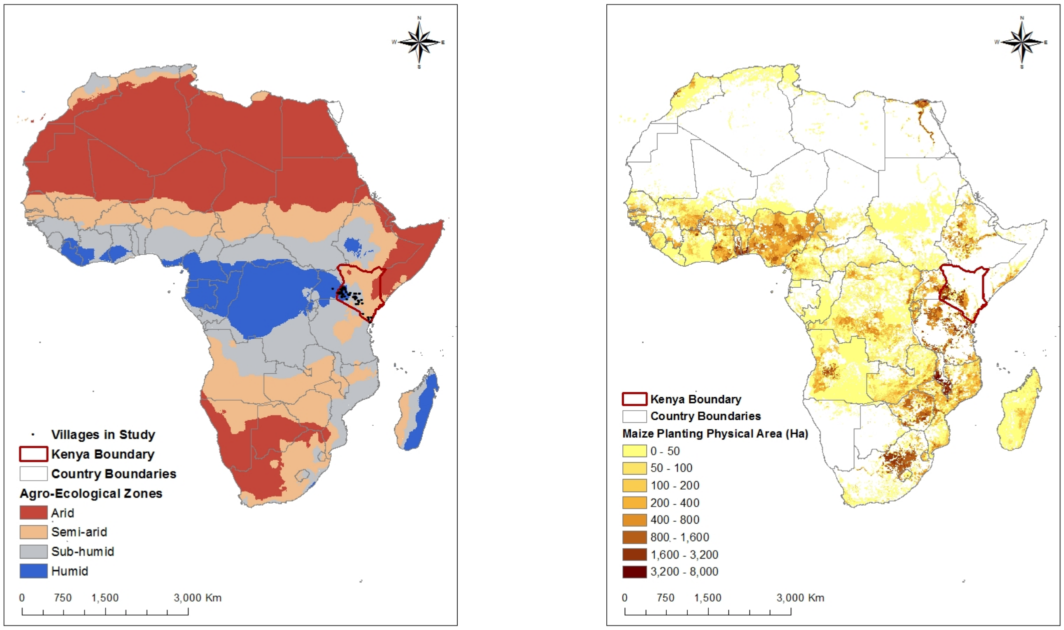


Figure 2: Daily Average Temperature in TAMPA Sample (1990-2012)



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 3: 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.

Figure 4: Household Pesticide Use

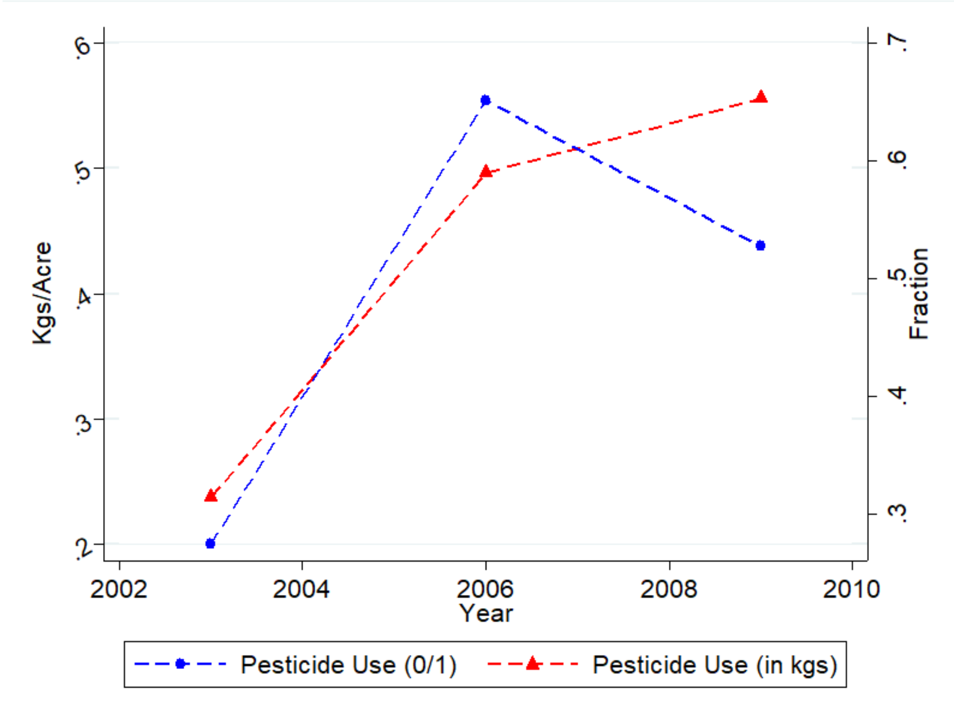


Figure 5: Household Weeding Labor

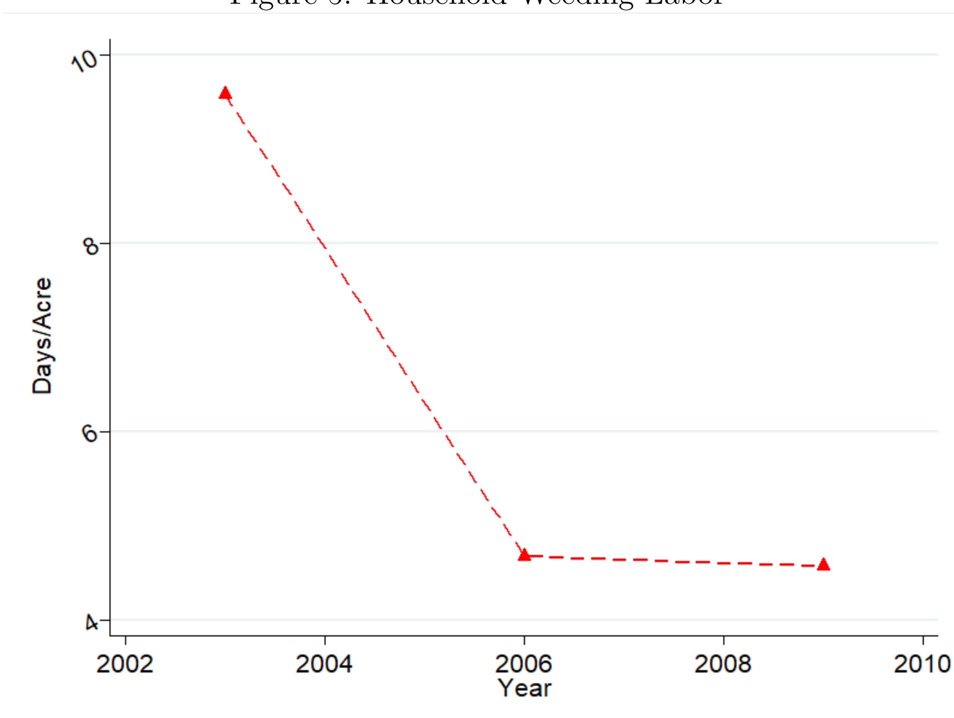


Figure 6: Household Fertilizer Use

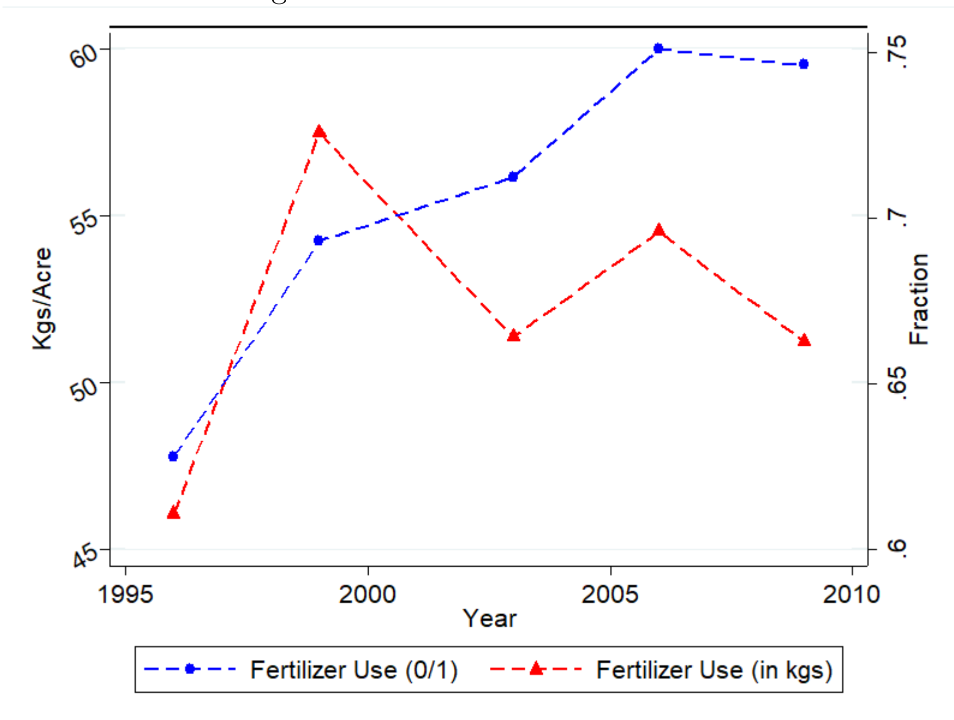


Figure 7: Amount Spent on Fertilizer, Pest Repellents and Hired Labor for Weeding by Adopters

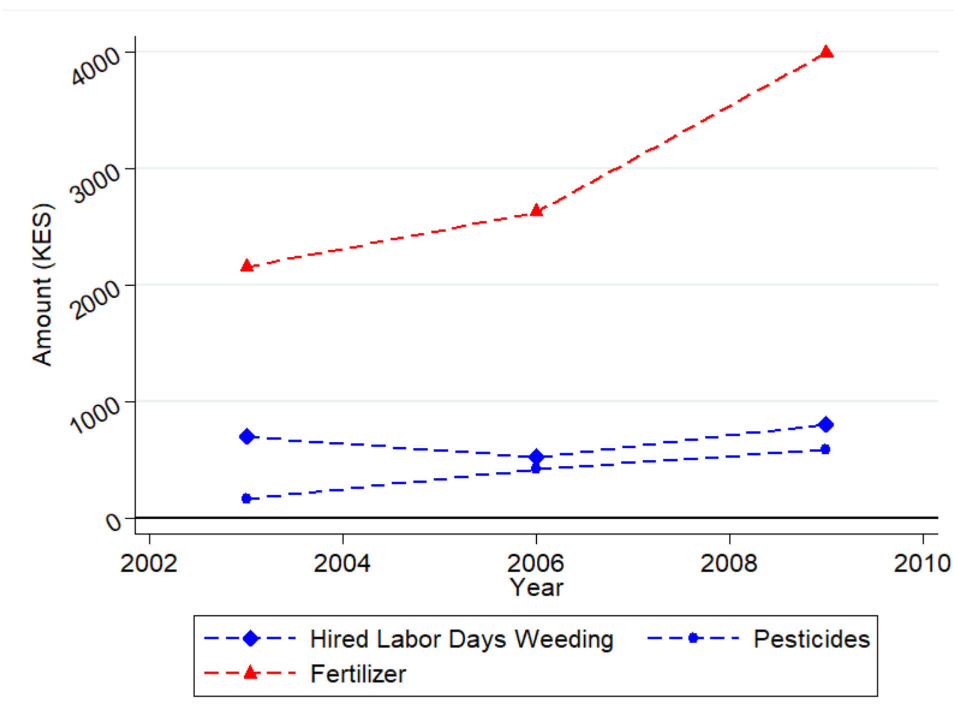


Figure 8: Mean Maize Yield (in Kgs/Acre)

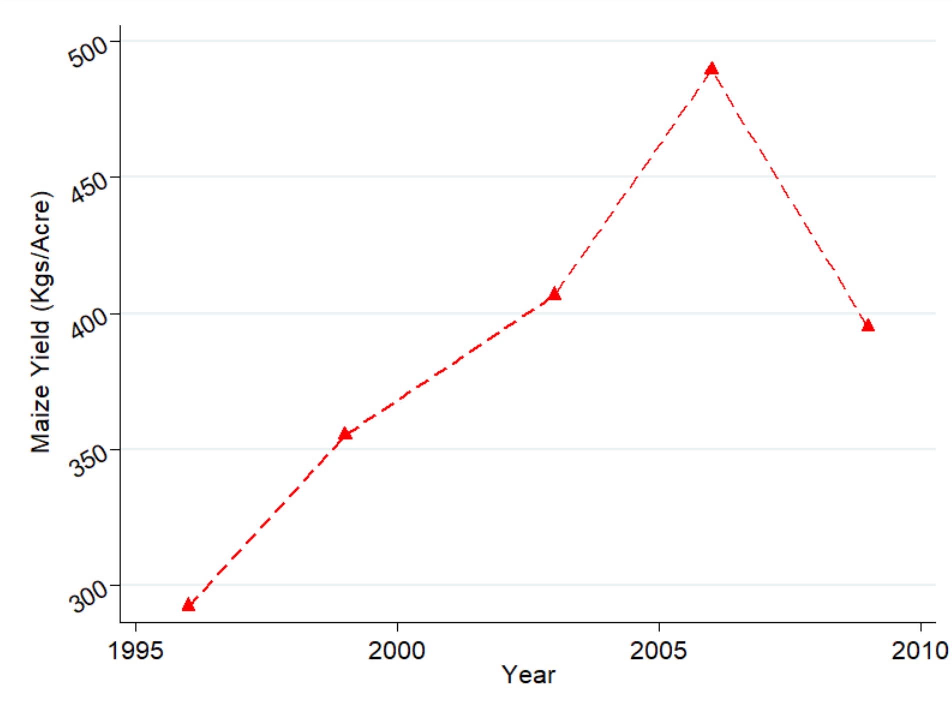


Figure 9: Distribution of Yields by Pesticide Use

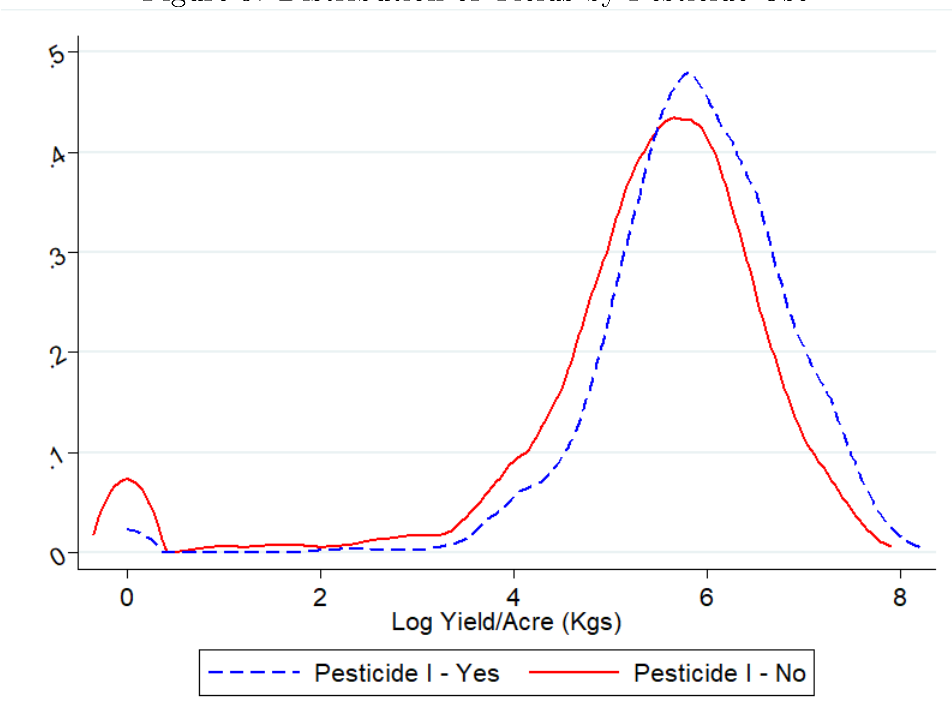


Figure 10: Distribution of Yields by Fertilizer Use

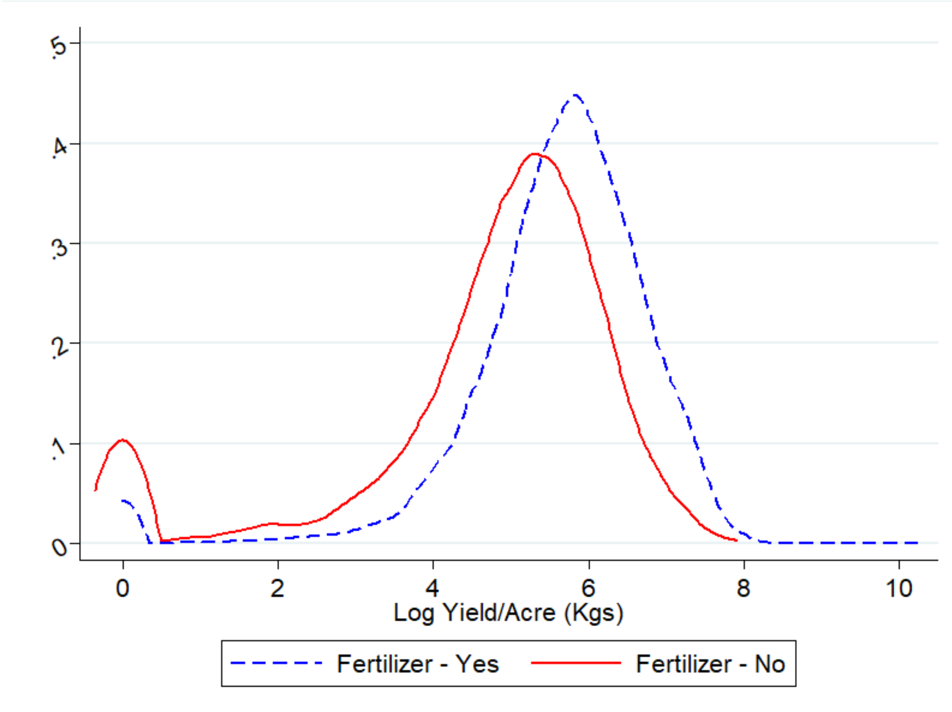
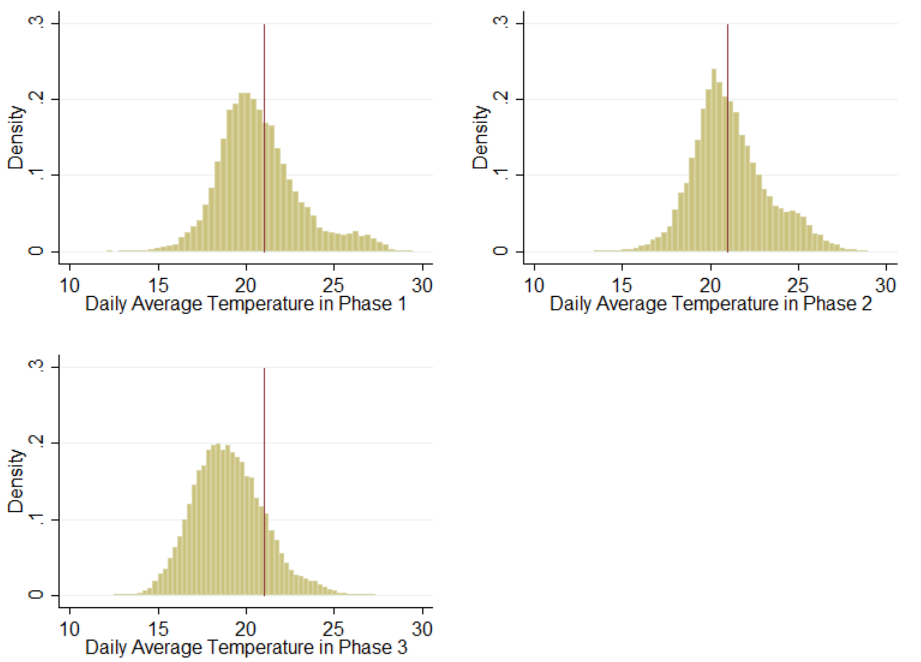
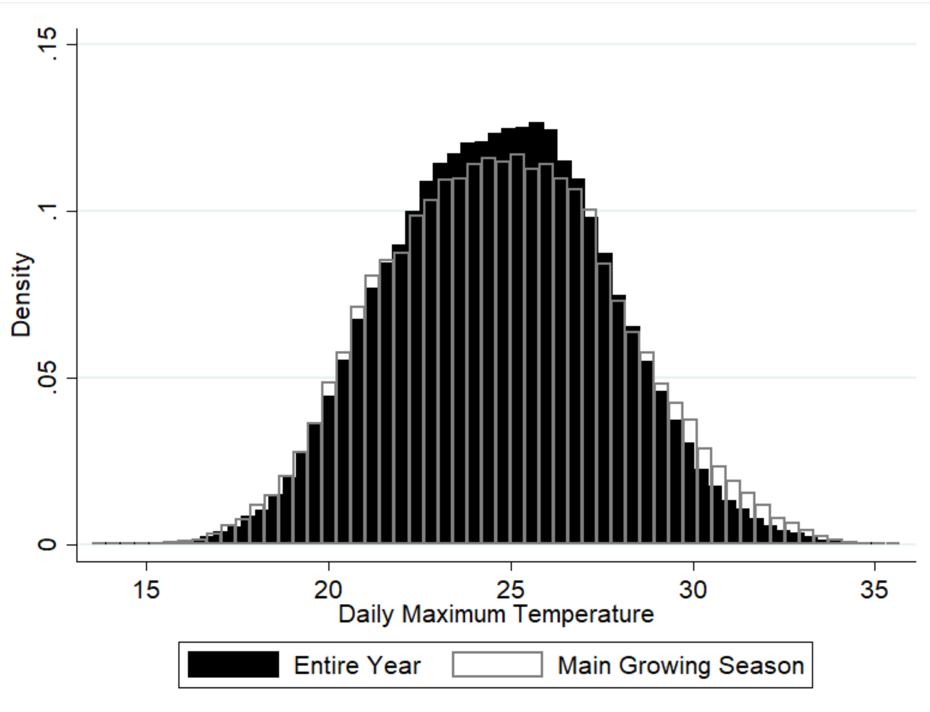


Figure 11: Daily Average Temperature by Phases in the Agricultural Cycle (1990-2012)



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)

Figure 12: Daily Maximum Temperature in TAMPA Sample (1990-2013)



Tables

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

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

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

Table 5: 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 6: 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 7: Temperature, Fertilizer and Pesticide Use

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

Notes: 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%.

A Appendix

Table A.1: Summary Statistics

	1997	2000	2004	2007	2010
Pesticides			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)
Pesticide Exp/Acre(KES)			46.79	274.87	312.50
			(199.58)	(617.82)	(894.09)
Hired Weeding Exp/Acre(KES)			340.23	236.16	397.80
			(638.27)	(418.45)	(705.59)
Fertilizer	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)
Fertilizer Exp/Acre(KES)	0.00	0.00	1540.48	1989.29	3019.45
	(0.00)	(0.00)	(1926.76)	(2168.13)	(3442.11)
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: Household FE: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Ln Weeding Days/Acre β / SE
CY PP DD >21C	0.0019	0.0084	-0.0003	-0.0054	0.0017
	(0.0017)	(0.0109)	(0.0006)	(0.0062)	(0.0025)
CY GS1 DD >21C	0.0063**	0.0450**	-0.0018*	-0.0180*	-0.0004
	(0.0031)	(0.0192)	(0.0009)	(0.0096)	(0.0058)
CY GS2 DD >21C	-0.0004	-0.0108	0.0003	0.0005	0.0084**
	(0.0018)	(0.0095)	(0.0005)	(0.0049)	(0.0038)
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	0.498

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.3: 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.4: District*Year FE: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Ln Weeding Days/Acre β / SE
CY PP DD >21C	0.0009	0.0063	-0.0016**	-0.0194**	0.0019
	(0.0015)	(0.0088)	(0.0008)	(0.0082)	(0.0030)
CY GS1 DD >21C	0.0051	0.0480**	-0.0031**	-0.0323**	0.0108
	(0.0038)	(0.0229)	(0.0014)	(0.0136)	(0.0085)
CY GS2 DD >21C	0.0013	0.0037	-0.0011**	-0.0148***	-0.0006
	(0.0016)	(0.0096)	(0.0005)	(0.0055)	(0.0041)
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	0.189

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.5: Standard Tobit Estimates: Temperature, Fertilizer and Pesticide Use

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE	(3) Ln Weeding Days/Acre β / SE
CY PP DD >21C	0.0349*	-0.0038	0.0011
	(0.0183)	(0.0074)	(0.0021)
CY GS1 DD >21C	0.1081***	-0.0317**	-0.0032
	(0.0365)	(0.0129)	(0.0055)
CY GS2 DD >21C	-0.0064	0.0001	0.0079***
	(0.0190)	(0.0054)	(0.0031)
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 clustered by village for columns 1-2. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.6: Honoré Fixed Effects Tobit: Temperature, Fertilizer and Pesticide Use

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE	(3) Ln Weeding Days/Acre β / SE
CY PP DD >21C	0.0259*	-0.0041	0.0007
	(0.0144)	(0.0075)	(0.0027)
CY GS1 DD >21C	0.0899***	-0.0375***	-0.0012
	(0.0265)	(0.0140)	(0.0064)
CY GS2 DD >21C	-0.0054	0.0014	0.0108***
	(0.0126)	(0.0058)	(0.0040)
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. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.7: Clustering Standard Errors by District-Round: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Ln Weeding Days/Acre β / SE
CY PP DD >21C	0.0019	0.0084	-0.0003	-0.0054	0.0017
	(0.0015)	(0.0094)	(0.0005)	(0.0059)	(0.0015)
CY GS1 DD >21C	0.0063**	0.0450**	-0.0018	-0.0180*	-0.0004
	(0.0029)	(0.0182)	(0.0011)	(0.0104)	(0.0040)
CY GS2 DD >21C	-0.0004	-0.0108	0.0003	0.0005	0.0084**
	(0.0025)	(0.0156)	(0.0008)	(0.0078)	(0.0033)
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	0.336	0.354	0.594	0.656	0.177

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 in parentheses, clustered by district-round. *Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.8: Alternative GDD Lower Bounds: Temperature, Fertilizer and Pesticide Use

	(1) Pesticides β / SE	(2) Pesticides β / SE	(3) Pesticides β / SE	(4) Fertilizer β / SE	(5) Fertilizer β / SE	(6) Fertilizer 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.9: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1-5)

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer β / SE	(4) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0026	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.10: 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.11: 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.12: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1)

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Fertilizer β / SE	(4) Ln Fertilizer/Acre β / SE
CY PP DD >21C	0.0025	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.13: 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.14: 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.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	0.0038
	(0.0041)	(0.0035)
CY GS1 DD >21C	-0.0027	0.0093
	(0.0066)	(0.0068)
CY GS2 DD >21C	0.0029	-0.0048
	(0.0028)	(0.0039)
Ln Pesticide/Acre		0.0507***
		(0.0091)
Ln Fertilizer/Acre		0.0309***
		(0.0088)
Ln Weeding Days/Acre		0.1067***
		(0.0169)
Village FE	Yes	Yes
Prov-by-Year FE	Yes	Yes
Rainfall Controls	Yes	Yes
Observations	6210	3726
R^2	0.374	0.406

Notes: 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: Accounting for Within-Day Temperature Variation: 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	0.0021	0.0047
	(0.0043)	(0.0037)
CY GS1 DD >21C	-0.0083**	-0.0028
	(0.0033)	(0.0036)
CY GS2 DD >21C	0.0002	-0.0036
	(0.0029)	(0.0029)
Ln Pesticide/Acre		0.0521***
		(0.0090)
Ln Fertilizer/Acre		0.0306***
		(0.0088)
Ln Weeding Days/Acre		0.1056***
		(0.0170)
Village FE	Yes	Yes
Prov-by-Year FE	Yes	Yes
Rainfall Controls	Yes	Yes
Observations	6210	3726
R^2	0.375	0.407

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 growing degree days over 21C and 0-29C and over 29C) 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.17: Controls for Daily Humidity: Temperature, Pesticides and Weeding Labor Days

	(1) Pesticides β / SE	(2) Ln Pesticide/Acre β / SE	(3) Ln Weeding Days/Acre β / SE
CY PP DD >21C	0.0023	0.0093	0.0004
	(0.0014)	(0.0090)	(0.0024)
CY GS1 DD >21C	0.0068**	0.0470***	-0.0029
	(0.0027)	(0.0165)	(0.0049)
CY GS2 DD >21C	0.0001	-0.0085	0.0063*
	(0.0018)	(0.0097)	(0.0035)
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	0.179

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.18: Controls for Soil Moisture: Temperature and Fertilizer Use

	(1) Fertilizer β / SE	(2) Fertilizer 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%.