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

Maulik Jagnani, Christopher B. Barrett, Yanyan Liu and Liangzhi You*

This version: May 5, 2019

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 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.

*Jagnani: Charles H. Dyson School of Applied Economics and Management, Cornell University (email: mvj22@cornell.edu); Barrett: Charles H. Dyson School of Applied Economics and Management, Cornell University (email: cbb2@cornell.edu); Liu: Professor, National School of Agricultural Institution and Development, South China Agricultural University and Senior Research Fellow, International Food Policy Research Institute (email: y.liu@cgiar.org); You: Visiting Professor, College of Economics and Management, Huazhong Agricultural University and Senior Research Fellow, International Food Policy Research Institute (email: l.you@cgiar.org). Tim Johnson and Yating Ru provided excellent research assistance. We thank Nicholas Flores, Eyal Frank, Teevrat Garg, Cynthia Lin Lawell, Ariel Ortiz-Bobea, Jeff Michler, Rebecca J. Nelson, Kibrom Tafere, Vis Taraz, and Chris Udry for helpful comments. We are grateful for feedback from seminar participants at the African Development Bank, IFPRI and Cornell University, as well as conference participants at the 2018 IPWSD – Columbia University, 2018 CSAE Annual Conference, 2017 CU Boulder – Environmental and Resource Economics Workshop, and the 2017 AERE Annual Meetings. Funding support came from the African Development Bank through the Structural Transformation of African Agriculture and Rural Spaces (STAARS) project generously supported by government of the Republic of Korea through the Korea-Africa Economic Cooperation Trust Fund and the CGIAR Research Program on Policies, Institutions, and Markets (PIM) led by the International Food Policy Research Institute (IFPRI). All errors are our own. An earlier version of this paper was circulated as "In the Weeds: Effects of Temperature on Agricultural Input Decisions in Moderate Climates".

1 Introduction

With short-run weather risk – e.g., due to extreme events like heat waves – widely projected to grow in the years ahead due to climate change, it is crucial to know how well and quickly farmers in low-income countries adjust to exogenous shocks to production. This question has interested development and agricultural economists for decades, at least since Schultz (1964), Antle (1983) and Fafchamps (1993). More recently, environmental economists have begun to explore this issue, recognizing that agricultural damages induced by global warming may be especially problematic for farmers in low-income countries who rely on traditional methods for weather forecasting and may be unable to detect a change in temperature or to respond promptly even to changes they notice, for example due to binding financial liquidity constraints. But if farmers indeed detect and quickly adjust to warming temperatures on their own, the resulting damages could be contained. Therefore, understanding how and how fast farmers adapt to temperature shocks can usefully inform allocation of scarce public resources to build resilience and avoid permanent damage.

In this paper we use household-level panel data from maize farmers in Kenya, and temperature data disaggregated across different stages of the crop growth cycle, to investigate if and how farmers adjust agricultural inputs in response to within-season temperature variation. Exploiting plausibly exogenous variation in temperature at the village level after absorbing fixed village level attributes (i.e., controlling for village fixed effects) as well as time varying province level characteristics (province-by-year fixed effects), we show that Kenyan farmers respond promptly to temperature variation. More specifically, they increase pesticide use in response to heat-induced increased biotic stress from diseases and pests that are most effectively addressed soon after emergence, early in the season. And farmers increase weeding effort 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, or binding financial liquidity constraints inducing trade-offs among input expenditures, or both. Farmers expressly identify warmer temperatures as a threat to maize productivity due to greater incidence of pests, weeds and crop diseases. And they undertake defensive investments quickly in response to short-run temperature shocks.

More precisely, we find that 10 extra growing degree days (GDD) over 8C 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 day increase in GDD increases pesticide application rates per acre by roughly 20%, while reducing fertilizer application rates by over 10%. And 10 extra GDD during the pre-planting phase increases weeding labor by 0.2 days. Because most farmers report financial liquidity constraints limit their purchase of inputs, temperature shocks may confront farmers with a trade-off between defensive investments in pesticides and weeding labor, versus yield-increasing fertilizers. Farmers' responsiveness to short-run temperature shocks also appears positively associated with wealth, as reflected in land holdings.[1] 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 constraints.

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 through higher temperatures accelerative effect on photosynthesis. Average daily temperatures in the villages we study range from 12-29C (Figure 1), a range over which maize yields typically increase with warming temperatures. In fact, the 99th percentile of the distribution of daily *maximum* temperatures for villages in our sample is 32C (Figure 2). Maize only declines physiologically due to heat stress above 29-30C (Lobell et al., 2011; Schlenker and Roberts, 2009). Large swaths of maize farms in Africa fall in similar agro-ecological zones (Figure 3). Because these Kenyan households' maize crops are unlikely to experience direct, abiotic heat stress from the modest warming observed in the data – and anticipated in coming years – any adverse effects on agriculture, and consequent margins of adjustment, almost surely result from indirect, biotic stresses arising from the temperature response of pests and pathogens.

In investigating if maize farmers in Kenya adapt in the short run to within-season tem-

[1] This result is consistent with numerous papers that show that financial constraints faced by farmers in low-income countries inhibit the adoption of modern agricultural inputs (e.g., Cole et al., 2013; Dercon and Christiaensen, 2011; Moser and Barrett, 2006; Rosenzweig and Binswanger, 1993).

perature variation, we contribute to two related literatures. First, a longstanding literature shows that farmers in low-income countries can and do adjust production decisions quickly, adapting to new information as it emerges (Antle, 1983; Fafchamps, 1993; Schultz, 1964). This paper appears to be the first since Fafchamps (1993) to empirically investigate if farmers promptly adjust their input allocation in response to exogenous shocks to production. However, while Fafchamps (1993) evaluates farmer response to initial rainfall in Burkina Faso, we examine how and how fast do Kenyan farmers adjust their inputs in response to warmer temperatures during the growing season.

Second, this paper also contributes to a large environmental economics literature on agricultural adaptation to climate change. Within this literature, few studies examine how farmers adjust to higher than normal temperatures in developing countries (e.g., Kurukulasuriya and Mendelsohn, 2007, 2008; Kurukulasuriya, Kala and Mendelsohn, 2011; Seo and Mendelsohn, 2008).[2] These papers typically rely on cross-sectional variation to compare longer-run outcomes such as irrigation and crop choice in hot versus cold areas. While the cross-sectional approach approximates the ideal climate change experiment, omitted variables concerns in this approach mean that the average climate could be correlated with other fixed, unobserved factors. In this paper, we exploit plausibly exogenous short-run variation in weather to examine within-season adjustments in agricultural inputs. If farmers promptly adapt input applications within season in response to warmer temperature that differentially affect crop growth across different stages in the agricultural cycle – both directly through plant physiological effects of temperature and indirectly through temperature-induced changes in the supporting agro-ecology – then any analyses based on seasonal or annual temperature variation may miss important behavioral responses in the short-run. Moreover, if farmers can adjust in the short run, it is more plausible that they will also be able to adjust in the long run using methods unavailable to them in the short run.[3] Lastly, this literature has also overlooked farmer defensive investments arising not due to heat stress but rather due to biotic stresses arising from broader agroecological response to warmer weather. To

[2] A number of papers have examined the extent of adaptation rather than how farmers adjust to warming 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). However, among these only Taraz (2017) examines agricultural adaptation in a developing country, India.

[3] For example, Samuelson (1947) famously argues that the Le Chatelier principle implies that demand and supply elasticities are lower in the short run than in the long run because of the quasi-fixed-cost constraint that binds only in the short run.

our knowledge, this is the first economics study to isolate this mechanism behind farmer adaptation to temperature.

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, Section 5 offers 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).

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). Lepidopteran stem borers such as the indigenous noctuids Busseola fusca (Fuller) and Sesamia calamistis (Hampson) and the exotic crambid Chilo partellus (Swinhoe) attack the maize crop in East Africa: larval survival rates across these stem borer species is highest at 20C.[4] On the other hand, growth rates for Busseola fusca (Fuller), Sesamia calamistis (Hampson), and Chilo partellus (Swinhoe) are highest at 30C, 25C, and 20C, respectively, and lowest at 15C (Ntiri et al., 2016). 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*a*). 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

[4]Busseola fusca (Fuller) has higher survival rates at 30C than at 25C. Sesamia calamistis (Hampson) and Chilo partellus (Swinhoe) have higher survival rate at 25C than at 30C (Ntiri et al., 2016).

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 (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 Liquidity Constraints and Risk

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 and reduce the capital they put at risk through fertilizer purchases. These two effects are not mutually exclusive and 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.

Typically, maize farmers apply fertilizer twice. Basal fertilizer applications occur at planting. Top dressing fertilizer application occurs after plant emerges but seldom 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; Fafchamps, 1993),[5] 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

[5]Dillon (2016) shows that within-season measures of the subjective probability distributions that farmers hold dictate the effectiveness of policies intended to support agrarian households.

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.[6] 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, and 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 dropping off somewhat 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 season on farmer defensive investments in preventing crop loss due to biotic stresses and any

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

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 sub-agro-ecological zone (AEZ) in Kenya, obtained from the Food and Agriculture Organization (FAO) of the United Nations, and broken into three distinct stages of the agricultural cycle.[7] This calendar gives the usual start and end dates of the planting period and harvest period for each sub-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.[8] 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).

Kenya's topography is quite heterogeneous (Figure A.3). There exist substantial heterogeneity in agro-ecological zones that span the villages in our data. Table A.4 provides maize crop calendar specific to each province in Kenya, broken into three stages of the agricultural cycle described above.[9] Although there exist differences in the maize crop calendar within provinces, discrepancies in the maize crop calendars across provinces are far more significant. Therefore, our baseline econometric specification includes village and province-by-round fixed

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

[8] 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.

[9] Growing degree days are calculated holding maize crop calendars fixed across survey-rounds. Therefore, growing degree days do not vary due to potentially endogenous weather-induced changes to the maize crop calendar from year to year.

effects. Any remaining temperature variation pertains only to within-province-round deviations from village means. For example, the amount by which western parts of Nyanza province are warmer than normal in a given survey round in GS1, compared to how much eastern Nyanza is warmer than normal in the same round in GS1.

There exist almost no differences in the maize crop calendar within districts. In robustness checks, we show our results are robust to the inclusion of district-by-round fixed effects where the remaining temperature variation pertains only to within-district-round deviations from village means. In addition, we show our point estimates are largely unaffected when we assign a uniform maize crop calendar to all villages in the Western, Coast, Central, Nyanza, and Rift Valley province and a uniform maize crop calendar to all villages in the Eastern province, as well as when we subsequently drop the Eastern province from our sample.

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 from the ERA-Interim Reanalysis archive, which is constructed by researchers at the European Centre for Medium-Term Weather Forecasting. It is a gridded reanalysis data set providing information on average daily temperature on a 1 degree x 1 degree latitude-longitude grid, from 1979 to present day (Dee et al., 2011). 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 containing daily temperature values for each village coordinate point for our study period. 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.[10] Daily relative humidity data came from NASA.[11] These satellite and model derived solar and meteorological data cover the global surface at 1 degree x 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

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

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

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.[12]

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. The 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 (8C), and below an upper bound (30C), and then sum these daily exposures for each of the three phases during the main growing season for those bounds. $GDD_{8,30}$ represents a typical measure used to predict maize development rates (Lobell et al., 2011), and is perfectly correlated with average growing-season temperature: we do not observe any temperatures below 8C. And average daily temperatures in the data are less than 30C (Figure 1).[13] 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 the TAMPA data. Table A.5 presents summary statistics for GDD above 8C in each phase of the agricultural cycle for all five rounds of the household survey.

4 Temperature and Agricultural Input Use Response

Almost 50% of households in this sample reported having 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.6).[14] If higher temperatures increase the incidence of pests, weeds and

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

[13]In fact, the 99th percentile of the distribution of *maximum* daily temperatures for villages in our sample is 32C (Figure 2). 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.

[14]Figure A.5 presents the historical temperature trends for villages in the TAMPA data and shows that average yearly temperatures have increased in the last 10 years.

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 the incidence of pests, weeds and crop diseases as one of the primary consequences of changes in temperature (Table A.7). Close to 60% of all non-adopters of fertilizer pointed to financial constraints as the reason for non-adoption (Table A.8).

In this section, we formally test the hypothesis 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.1.

4.1 Research Design

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

$$\begin{aligned} Y_{ijdqt} = \beta_1 (GDD_{8,30})^{PP}_{jdqt} + \beta_2 (GDD_{8,30})^{GS1}_{jdqt} + \\ \beta_3 (GDD_{8,30})^{GS2}_{jdqt} + f(Rain)^{PP}_{jdqt} + f(Rain)^{GS1}_{jdqt} \\ + f(Rain)^{GS2}_{jdqt} + \alpha_j + \mu_{qt} + \epsilon_{ijdqt} \end{aligned} \quad (1)$$

Y_{ijdqt} is fertilizer or pesticide use (a binary variable equal to one if pesticides were 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 tercile 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. $(GDD_{8,30})_{jdqt}$ is the sum of degree days over 8C during each stage of the main growing season in Kenya.[15] For example, β_1 represents the marginal effect of an extra growing degree day during the pre-planting phase.

[15] In Section 4.2, we demonstrate that our results are robust to the choice of lower bound used to calculate growing degree days.

We also estimate a second, more flexible model of the effects of temperature on agricultural input use:

$$\begin{aligned} Y_{ijdqt} = {} & \beta_2 T(18C-19C)^{PP}_{jdqt} + \beta_3 T(19C-20C)^{PP}_{jdqt} + \beta_4 T(20C-21C)^{PP}_{jdqt} \\ & + \beta_5 T(21C-22C)^{PP}_{jdqt} + \beta_6 T(>22C)^{PP}_{jdqt} \\ & + \gamma_2 T(18C-19C)^{GS1}_{jdqt} + \gamma_3 T(19C-20C)^{GS1}_{jdqt} + \gamma_4 T(20C-21C)^{GS1}_{jdqt} \\ & + \gamma_5 T(21C-22C)^{GS1}_{jdqt} + \gamma_6 T(>22C)^{GS1}_{jdqt} \\ & + \alpha_2 T(18C-19C)^{GS2}_{jdqt} + \alpha_3 T(19C-20C)^{GS2}_{jdqt} + \alpha_4 T(20C-21C)^{GS2}_{jdqt} \\ & + \alpha_5 T(21C-22C)^{GS2}_{jdqt} + \alpha_6 T(>22C)^{GS2}_{jdqt} \\ & + f(Rain)^{PP}_{jdqt} + f(Rain)^{GS1}_{jdqt} + f(Rain)^{GS2}_{jdqt} + \alpha_j + \mu_{qt} + \epsilon_{ijdqt} \end{aligned} \tag{2}$$

The notation is the same as in Equation (1). The key difference is our coefficients of interest: T(.). Temperature bins or T(.) are counts of the number of the days in each stage of the main growing season with average daily temperature within the specified range. For example, $T(20C-21C)^{GS1}_{jdqt}$ is the number of days in the initial vegetative growth phase (GS1) with average daily temperature between $20C$ and $21C$. The coldest temperature bin is a count of the number of days with average temperature less than 18C, and the hottest temperature bin is a count of the number of days with average temperature greater than 22C. We chose these endpoints because 18C and 22C are the 20th and 80th percentiles of average daily temperatures across villages in the TAMPA sample from 1990 to 2012. The bins in between are evenly spaced one degree apart. The omitted bin is the <18C bin, which we chose to omit because it has the maximum (minimum) coefficient of all the bins for fertilizer use (pesticide use and weeding labor). All other bins are interpreted relative to this bin. For example, γ_6, the coefficient on the hottest bin, is the marginal effect on agricultural inputs of an extra day with average temperature greater than $> 22C$ in GS1 relative to a day with average temperature below $18C$ in GS1. In estimating this flexible approach we follow prior work in climate economics and avoid imposing restrictive assumptions on the functional relationship between temperature and agricultural production decisions (Hsiang, 2016).

We cluster standard errors at the village level. The identifying assumption is that changes in temperature experienced by a village during each phase of the agricultural cycle is exogenous to unobservable household or village level 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 which we control for 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 to Temperature

We estimate equation (1) and find that an extra 1 degree day above 8C in the initial growth period (GS1) increases the proportion of households using pesticides by almost 0.3 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 1% increase in pesticide users. Similarly, an extra DD in GS1 leads to a 2% 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 in pre-planting (PP) or post-planting (GS2) periods. This is precisely what we find.

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 0.017 days (0.2%) increase in own (household) weeding labor per acre (Table 1: Column 5). 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.[16]

[16]The effect of an extra degree day over 8C in the initial growth period (GS1) and the post-planting period (GS2) on own weeding effort, however, is quite imprecise. If weed growth is aggressive, farmers might use herbicides - a pesticide targeted specially at weeds in the early post-planting stage (GS1) as a substitute for weeding labor (Gianessi, 2010). Once the crop is established (GS2), however, any further weed control requires additional labor effort, which continues nearly until harvest. One

Next, we estimate Equation (2) and find that an extra day above 22C relative to a day with average temperature below 18C in the initial growth period (GS1) increases the proportion of households using pesticides by over 1.5 percentage points (Figure 4: Panel (a)). Similarly, an extra day above 22C relative to a day below 18C in the initial growth period (GS1) leads to a 12% increase in the intensity of pesticide use (Figure 4: Panel (b)). Lastly, an extra day above 22C relative to a day below 18C in the pre-planting period (PP) is associated with a 0.14 day increase in own (household) weeding labor per acre (Figure 4: Panel (e)). The effects on weeding labor continues throughout the growing season: although imprecisely estimated, an extra day above 22C relative to a day below 18C in the initial growth period (post-planting period) is associated with a 0.04 (0.07) day increase in own weeding labor per acre.

Combined with the qualitative evidence presented in Table A.7, 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. We find no significant impact of heat during latter stages of the growing season, by which time farmer response to crop diseases and pests is likely unproductive. Effects on weeding labor start early, and are 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 arise 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 8C in the initial planting or basal fertilizer application period (GS1) decreases the proportion of households applying fertilizer by 0.1 percentage points (Table 1: Column 3). These effects coincide temporally with the pesticide effects observed, consistent

explanation for the noisy GS2 coefficient might be non-linearities in the effects of temperature on weed growth: (i) we find a statistically significant positive effect of an extra degree day over 21C in GS2 on own weeding labor and (ii) in our nonparametric econometric model, we find large positive effect of temperature on own weeding labor in the post-planting period. Lastly, we find an extra degree day over 8C in the initial vegetative growth phase (GS1) is associated with a 1% increase in expenditure on hired labor per acre (Table A.9). This suggests during the planting period (GS1), presumably facing greater constraints on own labor, farmers tackle aggressive weed growth using herbicides and hired weeding labor.

with a liquidity constraint or a production risk mechanism. Almost 65% of the households in our balanced panel applied fertilizer in 1997, so a 0.1 percentage point decrease translates into a 0.15% decrease from adoption levels in Round 1. Similarly, an extra DD over 8C in GS1 reduces fertilizer application rates per acre by around 1.3% (Table 1: Column 4). These effects are driven by early growing season temperatures, coinciding with the basal fertilizer application period, by which time financial constraints typically begin to bind, consistent with qualitative evidence presented in Table A.8.

We estimate Equation (2) and find that an extra day above 22C relative to a day with average temperature below 18C in the initial growth period (GS1) decreases the proportion of households applying fertilizer by roughly 1 percentage point (Figure 4: Panel (c)). Similarly, an extra day above 22C relative to a day below 18C in the initial growth period (GS1) reduces fertilizer application rates per acre by 10% (Figure 4: Panel (d)).

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 expected pesticide expenditure by KES 4.17, and reduces fertilizer expenditure by KES 12.99. Additionally, an extra degree day in PP increases the cost of own weeding labor (opportunity cost) by KES 9.87.[17,18] This might suggest that as liquidity constraints begin to bind for farmers, expenditure on loss-reducing adaptive inputs necessitates reduction in fertilizer use.

However, another mechanism might be that increased ex ante maize yield risk, due to an increase in disease, pest, and weed pressure, could adversely affect fertilizer uptake. In Table A.10, we show an extra degree day in the initial vegetative growth stage (GS1) decreases total agricultural input expenditure per acre by 0.9%. The negative and statistically significant point estimate is consistent with the hypothesis that farmers are trading off defensive input expenditures for productive input expenditures but perhaps also responding to changes in output risk due to increase in the incidence of pests, crop diseases, and weeds.

[17] 1 United States Dollar (USD) = 100 Kenyan Shilling (KES).

[18] 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 (0.01*52.14)*24.91. Similarly, pesticide expenditure increased by (0.02*0.43)*484.77, while cost of own weeding labor increased by (0.02*4.88)*101.08.

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.[19] After removing village and province-by-round fixed effects, any remaining temperature variation pertains only to within-province-round deviations from village means.

Since Kenyan provinces are large and topographically heterogeneous, 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, for example, eastern Migori, a district in Nyanza province, is warmer than normal, so is western Migori, because temperatures vary smoothly in space due to thermodynamics. Therefore, we might not have sufficient identifying variation in temperature after removing household and district-by-year fixed effects to get precise estimates.

We report within- and across-province temperature deviations from province-specific time trends and village means, as well as within-province-round and within-district-round temperature deviations from village means in Table A.12. 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 Prov-Specific Time Trends" degree-days column indicates that 65% and 49% of households-by-round observations observed deviations larger than 5 and 10 degree-days in the planting period (GS1), respectively. The corresponding percentages for the "Removed Province*Round Effects" and the "Removed District*Round Effects" degree-days columns are 50% and 21% and 23% and 7%, respectively. Unsurprisingly, an econometric model with province-round fixed effects exploit smaller (greater) residual temperature variation than a specification with province-specific time trends (district-round fixed effects).

In Table A.13 and Figure A.7, we remove province-by-round fixed effects, instead inclu-

[19]Including household fixed effects doesn't affect our estimates since the treatment (temperature) is at the village level (Table A.11 and Figure A.6).

ding province-specific linear, quadratic, and cubic time trends to control for province-specific time-variant unobservables. We exploit both within- and across-province temperature deviations from province-specific time trends and village means. Our point estimates remain unaffected.

Next, we estimate Equations (1) and (2) with district-by-round fixed effects instead of province-by-round effects. We lose precision for pesticide use, although the point estimate remains relatively unaffected (Table A.14 and Figure A.8).

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).[20]

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. We also provide regression estimates for weeding labor. Table A.15 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.16. Qualitative conclusions drawn from our main results presented in Table 1 remain unchanged with either censored dependent variable estimator.

In Tables A.17 and A.18, we show our results are relatively unaffected when we assign a uniform maize crop calendar across villages in the data. In Table A.19, we adjust standard errors to reflect spatial dependence as modeled in 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.[21] In Tables 2 - 6 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).

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

[21] We used 22 unique grid points to generate weather data for villages in our data (Figure A.1). In Table A.20, we cluster our standard errors at the grid point level. In Table A.21, we cluster-bootstrap (22 clusters) our standard errors following Cameron, Gelbach and Miller (2008). Our coefficients of interest remain precisely estimated.

Next, we employ a sinusoidal interpolation between the daily minimum and maximum temperature (D'Agostino and Schlenker, 2016; 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; the point estimates are qualitatively similar across temperature thresholds (Tables 7 - 10).

Lastly, we examine the relationship between growing degree days over 8C 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.7). Yet the warmer temperatures experienced in these temperate zones should not weaken maize growth physiologically.[22] Farmers' responses therefore most likely reflect the biotic stresses we have emphasized.

To unpack this effect, 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 8C in the initial growth stage (GS1) reduces maize yields by 0.38% (Table A.22). Next, we estimate a flexible model of the effects of temperature on maize yields. Relative to the kink point, $T(19C - 20C)_{jdqt}^{GS1}$, we find an extra day below 19C and above 20C in GS1 reduces maize yields, with comparatively model effects of an extra day below 19C and above 20C in PP and GS2 (Figure A.9). Lastly, we account for within-day temperature variations, we find an effect of between -0.6 and -0.9% from the initial planting period temperatures, consistent with our prior results (Table A.23).

In Appendix A.3, we present a lower bound back-of-the-envelope estimate of the value of these within-season adaptations. Defensive investments undertaken by the average maize farmer in response to an extra DD over 8C protected 3.48 kg of maize yield/acre, roughly 75% of expected loss.

[22] Maize yields only decline above 29-30C (Lobell et al., 2011; Schlenker and Roberts, 2009). The average daily temperatures for villages in our sample are well below 30C (Figure 1). In fact, the 99th percentile of the distribution of daily *maximum* temperatures for villages in our sample is 32C (Figure 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.

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.[23] 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 baseline (Round 1) land ownership 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 1996-97 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.

[23] 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).

We also examine the relationship between GDDs and fertilizer use by household wealth. We find that poorer households use less fertilizer in response to higher temperatures. Lastly, we find poorer households engage in fewer own (household) weeding labor days in response to higher temperatures (Tables A.24, A.25, and A.26).[24]

These results suggest that (i) wealthier farmers adapt more through increased pesticide use than their poorer neighbors in response to a temperature-induced increase in incidence of pests, weeds and diseases; (ii) wealthier farmers also 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 thus constrain uptake of loss-reducing inputs and aggravate 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 responses to higher temperatures holding input use constant, and the effects of induced changes 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 commu-

[24]In Tables A.27, A.28, and A.29, We use average land ownership across all five rounds as a proxy for wealth for all rounds. The point estimates remain largely unchanged.

nities. Finally, our results suggest that farmer responsiveness is sensitive to the distribution of landholding, and thus wealth, in these communities.

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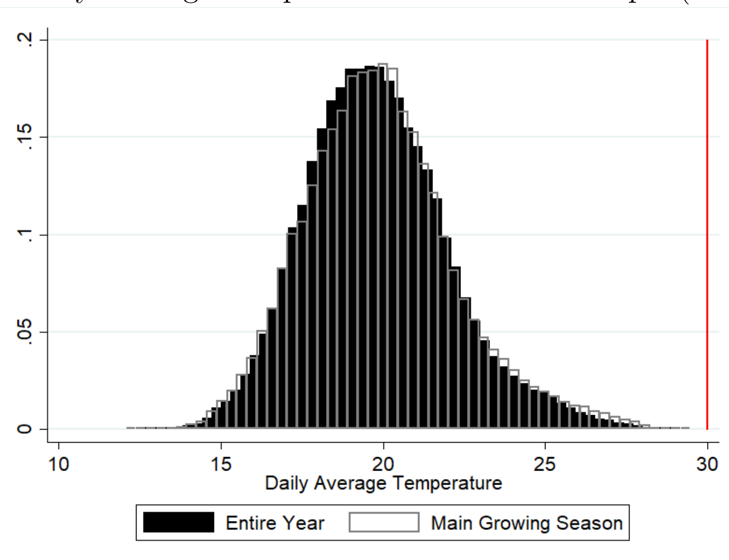
Tables and Figures

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

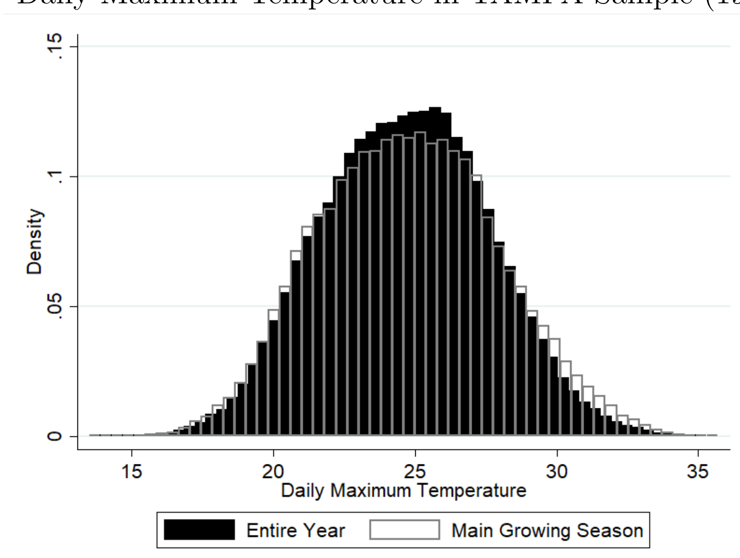
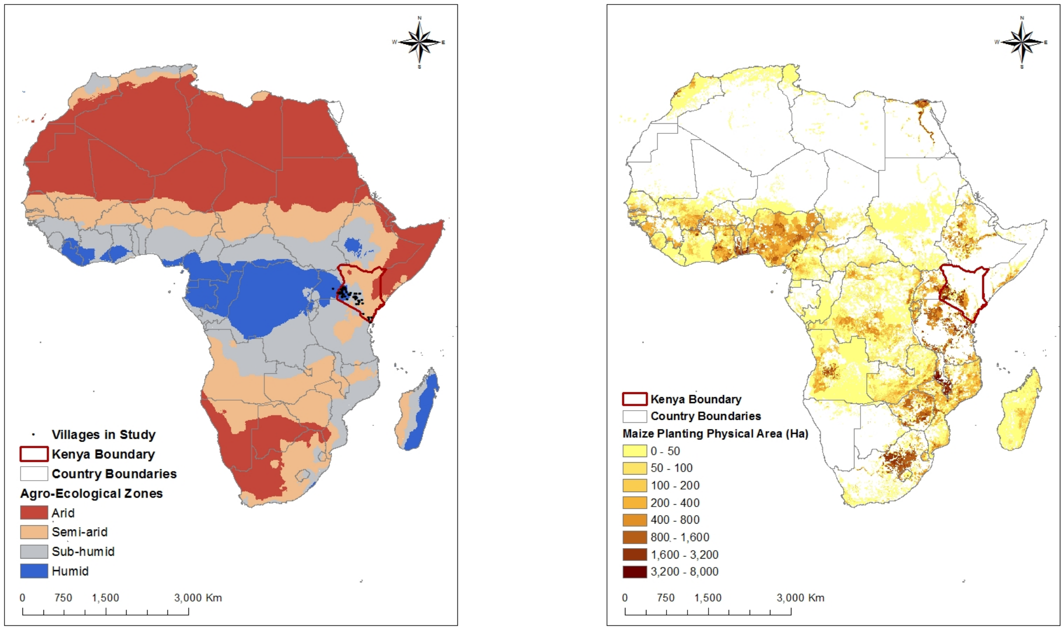


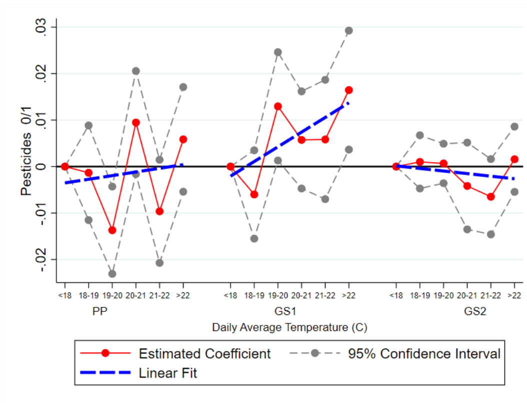
Figure 3: Agro-Ecological Zones and Maize Production in Africa



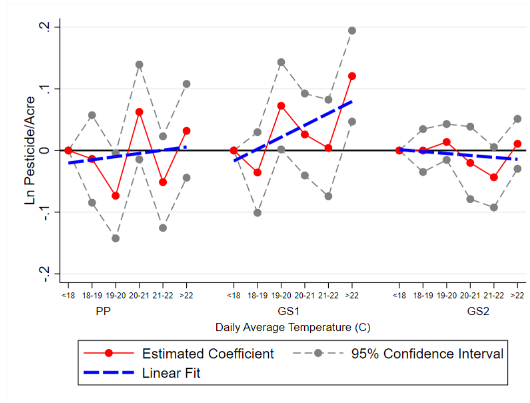
Source: Agro-ecological zones - IFPRI Harvest Choice (www.harvestchoice.org.); Maize Production in Africa: Spatial Production Allocation Model (SPAM), 2005 (www.mapSPAM.info)

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.

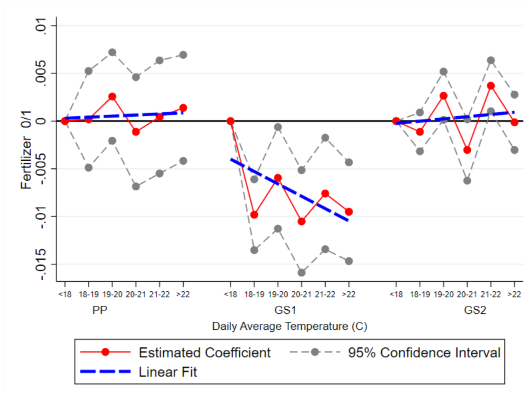
Figure 4: Temperature Bins: Temperature, Fertilizer and Pesticide Use



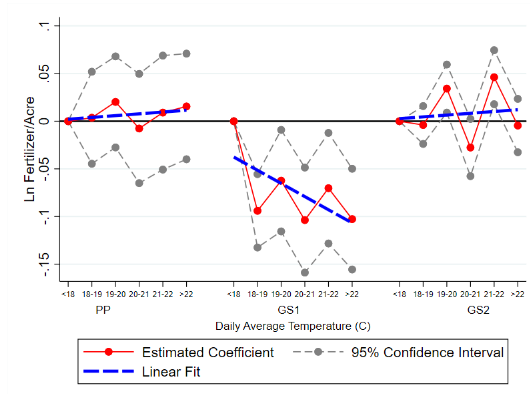
(a) Pesticides 0/1



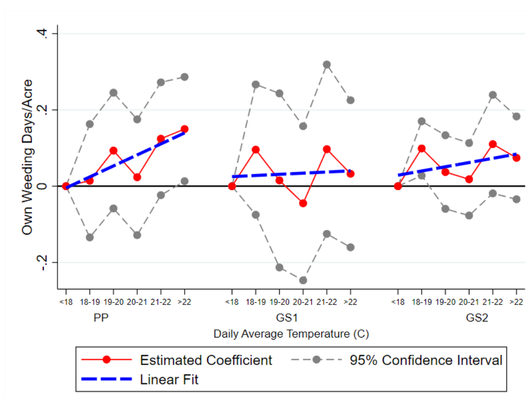
(b) Ln Pesticide/Acre



(c) Fertilizer 0/1



(d) Ln Fertilizer/Acre



(e) Own Weeding Days/Acre

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 figure presents the effects of temperature (captured via number of days in each temperature bin) 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. All figures include village and province-by-year fixed effects as well as controls for precipitation. Standard errors are clustered by village.

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 >8C	0.0010	0.0067	-0.0004	-0.0044	0.0171**
	(0.0008)	(0.0058)	(0.0004)	(0.0042)	(0.0086)
CY GS1 DD >8C	0.0027***	0.0214***	-0.0013**	-0.0131**	-0.0068
	(0.0009)	(0.0058)	(0.0005)	(0.0050)	(0.0117)
CY GS2 DD >8C	-0.0005	-0.0022	-0.0000	0.0005	0.0049
	(0.0004)	(0.0029)	(0.0002)	(0.0019)	(0.0062)
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	0.353	0.594	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 8C) 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: Alternative GDD Lower Bounds: Temperature and Pesticide Use (0/1)

	(1) Pesticides 0/1 β / SE	(2) Pesticides 0/1 β / SE	(3) Pesticides 0/1 β / SE	(4) Pesticides 0/1 β / SE
CY PP DD >18C	0.0013			
	(0.0010)			
CY GS1 DD >18C	0.0028***			
	(0.0010)			
CY GS2 DD >18C	-0.0005			
	(0.0005)			
CY PP DD >19C		0.0015		
		(0.0010)		
CY GS1 DD >19C		0.0029**		
		(0.0011)		
CY GS2 DD >19C		-0.0006		
		(0.0006)		
CY PP DD >20C			0.0017	
			(0.0012)	
CY GS1 DD >20C			0.0034**	
			(0.0016)	
CY GS2 DD >20C			-0.0007	
			(0.0008)	
CY PP DD >21C				0.0019
				(0.0014)
CY GS1 DD >21C				0.0063**
				(0.0026)
CY GS2 DD >21C				-0.0004
				(0.0015)
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	0.336	0.336	0.336	0.336

Notes: Sample includes 1242 households balanced over 3 survey rounds (2003-04, 2006-07 and 2009-10). The table presents the effects of temperature (captured via degree days (DD)) 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: Alternative GDD Lower Bounds: Temperature and Pesticide Use (kg/acre)

	(1) Ln Pesticide/Acre β / SE	(2) Ln Pesticide/Acre β / SE	(3) Ln Pesticide/Acre β / SE	(4) Ln Pesticide/Acre β / SE
CY PP DD >18C	0.0081			
	(0.0066)			
CY GS1 DD >18C	0.0229***			
	(0.0064)			
CY GS2 DD >18C	-0.0025			
	(0.0036)			
CY PP DD >19C		0.0084		
		(0.0071)		
CY GS1 DD >19C		0.0236***		
		(0.0072)		
CY GS2 DD >19C		-0.0042		
		(0.0043)		
CY PP DD >20C			0.0088	
			(0.0079)	
CY GS1 DD >20C			0.0285***	
			(0.0104)	
CY GS2 DD >20C			-0.0064	
			(0.0052)	
CY PP DD >21C				0.0084
				(0.0090)
CY GS1 DD >21C				0.0450***
				(0.0159)
CY GS2 DD >21C				-0.0108
				(0.0079)
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	0.353	0.353	0.353	0.354

Notes: Sample includes 1242 households balanced over 3 survey rounds (2003-04, 2006-07 and 2009-10). The table presents the effects of temperature (captured via degree days (DD)) 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 4: Alternative GDD Lower Bounds: Temperature and Fertilizer Use (0/1)

	(1) Fertilizer 0/1 β / SE	(2) Fertilizer 0/1 β / SE	(3) Fertilizer 0/1 β / SE	(4) Fertilizer 0/1 β / SE
CY PP DD >18C	-0.0003			
	(0.0004)			
CY GS1 DD >18C	-0.0014**			
	(0.0005)			
CY GS2 DD >18C	0.0001			
	(0.0002)			
CY PP DD >19C		-0.0004		
		(0.0004)		
CY GS1 DD >19C		-0.0014**		
		(0.0006)		
CY GS2 DD >19C		-0.0000		
		(0.0003)		
CY PP DD >20C			-0.0004	
			(0.0005)	
CY GS1 DD >20C			-0.0016**	
			(0.0007)	
CY GS2 DD >20C			0.0001	
			(0.0004)	
CY PP DD >21C				-0.0003
				(0.0005)
CY GS1 DD >21C				-0.0018**
				(0.0008)
CY GS2 DD >21C				0.0003
				(0.0004)
Village FE	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes
Observations	6210	6210	6210	6210
R^2	0.594	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). The table presents the effects of temperature (captured via degree days (DD)) 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 5: Alternative GDD Lower Bounds: Temperature and Fertilizer Use (kg/acre)

	(1) Ln Fertilizer/Acre β / SE	(2) Ln Fertilizer/Acre β / SE	(3) Ln Fertilizer/Acre β / SE	(4) Ln Fertilizer/Acre β / SE
CY PP DD >18C	-0.0044			
	(0.0043)			
CY GS1 DD >18C	-0.0130**			
	(0.0055)			
CY GS2 DD >18C	0.0005			
	(0.0025)			
CY PP DD >19C		-0.0051		
		(0.0045)		
CY GS1 DD >19C		-0.0132**		
		(0.0059)		
CY GS2 DD >19C		-0.0009		
		(0.0029)		
CY PP DD >20C			-0.0053	
			(0.0048)	
CY GS1 DD >20C			-0.0160**	
			(0.0072)	
CY GS2 DD >20C			-0.0008	
			(0.0038)	
CY PP DD >21C				-0.0054
				(0.0055)
CY GS1 DD >21C				-0.0180**
				(0.0087)
CY GS2 DD >21C				0.0005
				(0.0044)
Village FE	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes
Observations	6210	6210	6210	6210
R^2	0.657	0.656	0.656	0.656

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)) 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 6: Alternative GDD Lower Bounds: Temperature and Own (Household) Weeding Labor Days

	(1) Own Weeding Days/Acre β / SE	(2) Own Weeding Days/Acre β / SE	(3) Own Weeding Days/Acre β / SE	(4) Own Weeding Days/Acre β / SE
CY PP DD >18C	0.0166*			
	(0.0093)			
CY GS1 DD >18C	-0.0072			
	(0.0128)			
CY GS2 DD >18C	0.0041			
	(0.0066)			
CY PP DD >19C		0.0184*		
		(0.0105)		
CY GS1 DD >19C		-0.0058		
		(0.0140)		
CY GS2 DD >19C		0.0047		
		(0.0083)		
CY PP DD >20C			0.0236*	
			(0.0125)	
CY GS1 DD >20C			0.0145	
			(0.0194)	
CY GS2 DD >20C			0.0159	
			(0.0125)	
CY PP DD >21C				0.0323**
				(0.0149)
CY GS1 DD >21C				0.0375
				(0.0271)
CY GS2 DD >21C				0.0392*
				(0.0219)
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	0.164	0.164	0.164	0.165

Notes: Sample includes 1242 households balanced over 3 survey rounds (2003-04, 2006-07 and 2009-10). The table presents the effects of temperature (captured via degree days (DD)) 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 7: Accounting for Within-Day Temperature Variation: Temperature and Pesticide Use (0/1)

	(1) Pesticides 0/1 β / SE	(2) Pesticides 0/1 β / SE	(3) Pesticides 0/1 β / SE	(4) Pesticides 0/1 β / SE	(5) Pesticides 0/1 β / SE
CY PP DD >21C II	0.0017				
	(0.0012)				
CY GS1 DD >21C II	0.0017				
	(0.0014)				
CY GS2 DD >21C II	-0.0011				
	(0.0008)				
CY PP DD >22C II		0.0021*			
		(0.0012)			
CY GS1 DD >22C II		0.0019			
		(0.0018)			
CY GS2 DD >22C II		-0.0009			
		(0.0010)			
CY PP DD >23C II			0.0023		
			(0.0017)		
CY GS1 DD >23C II			0.0048***		
			(0.0015)		
CY GS2 DD >23C II			-0.0010		
			(0.0013)		
CY PP DD >24C II				0.0027	
				(0.0022)	
CY GS1 DD >24C II				0.0067**	
				(0.0028)	
CY GS2 DD >24C II				-0.0011	
				(0.0018)	
CY PP DD >25C II					0.0039
					(0.0027)
CY GS1 DD >25C II					0.0100**
					(0.0039)
CY GS2 DD >25C II					-0.0008
					(0.0024)
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	3726	3726	3726
R^2	0.335	0.335	0.336	0.336	0.336

Notes: Sample includes 1242 households balanced over 3 survey rounds (2003-04, 2006-07 and 2009-10). The table presents the effects of temperature (captured via degree days (DD)) 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 8: Accounting for Within-Day Temperature Variation: Temperature and Pesticide Use (kg/acre)

	(1) Ln Pesticide/Acre β / SE	(2) Ln Pesticide/Acre β / SE	(3) Ln Pesticide/Acre β / SE	(4) Ln Pesticide/Acre β / SE	(5) Ln Pesticide/Acre β / SE
CY PP DD >21C II	0.0096				
	(0.0078)				
CY GS1 DD >21C II	0.0215***				
	(0.0082)				
CY GS2 DD >21C II	-0.0054				
	(0.0060)				
CY PP DD >22C II		0.0103			
		(0.0080)			
CY GS1 DD >22C II		0.0225**			
		(0.0103)			
CY GS2 DD >22C II		-0.0050			
		(0.0079)			
CY PP DD >23C II			0.0126		
			(0.0114)		
CY GS1 DD >23C II			0.0389***		
			(0.0095)		
CY GS2 DD >23C II			-0.0059		
			(0.0099)		
CY PP DD >24C II				0.0163	
				(0.0144)	
CY GS1 DD >24C II				0.0495***	
				(0.0172)	
CY GS2 DD >24C II				-0.0090	
				(0.0122)	
CY PP DD >25C II					0.0216
					(0.0181)
CY GS1 DD >25C II					0.0680***
					(0.0241)
CY GS2 DD >25C II					-0.0137
					(0.0156)
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	3726	3726	3726
R^2	0.352	0.352	0.354	0.352	0.352

Notes: Sample includes 1242 households balanced over 3 survey rounds (2003-04, 2006-07 and 2009-10). The table presents the effects of temperature (captured via degree days (DD)) 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 9: Accounting for Within-Day Temperature Variation: Temperature and Fertilizer Use (0/1)

	(1) Fertilizer 0/1 β / SE	(2) Fertilizer 0/1 β / SE	(3) Fertilizer 0/1 β / SE	(4) Fertilizer 0/1 β / SE	(5) Fertilizer 0/1 β / SE
CY PP DD >21C II	-0.0008				
	(0.0006)				
CY GS1 DD >21C II	-0.0022***				
	(0.0008)				
CY GS2 DD >21C II	0.0001				
	(0.0004)				
CY PP DD >22C II		-0.0004			
		(0.0006)			
CY GS1 DD >22C II		-0.0020**			
		(0.0008)			
CY GS2 DD >22C II		0.0004			
		(0.0006)			
CY PP DD >23C II			-0.0009		
			(0.0008)		
CY GS1 DD >23C II			-0.0023**		
			(0.0011)		
CY GS2 DD >23C II			0.0002		
			(0.0007)		
CY PP DD >24C II				-0.0013	
				(0.0009)	
CY GS1 DD >24C II				-0.0043***	
				(0.0014)	
CY GS2 DD >24C II				0.0000	
				(0.0010)	
CY PP DD >25C II					-0.0015
					(0.0012)
CY GS1 DD >25C II					-0.0052***
					(0.0018)
CY GS2 DD >25C II					-0.0000
					(0.0013)
Village FE	Yes	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	6210	6210	6210	6210	6210
R^2	0.595	0.594	0.594	0.595	0.595

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)) 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 10: Accounting for Within-Day Temperature Variation: Temperature and Fertilizer Use (kg/acre)

	(1) Ln Fertilizer/Acre β / SE	(2) Ln Fertilizer/Acre β / SE	(3) Ln Fertilizer/Acre β / SE	(4) Ln Fertilizer/Acre β / SE	(5) Ln Fertilizer/Acre β / SE
CY PP DD >21C II	-0.0093				
	(0.0059)				
CY GS1 DD >21C II	-0.0213***				
	(0.0074)				
CY GS2 DD >21C II	0.0016				
	(0.0045)				
CY PP DD >22C II		-0.0056			
		(0.0059)			
CY GS1 DD >22C II		-0.0193**			
		(0.0083)			
CY GS2 DD >22C II		0.0041			
		(0.0059)			
CY PP DD >23C II			-0.0103		
			(0.0077)		
CY GS1 DD >23C II			-0.0231**		
			(0.0099)		
CY GS2 DD >23C II			0.0016		
			(0.0075)		
CY PP DD >24C II				-0.0129	
				(0.0091)	
CY GS1 DD >24C II				-0.0402***	
				(0.0138)	
CY GS2 DD >24C II				0.0003	
				(0.0104)	
CY PP DD >25C II					-0.0146
					(0.0109)
CY GS1 DD >25C II					-0.0461**
					(0.0178)
CY GS2 DD >25C II					-0.0014
					(0.0135)
Village FE	Yes	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	6210	6210	6210	6210	6210
R^2	0.657	0.657	0.657	0.657	0.657

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)) 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 11: Accounting for Within-Day Temperature Variation: Temperature and Own (Household) Weeding Labor Days

	(1) Own Weeding Days/Acre β / SE	(2) Own Weeding Days/Acre β / SE	(3) Own Weeding Days/Acre β / SE	(4) Own Weeding Days/Acre β / SE	(5) Own Weeding Days/Acre β / SE
CY PP DD >21C II	0.0264**				
	(0.0122)				
CY GS1 DD >21C II	-0.0192				
	(0.0145)				
CY GS2 DD >21C II	0.0080				
	(0.0111)				
CY PP DD >22C II		0.0284**			
		(0.0123)			
CY GS1 DD >22C II		-0.0215			
		(0.0140)			
CY GS2 DD >22C II		0.0064			
		(0.0131)			
CY PP DD >23C II			0.0350*		
			(0.0184)		
CY GS1 DD >23C II			-0.0141		
			(0.0232)		
CY GS2 DD >23C II			0.0106		
			(0.0161)		
CY PP DD >24C II				0.0391*	
				(0.0234)	
CY GS1 DD >24C II				-0.0044	
				(0.0361)	
CY GS2 DD >24C II				0.0210	
				(0.0206)	
CY PP DD >25C II					0.0500*
					(0.0290)
CY GS1 DD >25C II					0.0095
					(0.0483)
CY GS2 DD >25C II					0.0428
					(0.0295)
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	3726	3726	3726
R^2	0.164	0.164	0.164	0.164	0.164

Notes: Sample includes 1242 households balanced over 3 survey rounds (2003-04, 2006-07 and 2009-10). The table presents the effects of temperature (captured via degree days (DD)) 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

A.1 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 affecting 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.30). 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 by inadequate soil moisture. 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. Local effects of heat stress on soil moisture will also vary with soil characteristics. Boix-Fayos et al. (1998), for example, show that the 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 village fixed effects in our model, we control for time invariant qualities of the soil. We also control for time varying attributes of soil at province level via province-round fixed effects. 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.31).[25]

A.2 The Effects of Rainfall on Pesticides and Fertilizer Use

In Table A.32 and A.33 we report the coefficients on the upper and lower rainfall terciles for each period within the agricultural growing season. The effects are as one would expect. High rainfall (upper tercile) is commonly associated with greater leaching and lowered effectiveness of pesticide applications once plants have emerged (in GS2), so farmers predictably reduce pesticide application in the wettest years. Conversely, in the driest years, the risk of top dressing fertilizer damaging maize increases, to farmers optimally respond by reducing fertilizer application in the driest (lowest rainfall tercile) seasons.[26] The weeding labor effect in GS1 likely reflects farmers' efforts to reduce weed competition with newly planted seed and emergent seedlings when they face moisture stress. The yield effects of rainfall are likewise as one would predict. And the core results on which we focus are unchanged by including the upper and lower rainfall terciles. We now include these results in the appendix and briefly discuss them in the revised manuscript.

A.3 Protective Effects of Adaptation

In Table A.22, 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.[27] We find an extra degree day over 8C in the initial growth stage (GS1) reduces maize yields by 0.38%. At baseline (round 1), the average maize output was roughly 292 kg/acre. Therefore, 0.38% corresponds to 1.1 kg/acre decrease in output. We find an extra degree day over 8C in the initial growth stage (GS1) increases

[25] Unfortunately, daily soil moisture data could not be obtained for the entire sample.

[26] The GS1 rain top tercile point estimate on fertilizer may reflect that early in what seems like a good season (solid rainfall) farmers might try going without fertilizer. Indeed, the qualitative evidence from the TAMPA data set supports such an explanation: almost 40% of all non-adopters of fertilizer claimed they had no need to use fertilizer. Alternatively, it could be that fertilizer response is pretty sensitive to soil conditions and anything outside of the regular rainfall zone causes farmers to worry that they will either waste the fertilizer (if it leaches away with too much rainfall) or burn the crop (if there is too little rainfall).

[27] Average daily temperatures in the data are less than 30C. In fact, the 99th percentile of the distribution of daily *maximum* temperatures for villages in our sample is 32C. 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.

pesticide use by 2.14% and reduces fertilizer use by 1.31% (Table 1).[28]

Existing evidence strongly suggests that fertilizer and pesticide applications are associated with large productivity gains for maize farmers in Kenya. Marenya and Barrett (2009) estimate the mean marginal physical product of 17.64 kg maize/kg nitrogen fertilizer. Duflo, Kremer and Robinson (2008) show 1 teaspoon fertilizer applied to each plant increases maize yield by 63%. Tests in Zambia indicate maize yield differences in sprayed and unsprayed fungicide treatments range from 27 to 54% (Gianessi, 2014*b*). In Zimbabwe, research with herbicides resulted in yield increases of up to 50% in maize. Use of herbicides in Kenyan weed trials resulted in 33% higher maize yields than with the farmer practice of hand weeding on account of better weed control (Gianessi, 2013). Unfortunately, to our knowledge, there exist no studies that examine the intensive margin effects of pesticide use on agricultural yields in developing countries.

Therefore, we present back-of-the-envelope calculations using agricultural input productivity estimates from the TAMPA data. We estimate the intensive-margin effects of pesticide and fertilizer applications on maize yields after absorbing household-specific time invariant unobservables via household fixed effects and village-specific time varying confounders via village-by-round fixed effects (Table A.34). We find a 1% increase in pesticide (fertilizer) application is associated with a 2.7% (3.5%) increase in maize yields. It is important to note these estimates may be biased upwards due to household-specific time varying unobservables correlated with maize yields and adoption of modern agricultural technologies (e.g., household-specific transitory income shocks).

A 1.31% decrease in fertilizer use decreases maize yields by 4.56% or 13.39 kg/acre and a 2.14% increase in pesticide use increases maize yields by 5.78% or 16.87 kg/acre. The decrease in maize yields in presence of an extra DD over 8C, and the consequent agricultural adaptation, is 1.1 kg/acre **(Qn. C)**. If the average maize farmer did not adjust production decisions in response to an extra DD increase in temperature over 8C, maize yields would decline by 4.58 kg/acre (-1.1 - 16.87 + 13.39) **(Qn. B)**. Lastly, maize yield would increase by 13.39 kg/acre if the average maize farmer did not experience an extra DD over 8C **(Qn. A)**.

Therefore, defensive investments undertaken by the average maize farmer in response to an extra DD over 8C protected 3.48 kg of maize yield/acre, roughly 75% of expected loss.

[28] At baseline, the average maize farmer used 0.24 kg/acre of pesticides and 46.07 kg/acre of fertilizer. Therefore, an extra degree day over 8C in the initial growth stage (GS1) increased pesticide use by 0.005 kg/acre and reduced fertilizer use by 0.6 kg/acre.

Figures

Figure A.1: Location of Sample Villages

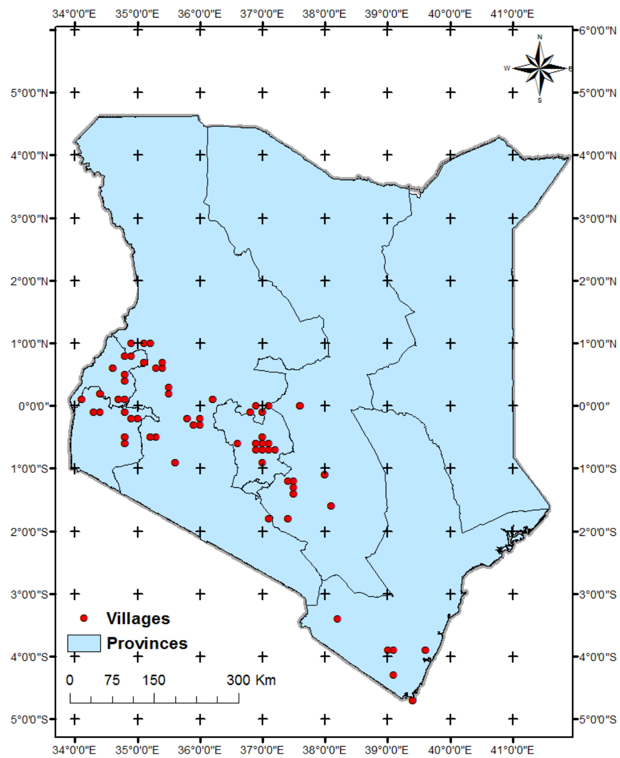


Figure A.2: Maize Calendar in Sample Villages

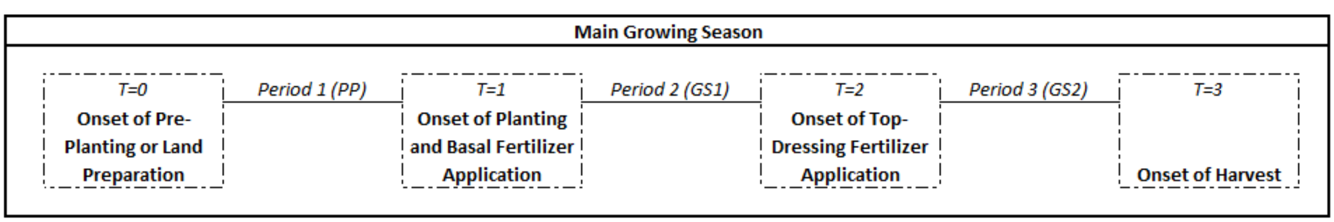
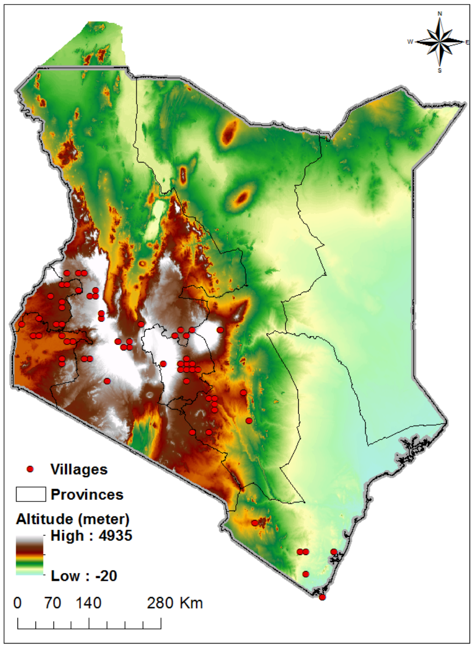
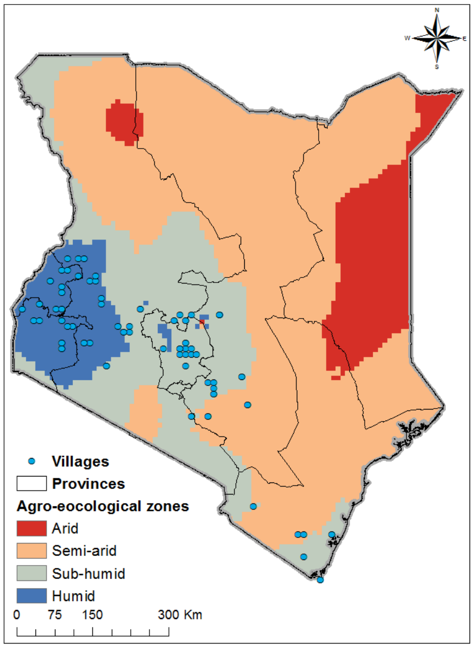


Figure A.3: Spatial Variation in Altitude and Agro-Ecological Zones across TAMPA Villages



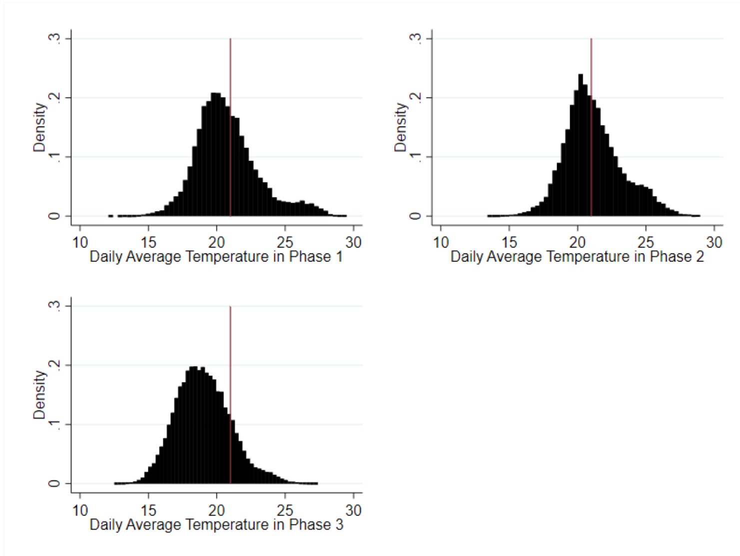
(a) Altitude



(b) Agro-Ecological Zones

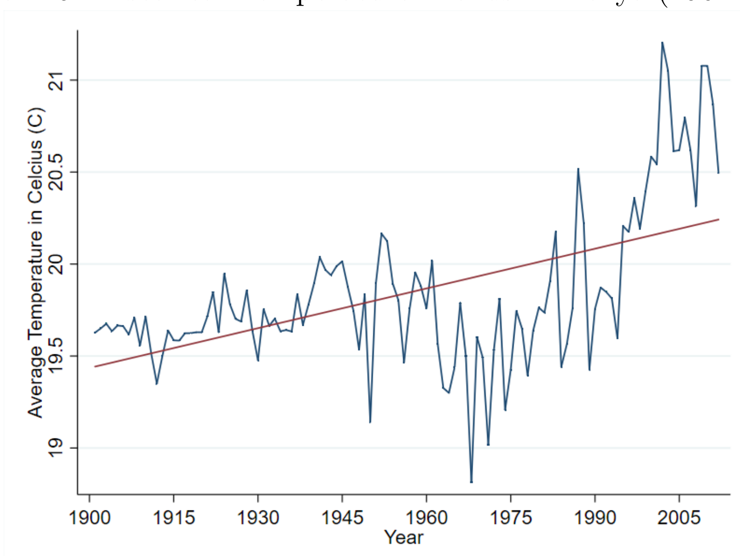
Notes: This figure shows spatial variation in altitude and agro-ecological zones across TAMPA villages.

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



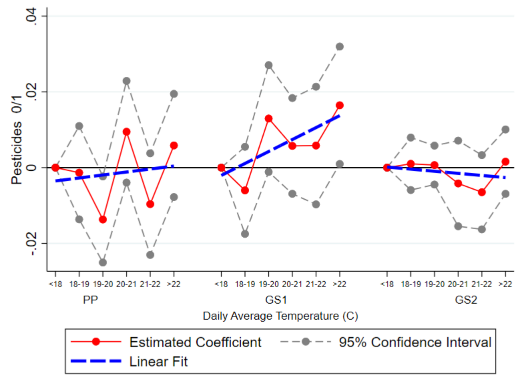
Notes: Distribution of average daily temperatures from 1990-2012 for three phases of the agricultural cycle. Phase 1: pre-planting or land preparation - onset of planting; Phase 2: planting or basal fertilizer application - onset of top dressing fertilizer; Phase 3: top dressing fertilizer application - onset harvest. We calculate cumulative growing degree days from a lower bound of 8C (represented by red vertical line)

Figure A.5: Historical Temperature Trends in Kenya (1901-2012)

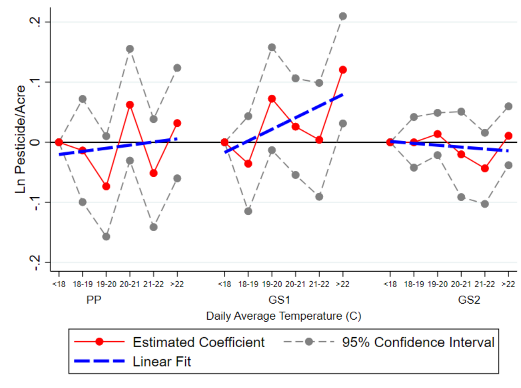


Notes: This figure presents average yearly temperatures as well as the linear fit for villages in the TAMPA sample generated using monthly average temperatures from the Climate Research Unit Time Series Grid Version 3.23 at the University of East Anglia.

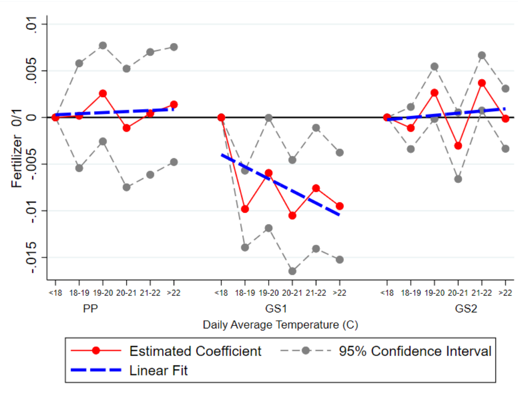
Figure A.6: Temperature Bins | Household FE: Temperature, Fertilizer and Pesticide Use



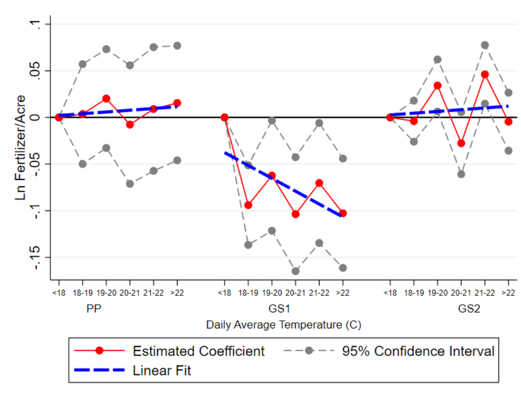
(a) Pesticides 0/1



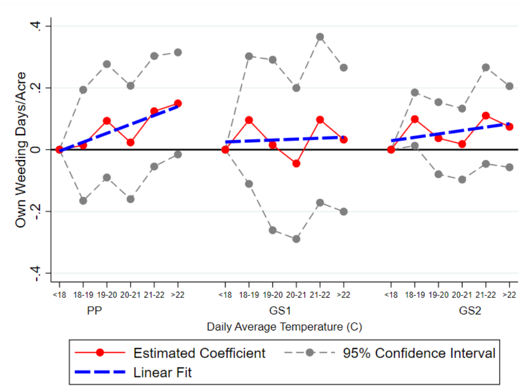
(b) Ln Pesticide/Acre



(c) Fertilizer 0/1



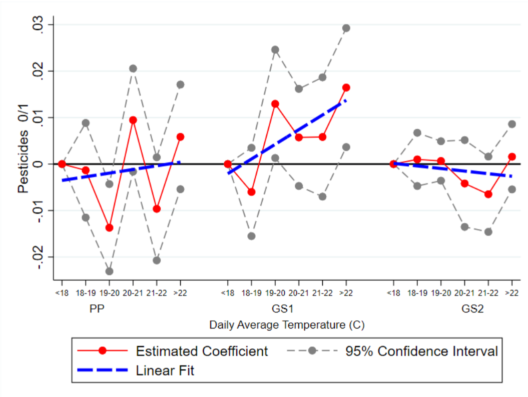
(d) Ln Fertilizer/Acre



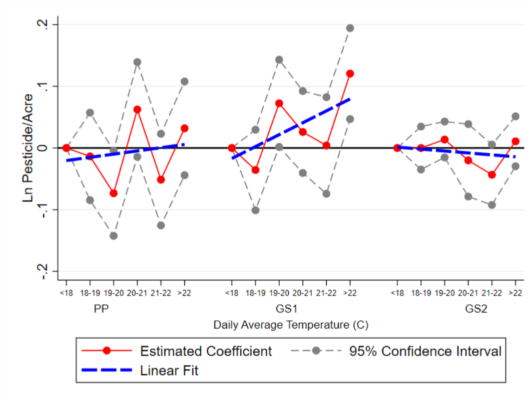
(e) Own Weeding Days/Acre

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 figure presents the effects of temperature (captured via number of days in each temperature bin) 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. All figures include household and province-by-year fixed effects as well as controls for precipitation. Standard errors are clustered by village.

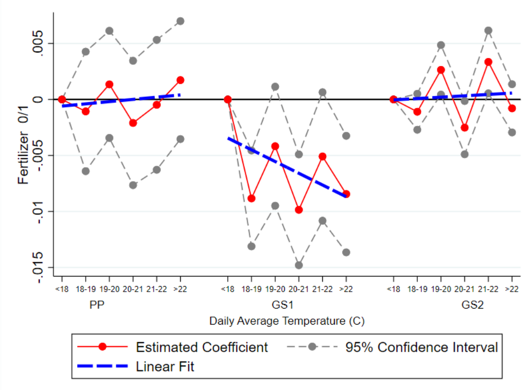
Figure A.7: Temperature Bins | Province-Specific Time Trends: Temperature, Fertilizer and Pesticide Use



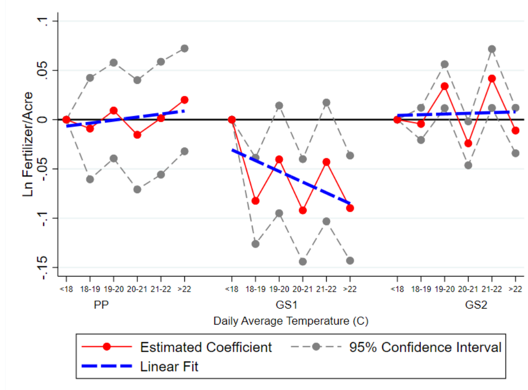
(a) Pesticides 0/1



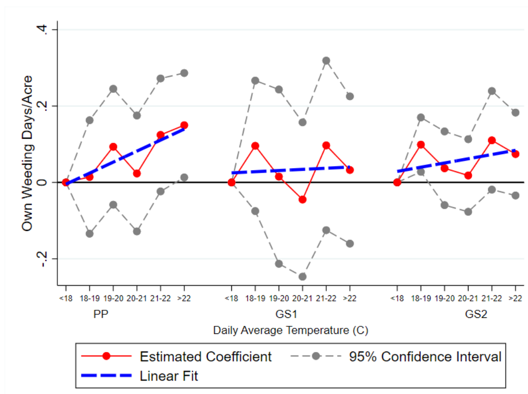
(b) Ln Pesticide/Acre



(c) Fertilizer 0/1



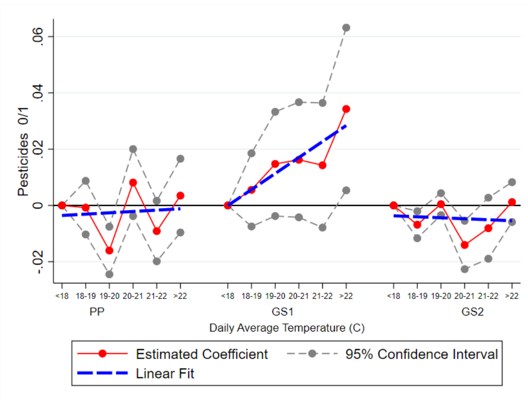
(d) Ln Fertilizer/Acre



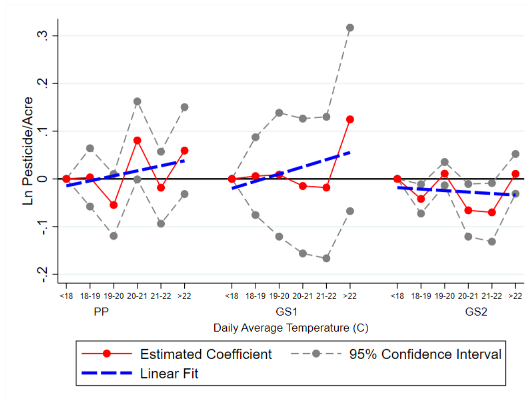
(e) Own Weeding Days/Acre

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 figure presents the effects of temperature (captured via number of days in each temperature bin) 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. All figures include village fixed effects and province-specific (linear, quadratic, and cubic) time trends as well as controls for precipitation. Standard errors are clustered by village.

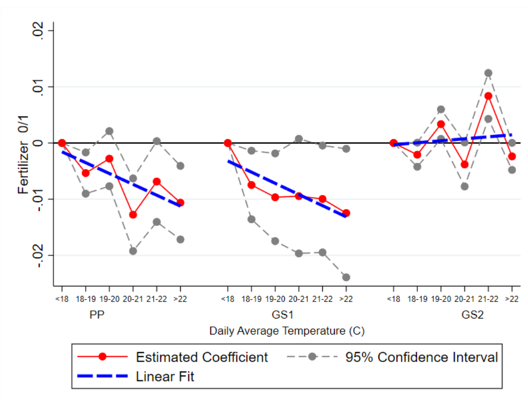
Figure A.8: Temperature Bins | District*Year FE: Temperature, Fertilizer and Pesticide Use



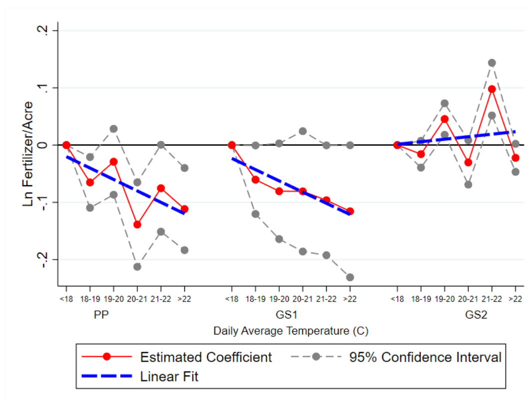
(a) Pesticides 0/1



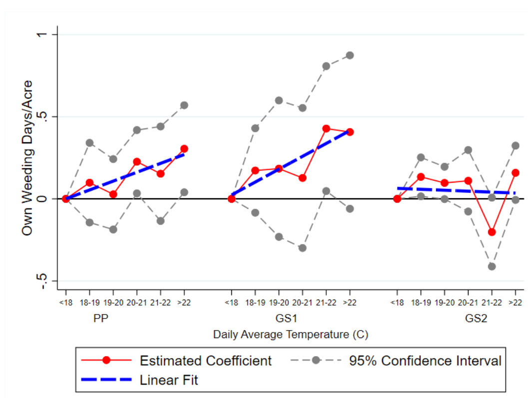
(b) Ln Pesticide/Acre



(c) Fertilizer 0/1



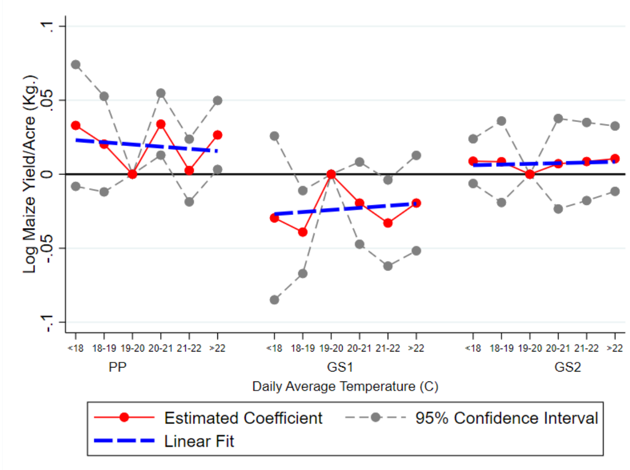
(d) Ln Fertilizer/Acre



(e) Own Weeding Days/Acre

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 figure presents the effects of temperature (captured via number of days in each temperature bin) 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. All figures include village and district-by-year fixed effects as well as controls for precipitation. Standard errors are clustered by village.

Figure A.9: Temperature Bins: Log Total Maize Output and Temperature



Notes: Sample includes 1242 households balanced over 5 survey rounds (1996-97, 1999-00, 2003-04, 2006-07 and 2009-10). The figure presents the effects of temperature (captured via number of days in each temperature bin) on 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. All figures include village and province-by-year fixed effects as well as controls for precipitation. Standard errors are clustered by village.

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: Maize Crop Calendar Across Provinces

	Eastern	Western	Coast	Central	Nyanza	Rift Valley	
	1st Jun/1st Aug	1st Jan/15th Jan	15th Jan	1st Jan/15th Jan	1st Jan	1st Jan/15th Jan	Pre-Planting
PP							
	1st Aug/1st Oct	15th Feb/1st Mar/15th Mar	15th Mar	15th Feb/1st Mar/15th Mar	15th Feb/1st Mar	1st Mar/15th Mar	Planting
GS1							
	16th Oct/22nd Oct/1st Nov	1st Apr/16th Apr	1st May	1st Apr/16th Apr	1st Apr	1st Apr/6th Apr/16th Apr	Post-Planting
GS2							
	15th Dec/31st Dec	1st Aug	15th Jul	1st Aug/1st Sep	1st Jul/1st Aug	15th Jul/1st Aug/1st Sep	Harvest

Notes: The table presents maize crop calendars across provinces in Kenya. 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.5: Growing Degree Days: Mean and Standard Deviations – Rounds 1-5

	All	1997	2000	2004	2007	2010
CY PP DD >8C	746.57	743.48	744.48	732.39	778.31	734.17
	(127.74)	(125.46)	(125.84)	(129.89)	(127.41)	(124.80)
CY GS1 DD >8C	489.06	480.81	474.85	504.17	481.38	504.07
	(220.00)	(214.76)	(221.84)	(223.81)	(213.96)	(223.96)
CY GS2 DD >8C	1143.27	1157.08	1136.57	1130.27	1142.41	1150.01
	(278.22)	(282.89)	(280.64)	(272.49)	(283.07)	(271.42)
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 8C 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.6: 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.7: 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.8: 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.9: Temperature and Log Hired Weeding Labor KES/acre

	(1) OLS β / SE	(2) Tobit β / SE	(3) Honoré's Tobit β / SE
CY PP DD >8C	0.0013	0.0065	0.0045
	(0.0030)	(0.0064)	(0.0059)
CY GS1 DD >8C	0.0119**	0.0255**	0.0204*
	(0.0055)	(0.0112)	(0.0105)
CY GS2 DD >8C	0.0018	0.0037	0.0036
	(0.0020)	(0.0037)	(0.0035)
Village FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	3726	3726
R^2	0.154		

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 8C) on hired weeding labor. Columns 2 and 3 present Standard Tobit and Honoré Fixed Effects 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, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.10: Temperature and Log Total Agricultural Input Expenditures

	(1) Ln Total Input Expenditures/Acre β / SE
CY PP DD >8C	-0.0027
	(0.0019)
CY GS1 DD >8C	-0.0091***
	(0.0028)
CY GS2 DD >8C	-0.0004
	(0.0010)
Village FE	Yes
Province-by-Year FE	Yes
Rainfall Controls	Yes
Observations	3726
R^2	0.428

Notes: Sample includes 1242 households balanced over 3 survey rounds (2003-04, 2006-07 and 2009-10) for agricultural input expenditures. The table presents the effects of temperature (captured via degree days (DD) over 8C) on total agricultural input expenditures/acre. 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.11: 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 >8C	0.0010	0.0067	-0.0004	-0.0044	0.0171
	(0.0010)	(0.0070)	(0.0005)	(0.0046)	(0.0104)
CY GS1 DD >8C	0.0027**	0.0214***	-0.0013**	-0.0131**	-0.0068
	(0.0011)	(0.0070)	(0.0006)	(0.0056)	(0.0142)
CY GS2 DD >8C	-0.0005	-0.0022	-0.0000	0.0005	0.0049
	(0.0005)	(0.0035)	(0.0002)	(0.0022)	(0.0075)
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	0.586	0.586	0.740	0.789	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 8C) 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: Observed temperature variation: proportion of households with degree-days below/above average (degrees) after removing province-specific time trends, province*year effects and district*year effects

	Removed Prov-Specific Time Trends % HHs	Removed Prov*Round FE % HHs	Removed Dist*Round FE % HHs
CY PP DD >8C: DD below/above 5 degrees	0.76		
CY PP DD >8C: DD below/above 10 degrees	0.50		
CY GS1 DD >8C: DD below/above 5 degrees	0.65		
CY GS1 DD >8C: DD below/above 10 degrees	0.49		
CY GS2 DD >8C: DD below/above 5 degrees	0.78		
CY GS2 DD >8C: DD below/above 10 degrees	0.60		
CY PP DD >8C: DD below/above 5 degrees		0.69	
CY PP DD >8C: DD below/above 10 degrees		0.38	
CY GS1 DD >8C: DD below/above 5 degrees		0.50	
CY GS1 DD >8C: DD below/above 10 degrees		0.21	
CY GS2 DD >8C: DD below/above 5 degrees		0.57	
CY GS2 DD >8C: DD below/above 10 degrees		0.34	
CY PP DD >8C: DD below/above 5 degrees			0.33
CY PP DD >8C: DD below/above 10 degrees			0.15
CY GS1 DD >8C: DD below/above 5 degrees			0.23
CY GS1 DD >8C: DD below/above 10 degrees			0.07
CY GS2 DD >8C: DD below/above 5 degrees			0.33
CY GS2 DD >8C: DD below/above 10 degrees			0.17

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-specific time trends, 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.13: Province-Specific Time Trends: 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 >8C	0.0010	0.0067	-0.0000	0.0001	0.0171**
	(0.0008)	(0.0058)	(0.0003)	(0.0025)	(0.0086)
CY GS1 DD >8C	0.0027***	0.0214***	-0.0010***	-0.0118***	-0.0068
	(0.0009)	(0.0058)	(0.0004)	(0.0036)	(0.0117)
CY GS2 DD >8C	-0.0005	-0.0022	0.0001	0.0015	0.0049
	(0.0004)	(0.0029)	(0.0002)	(0.0015)	(0.0062)
Village FE	Yes	Yes	Yes	Yes	Yes
Prov-Specific Time Trends	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210	3726
R^2	0.336	0.353	0.593	0.656	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 8C) 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: 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 >8C	0.0007	0.0089	-0.0019***	-0.0220***	0.0326*
	(0.0011)	(0.0065)	(0.0005)	(0.0058)	(0.0187)
CY GS1 DD >8C	0.0021	0.0047	-0.0014*	-0.0150*	0.0865**
	(0.0021)	(0.0124)	(0.0008)	(0.0078)	(0.0349)
CY GS2 DD >8C	-0.0008*	-0.0070**	-0.0004*	-0.0034	0.0041
	(0.0005)	(0.0032)	(0.0002)	(0.0022)	(0.0080)
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	0.389	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 8C) 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: 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 >8C	0.0142	-0.0052	0.0466*
	(0.0106)	(0.0057)	(0.0263)
CY GS1 DD >8C	0.0277***	-0.0231***	-0.0239
	(0.0076)	(0.0063)	(0.0255)
CY GS2 DD >8C	-0.0055	0.0031	0.0220
	(0.0032)	(0.0026)	(0.0143)
Village FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	6210	3726

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 8C) 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.16: 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 >8C	0.0179	-0.0048	0.0199**
	(0.0120)	(0.0055)	(0.0098)
CY GS1 DD >8C	0.0381***	-0.0216***	-0.0189
	(0.0108)	(0.0066)	(0.0124)
CY GS2 DD >8C	-0.0057	0.0019	0.0092
	(0.0044)	(0.0027)	(0.0062)
Village FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	6210	3726

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 8C) 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, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.17: Uniform Maize Crop Calendar: 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 >8C	0.0021**	0.0148**	-0.0003	-0.0051	-0.0008
	(0.0011)	(0.0073)	(0.0005)	(0.0051)	(0.0125)
CY GS1 DD >8C	0.0043**	0.0283**	-0.0013	-0.0106	0.0262
	(0.0017)	(0.0119)	(0.0008)	(0.0078)	(0.0262)
CY GS2 DD >8C	-0.0012*	-0.0078*	-0.0000	0.0002	0.0020
	(0.0006)	(0.0046)	(0.0003)	(0.0025)	(0.0110)
Village FE	Yes	Yes	Yes	Yes	Yes
Province-by-Year FE	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210	3726
R^2	0.341	0.357	0.594	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 8C) 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: Uniform Maize Crop Calendar, Drop Eastern Province: 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 >8C	0.0021	0.0124	0.0000	0.0004	-0.0037
	(0.0014)	(0.0097)	(0.0005)	(0.0054)	(0.0167)
CY GS1 DD >8C	0.0039**	0.0225*	-0.0015	-0.0135*	0.0306
	(0.0017)	(0.0122)	(0.0009)	(0.0081)	(0.0290)
CY GS2 DD >8C	-0.0011	-0.0074	0.0001	0.0031	-0.0009
	(0.0007)	(0.0050)	(0.0003)	(0.0025)	(0.0121)
Village FE	Yes	Yes	Yes	Yes	Yes
Province-by-Year FE	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	3093	3093	5155	5155	3093
R^2	0.307	0.332	0.611	0.662	0.164

Notes: Sample includes 1031 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 8C) 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.19: 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 >8C	0.0010	0.0067	-0.0004	-0.0044*	0.0171***
	(0.0008)	(0.0053)	(0.0002)	(0.0025)	(0.0032)
CY GS1 DD >8C	0.0027***	0.0214***	-0.0013**	-0.0131**	-0.0068
	(0.0008)	(0.0055)	(0.0006)	(0.0053)	(0.0106)
CY GS2 DD >8C	-0.0005	-0.0022	-0.0000	0.0005	0.0049
	(0.0005)	(0.0033)	(0.0001)	(0.0012)	(0.0045)
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	0.044	0.047	0.018	0.023	0.011

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.20: Standard Errors Clustered at Grid Point Level: 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 >8C	0.0010	0.0067	-0.0004	-0.0044	0.0171**
	(0.0014)	(0.0095)	(0.0005)	(0.0046)	(0.0066)
CY GS1 DD >8C	0.0027**	0.0214**	-0.0013**	-0.0131**	-0.0068
	(0.0011)	(0.0076)	(0.0005)	(0.0056)	(0.0151)
CY GS2 DD >8C	-0.0005	-0.0022	-0.0000	0.0005	0.0049
	(0.0005)	(0.0036)	(0.0002)	(0.0019)	(0.0050)
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	0.353	0.594	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 8C) 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. Standard errors are in parentheses, clustered by grid point.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.21: Cluster-Bootstrap P-Values at Grid Point Level: 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 >8C	0.0010	0.0067	-0.0004	-0.0044	0.0171
	(0.49)	(0.66)	(0.45)	(0.44)	(0.03)
CY GS1 DD >8C	0.0027	0.0214	-0.0013	-0.0131	-0.0068
	(0.09)	(0.05)	(0.01)	(0.01)	(0.69)
CY GS2 DD >8C	-0.0005	-0.0022	-0.0000	0.0005	0.0049
	(0.04)	(0.55)	(0.95)	(0.85)	(0.37)
Village FE	Yes	Yes	Yes	Yes	Yes
Prov-Specific Time Trends	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210	3726
R^2	0.336	0.353	0.594	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 8C) 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 clustered by grid point (200 replications). **P-values are in parentheses.**
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.22: Log Total Maize Output and Temperature

	(1) Log Maize Yield/Acre (Kg.) β / SE
CY PP DD >8C	0.0018
	(0.0033)
CY GS1 DD >8C	-0.0038*
	(0.0023)
CY GS2 DD >8C	0.0006
	(0.0015)
Village FE	Yes
Province-by-Year FE	Yes
Rainfall Controls	Yes
Observations	6210
R^2	0.374

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 8C) 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.23: Accounting for Within-Day Temperature Variation: Log Total Maize Output and Temperature

	(1) Log Yield/Acre β / SE	(2) Log Yield/Acre β / SE	(3) Log Yield/Acre β / SE	(4) Log Yield/Acre β / SE	(5) Log Yield/Acre β / SE
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)				
CY PP DD >22C II		0.0034 (0.0044)			
CY GS1 DD >22C II		-0.0089*** (0.0030)			
CY GS2 DD >22C II		0.0010 (0.0037)			
CY PP DD >23C II			0.0043 (0.0058)		
CY GS1 DD >23C II			-0.0063 (0.0048)		
CY GS2 DD >23C II			0.0027 (0.0050)		
CY PP DD >24C II				0.0058 (0.0064)	
CY GS1 DD >24C II				-0.0094 (0.0076)	
CY GS2 DD >24C II				0.0066 (0.0068)	
CY PP DD >25C II					0.0077 (0.0076)
CY GS1 DD >25C II					-0.0095 (0.0109)
CY GS2 DD >25C II					0.0132 (0.0092)
Village FE	Yes	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes
Observations	6210	6210	6210	6210	6210
R^2	0.375	0.375	0.374	0.375	0.376

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)) 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.24: 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	(5) Own Weeding Days/Acre β / SE
CY PP DD >8C	0.0015	0.0104	-0.0003	-0.0043	0.0188
	(0.0010)	(0.0071)	(0.0004)	(0.0046)	(0.0115)
CY GS1 DD >8C	0.0031***	0.0238***	-0.0009	-0.0111*	0.0121
	(0.0012)	(0.0076)	(0.0006)	(0.0060)	(0.0163)
CY GS2 DD >8C	-0.0003	-0.0013	-0.0000	0.0003	0.0061
	(0.0005)	(0.0036)	(0.0002)	(0.0022)	(0.0077)
CY PP DD >8C*Bottom Wealth Tercile	-0.0009**	-0.0075***	-0.0002	-0.0010	-0.0057
	(0.0005)	(0.0028)	(0.0003)	(0.0026)	(0.0097)
CY GS1 DD >8C*Bottom Wealth Tercile	-0.0005	-0.0021	-0.0008**	-0.0041	-0.0405*
	(0.0009)	(0.0054)	(0.0004)	(0.0037)	(0.0214)
CY GS2 DD >8C*Bottom Wealth Tercile	-0.0004	-0.0025	0.0002	0.0013	-0.0051
	(0.0005)	(0.0031)	(0.0003)	(0.0024)	(0.0116)
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	0.588	0.740	0.789	0.479

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 8C) 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.25: Standard Tobit Estimates: Temperature, Pesticides and Fertilizer Use, by Wealth (Round 1)

	(1) Ln Pesticide/Acre β / SE	(2) Ln Fertilizer/Acre β / SE	(3) Own Weeding Days/Acre β / SE
CY PP DD >8C	0.0208*	-0.0047	0.0188
	(0.0125)	(0.0057)	(0.0116)
CY GS1 DD >8C	0.0410***	-0.0192**	0.0078
	(0.0119)	(0.0076)	(0.0154)
CY GS2 DD >8C	-0.0057	0.0022	0.0095
	(0.0043)	(0.0029)	(0.0070)
CY PP DD >8C*Bottom Wealth Tercile	-0.0071	-0.0022	-0.0036
	(0.0058)	(0.0034)	(0.0091)
CY GS1 DD >8C*Bottom Wealth Tercile	-0.0043	-0.0063	-0.0557***
	(0.0111)	(0.0058)	(0.0193)
CY GS2 DD >8C*Bottom Wealth Tercile	-0.0028	0.0018	0.0009
	(0.0045)	(0.0030)	(0.0101)
Household 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. The table presents the heterogeneous effects of temperature (captured via degree days (DD) over 8C) 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.26: 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	(3) Own Weeding Days/Acre β / SE
CY PP DD >8C	0.0162**	-0.0048	0.0373
	(0.0064)	(0.0039)	(0.0366)
CY GS1 DD >8C	0.0292***	-0.0201***	0.0257
	(0.0072)	(0.0054)	(0.0345)
CY GS2 DD >8C	-0.0051	0.0028	0.0192
	(0.0026)	(0.0021)	(0.0204)
CY PP DD >8C*Bottom Wealth Tercile	-0.0062	-0.0021	0.0013
	(0.0047)	(0.0027)	(0.0205)
CY GS1 DD >8C*Bottom Wealth Tercile	-0.0027	-0.0057	-0.0979***
	(0.0081)	(0.0051)	(0.0334)
CY GS2 DD >8C*Bottom Wealth Tercile	-0.0014	0.0016	0.0102
	(0.0041)	(0.0026)	(0.0217)
Household FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	6210	3726

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 8C) 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.27: 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	(5) Own Weeding Days/Acre β / SE
CY PP DD >8C	0.0015	0.0099	-0.0003	-0.0043	0.0159
	(0.0010)	(0.0071)	(0.0004)	(0.0046)	(0.0114)
CY GS1 DD >8C	0.0030***	0.0230***	-0.0009	-0.0110*	0.0055
	(0.0011)	(0.0074)	(0.0006)	(0.0059)	(0.0151)
CY GS2 DD >8C	-0.0004	-0.0016	-0.0001	-0.0000	0.0049
	(0.0005)	(0.0036)	(0.0002)	(0.0021)	(0.0073)
CY PP DD >8C*Bottom Wealth Tercile	-0.0010**	-0.0069**	-0.0002	-0.0012	0.0006
	(0.0005)	(0.0028)	(0.0003)	(0.0027)	(0.0082)
CY GS1 DD >8C*Bottom Wealth Tercile	-0.0002	-0.0008	-0.0007*	-0.0040	-0.0286*
	(0.0008)	(0.0049)	(0.0004)	(0.0035)	(0.0165)
CY GS2 DD >8C*Bottom Wealth Tercile	-0.0001	-0.0014	0.0004	0.0028	-0.0004
	(0.0005)	(0.0031)	(0.0002)	(0.0025)	(0.0112)
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	0.740	0.789	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. The table presents the heterogeneous effects of temperature (captured via degree days (DD) over 8C) 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.28: 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	(3) Own Weeding Days/Acre β / SE
CY PP DD >8C	0.0207*	-0.0045	0.0158
	(0.0125)	(0.0057)	(0.0113)
CY GS1 DD >8C	0.0397***	-0.0192***	0.0001
	(0.0115)	(0.0073)	(0.0143)
CY GS2 DD >8C	-0.0063	0.0017	0.0088
	(0.0041)	(0.0028)	(0.0066)
CY PP DD >8C*Bottom Wealth Tercile	-0.0079	-0.0030	0.0037
	(0.0053)	(0.0037)	(0.0079)
CY GS1 DD >8C*Bottom Wealth Tercile	-0.0008	-0.0058	-0.0421***
	(0.0097)	(0.0055)	(0.0153)
CY GS2 DD >8C*Bottom Wealth Tercile	0.0001	0.0037	0.0029
	(0.0046)	(0.0030)	(0.0097)
Household FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	6210	3726

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 8C) 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.29: 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	(3) Own Weeding Days/Acre β / SE
CY PP DD >8C	0.0158**	-0.0049	0.0330
	(0.0064)	(0.0039)	(0.0362)
CY GS1 DD >8C	0.0293***	-0.0201***	0.0110
	(0.0074)	(0.0055)	(0.0357)
CY GS2 DD >8C	-0.0055*	0.0024	0.0175
	(0.0025)	(0.0020)	(0.0197)
CY PP DD >8C*Bottom Wealth Tercile	-0.0060	-0.0021	0.0117
	(0.0049)	(0.0028)	(0.0197)
CY GS1 DD >8C*Bottom Wealth Tercile	-0.0024	-0.0053	-0.0721**
	(0.0081)	(0.0051)	(0.0344)
CY GS2 DD >8C*Bottom Wealth Tercile	0.0005	0.0033	0.0147
	(0.0043)	(0.0027)	(0.0237)
Household FE	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes
Observations	3726	6210	3726

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 8C) 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. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.

Table A.30: 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 >8C	0.0015*	0.0079	0.0053
	(0.0008)	(0.0054)	(0.0111)
CY GS1 DD >8C	0.0027***	0.0220***	-0.0032
	(0.0009)	(0.0062)	(0.0126)
CY GS2 DD >8C	-0.0005	-0.0030	0.0029
	(0.0004)	(0.0029)	(0.0061)
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	0.165

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 8C) 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.31: 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 >8C	-0.0004	-0.0001	-0.0044	-0.0034
	(0.0004)	(0.0006)	(0.0042)	(0.0063)
CY GS1 DD >8C	-0.0013**	-0.0016*	-0.0131**	-0.0133
	(0.0005)	(0.0009)	(0.0050)	(0.0082)
CY GS2 DD >8C	-0.0000	-0.0004	0.0005	-0.0032
	(0.0002)	(0.0002)	(0.0019)	(0.0022)
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	6210	2352	6210	2352
R^2	0.594	0.589	0.657	0.646

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 8C) 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.32: Rainfall Coefficients: 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 >8C	0.0010	0.0067	-0.0004	-0.0044	0.0171**
	(0.0008)	(0.0058)	(0.0004)	(0.0042)	(0.0086)
CY GS1 DD >8C	0.0027***	0.0214***	-0.0013**	-0.0131**	-0.0068
	(0.0009)	(0.0058)	(0.0005)	(0.0050)	(0.0117)
CY GS2 DD >8C	-0.0005	-0.0022	-0.0000	0.0005	0.0049
	(0.0004)	(0.0029)	(0.0002)	(0.0019)	(0.0062)
CY PP Rain Bottom Tercile	0.0173	0.1992	-0.0055	0.0235	0.5520
	(0.0327)	(0.2045)	(0.0144)	(0.1448)	(0.4497)
CY PP Rain Top Tercile	0.0001	0.0804	-0.0056	0.0721	0.4659
	(0.0391)	(0.2197)	(0.0215)	(0.2092)	(0.5053)
CY GS1 Rain Bottom Tercile	0.0716*	0.3051	0.0024	0.0085	0.9740**
	(0.0370)	(0.2436)	(0.0165)	(0.1770)	(0.3962)
CY GS1 Rain Top Tercile	0.0402	-0.0787	-0.0342**	-0.3063*	-0.2206
	(0.0391)	(0.2660)	(0.0147)	(0.1556)	(0.5700)
CY GS2 Rain Bottom Tercile	-0.0485	-0.2918	-0.0489**	-0.5361***	-0.5438
	(0.0373)	(0.2565)	(0.0204)	(0.1877)	(0.7960)
CY GS2 Rain Top Tercile	-0.0911**	-0.7127**	-0.0076	-0.0916	-1.0003
	(0.0428)	(0.2920)	(0.0148)	(0.1483)	(0.7652)
Village FE	Yes	Yes	Yes	Yes	Yes
Prov-by-Year FE	Yes	Yes	Yes	Yes	Yes
Observations	3726	3726	6210	6210	3726
R^2	0.336	0.353	0.594	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 8C) 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.33: Rainfall Coefficients: Log Total Maize Output and Temperature

	(1) Log Maize Yield/Acre (Kg.) β / SE
CY PP DD >8C	0.0018
	(0.0033)
CY GS1 DD >8C	-0.0038*
	(0.0023)
CY GS2 DD >8C	0.0006
	(0.0015)
CY PP Rain Bottom Tercile	-0.2430**
	(0.1020)
CY PP Rain Top Tercile	0.1067
	(0.0831)
CY GS1 Rain Bottom Tercile	0.0804
	(0.0823)
CY GS1 Rain Top Tercile	-0.1130
	(0.1071)
CY GS2 Rain Bottom Tercile	-0.0904
	(0.1173)
CY GS2 Rain Top Tercile	0.3880***
	(0.1129)
Village FE	Yes
Prov-by-Year FE	Yes
Observations	6210
R^2	0.374

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 8C) 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.34: Log Total Maize Output and Agricultural Inputs

	(1) Log Yield/Acre β / SE	(2) Log Yield/Acre β / SE
Ln Pesticide/Acre	0.0268**	
	(0.0118)	
Ln Fertilizer/Acre		0.0355***
		(0.0112)
Household FE	Yes	Yes
Village-by-Year FE	Yes	Yes
Observations	3726	6210
R^2	0.695	0.650

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 pesticide use. The table presents the effects of pesticide and fertilizer use on total maize output. Standard errors are in parentheses, clustered by village.
*Significant at 10%. **Significant at 5%. ***Significant at 1%.