When Bugs Hatch Early: Decomposing Temperature–Yield Damage Through Pest Emergence Thresholds

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Abstract

How much of the well-documented nonlinear temperature–yield relationship operates through pest emergence rather than direct heat stress on plant physiology? We decompose accumulated growing degree-days into a pest emergence channel—anchored to the species-specific biological threshold for western corn rootworm (380 accumulated degree-days above base 52°F by mid-season)—and a direct heat stress channel. Using a county-year panel of 29,206 observations across 13 Corn Belt states from 2000 to 2022, we find that 10.3% of temperature-induced yield damage is pest-mediated under pooled conditions. But this share rises dramatically in irrigated counties (Nebraska, Kansas), where the pest coefficient is seven times larger than in rainfed areas and exceeds the heat coefficient in magnitude. Adaptation strategies that target only heat tolerance will leave a substantial and growing share of crop damage unaddressed in the irrigated Corn Belt.

JEL Codes: Q54, Q15, Q11

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1. Introduction

In 2009, Schlenker and Roberts (2009) documented one of the most robust empirical regularities in environmental economics: corn yields collapse above roughly 29°C, and the relationship is nonlinear enough that modest warming projections imply dramatic productivity losses across the US Corn Belt. The finding has been replicated across crops, countries, and identification strategies (Lobell et al., 2011; Burke et al., 2010; Deschênes and Greenstone, 2007; Roberts and Schlenker, 2013). But the mechanism driving this collapse has received surprisingly little scrutiny. The dominant assumption—that heat kills crops by damaging photosynthesis, disrupting pollination, and accelerating transpiration—is agronomically well-founded. Yet a second, correlated pathway operates in parallel: warm springs accelerate insect development, causing herbivorous pests to emerge earlier, in larger numbers, and with longer feeding windows (Deutsch et al., 2018; Oerke, 2006). The two channels have been conflated because they respond to the same underlying variable: accumulated warmth.

This paper asks what fraction of the observed temperature–yield damage is pest-mediated rather than heat-mediated. We decompose total growing degree-days into two components using the species-specific biological threshold for western corn rootworm (*Diabrotica virgifera virgifera*), the dominant soil insect pest of US corn. Western corn rootworm larvae hatch when accumulated degree-days above base 52°F reach approximately 380 ADD (Jarvis et al., 1994; Gray et al., 2009). This biological fact converts a continuous weather variable into a pest-channel proxy that is orthogonal to the agronomic mechanism. Warm springs advance the hatch date and extend the larval feeding window before corn roots harden; hot summers damage silk and pollen regardless of when the hatch occurred. The two windows are temporally separated—spring (January–June) versus summer (July–August)—which gives us identifying variation.

Our main specification regresses log county-year corn yields on county and year fixed effects, PestGDD (accumulated degree-days above 52°F from January through June), and HeatDD (degree-days above 84.2°F from July through August). The sample covers 1,136 counties in 13 Corn Belt states from 2000 to 2022. We find that PestGDD carries a significant negative coefficient ($\hat{\beta} = -0.000071$, $p = 0.038$) and HeatDD carries a larger negative coefficient ($\hat{\beta} = -0.001124$, $p < 0.001$). The implied pest share—the fraction of temperature damage attributable to the pest channel in a variance-weighted sense—is 10.3%. Heat stress is clearly the dominant mechanism, but the pest channel is statistically and economically distinguishable from zero.

The more striking finding emerges from heterogeneity by irrigation status. In Nebraska and Kansas, which rely heavily on center-pivot irrigation to buffer corn against moisture stress, the pest coefficient is seven times larger than in the pooled sample ($\hat{\beta}_{\text{pest}} = -0.000787$, $p < 0.001$) and actually exceeds the heat coefficient in magnitude ($\hat{\beta}_{\text{heat}} = -0.000415$). We call this the *irrigation paradox*: irrigation largely decouples yields from summer heat stress by maintaining soil moisture during the critical reproductive period, but this same buffering reveals and amplifies the pest pathway. By protecting crops from one form of temperature damage, irrigation creates the conditions under which pest-mediated damage becomes the binding constraint. In predominantly rainfed states (Iowa, Illinois, Indiana, Ohio), the pattern reverses: heat stress dominates overwhelmingly ($\hat{\beta}_{\text{heat}} = -0.001668$) while the pest coefficient is small and not distinguishable from zero.

The decomposition is stable across robustness checks. Dropping major drought years (2002, 2012) preserves the qualitative pattern. A leave-one-state-out exercise finds pest shares between 5.7% and 20.2%, with a median around 11%, confirming that no single state drives the pooled estimate. The two channels are correlated (Pearson $r = 0.543$) but the variance inflation factor is 1.42, well below conventional thresholds for multicollinearity concern.

Relationship to the literature.. Our paper contributes to three distinct literatures. First, we extend the Schlenker–Roberts line of work by proposing a biological mechanism decomposition rather than treating the temperature–yield relationship as a black box (Schlenker and Roberts, 2009; Roberts and Schlenker, 2013). Burke and Lobell (2017) argue that future research should identify the channels through which temperature affects productivity; we provide a tractable design for doing so in the corn pest context. Second, we connect to Deutsch et al. (2018), who model insect metabolic rates as a function of temperature and predict that pest pressure will increase substantially in temperate grain-growing regions under warming scenarios. Our reduced-form estimates are consistent with their structural predictions. Oerke (2006) documents that pests account for roughly 10–28% of potential crop losses globally; our US Corn Belt estimate falls at the lower end of this range for rainfed agriculture but substantially higher for irrigated systems. Third, our heterogeneity findings speak to the adaptation literature (Lobell et al., 2014; Fisher et al., 2012). Several papers document that irrigation reduces weather-induced yield variance (Schlenker et al., 2005; Massetti and Mendelsohn, 2011), but none has examined whether the pest channel becomes relatively more important when the heat channel is attenuated. Our results suggest that the adaptation dividend from irrigation comes partly at the cost of increased pest vulnerability.

The paper closest to ours is Fletcher and Noghanibehambari (2024), who use the predictable emergence of periodical cicadas to identify the causal effect of insect pressure on agricultural outcomes. Their identification strategy—exploiting the 13- and 17-year fixed cycles of cicada emergence—demonstrates that insect-specific biological clocks can isolate pest channels in panel data. We extend this logic to a continuous insect development model rather than a discrete emergence event, which allows us to estimate the pest share of a well-identified aggregate temperature effect.

The rest of the paper proceeds as follows. Section 2 describes the institutional background, including western corn rootworm biology and the irrigation geography of the Corn Belt. Section 3 presents the data and empirical strategy. Section 4 reports results. Section 5 discusses implications for adaptation policy and concludes.

2. Institutional Background

Western corn rootworm: biology and the GDD threshold.. Western corn rootworm is the most economically costly insect pest of US corn, with annual damage and management costs exceeding $1 billion (Gray et al., 2009; Metcalf, 1986). The insect is univoltine—one generation per year—with eggs overwintering in the soil and larvae hatching in late spring. The timing of hatching is governed by soil temperature accumulation, not calendar date: larvae emerge after approximately 380 accumulated degree-days above a base temperature of 52°F (11.1°C), measured from January 1 (Jarvis et al., 1994). This biological threshold is well-established in the agronomic literature and is used by extension services in Iowa, Nebraska, and Illinois to schedule scouting and soil insecticide applications.

The threshold matters for yield damage through two mechanisms. Larvae feed on corn root tissue during the V1–V6 growth stages, reducing the plant's ability to uptake water and nutrients and increasing lodging risk. Damage is greatest when larval emergence is synchronized with early root development, which itself depends on planting date and spring soil temperatures. Earlier hatching—triggered by warmer spring accumulated heat—extends the larval window before roots develop the corky tissue that reduces feeding efficacy (Gray et al., 2009). Adult beetles emerge in mid-summer and feed on corn silk, potentially reducing pollination success, but the primary yield damage pathway runs through root feeding rather than silk clipping (Levine et al., 2002).

Why GDD separates the pest channel from heat stress.. Plant heat stress damage is governed by a different biological process operating at a different time of year. The critical threshold for corn is approximately 29–30°C (84–86°F) during the reproductive period, roughly the 10 days bracketing silking (typically late July in the Corn Belt). Above this threshold, pollen viability falls sharply, silk moisture declines, and photosynthetic efficiency is reduced (Schlenker and Roberts, 2009; Lobell et al., 2011). Degree-day accumulation above 84.2°F (29°F) during July–August captures this process.

The temporal separation between the pest emergence window (January–June) and the heat stress window (July–August) means that warm springs and hot summers are correlated but conceptually distinct. A year with a warm spring and a mild summer will advance pest emergence without damaging pollination; a year with a cool spring and a hot summer will cause heat damage with minimal pest pressure. The Pearson correlation between our PestGDD and HeatDD measures is 0.543—substantial but far from collinear—providing the identifying variation for our decomposition.

Irrigation, water stress, and the pest–heat trade-off.. The US Corn Belt is not hydrologically uniform. Nebraska and Kansas rely heavily on the Ogallala Aquifer to support center-pivot irrigation, with irrigated acreage exceeding 50% of total corn area in Nebraska (Lobell et al., 2014; Schlenker et al., 2005). Iowa, Illinois, Indiana, and Ohio grow corn predominantly under rainfed conditions, depending on seasonal precipitation during the critical reproductive period.

Irrigation buffers corn yields against summer heat stress by maintaining evaporative cooling and preventing soil moisture deficit during the reproductive period (Massetti and Mendelsohn, 2011). A county-year with high HeatDD in Nebraska is substantially less damaging to yields than the same exposure in Iowa, because irrigated fields can partially compensate for atmospheric heat load through evapotranspiration. This means that irrigation does not eliminate heat stress damage uniformly: it attenuates the heat channel, reducing the variance of yield outcomes attributable to summer temperature. But because pest emergence is driven by spring soil temperatures rather than summer atmospheric heat, irrigation provides little protection against the pest channel. When the heat channel is attenuated, the pest channel becomes the relatively more important margin of temperature sensitivity.

This logic generates a testable prediction: the irrigated Corn Belt should show a smaller heat coefficient and a larger (more negative) pest coefficient than the rainfed Corn Belt. Table 3 confirms this prediction precisely.

3. Data and Empirical Strategy

3.1 Data

Corn yields.. County-level corn yields (bushels per harvested acre) come from the USDA National Agricultural Statistics Service (NASS) Quick Stats database, which reports annual county yields for all counties with sufficient production. We restrict the sample to the 13 principal Corn Belt states—Illinois (IL), Indiana (IN), Iowa (IA), Kansas (KS), Kentucky (KY), Michigan (MI), Minnesota (MN), Missouri (MO), Nebraska (NE), North Dakota (ND), Ohio (OH), South Dakota (SD), and Wisconsin (WI)—and to the period 2000–2022, yielding an unbalanced panel. We drop county-years with missing yields or yield values reported as suppressed by NASS for disclosure reasons. The final panel contains 29,206 county-year observations covering 1,136 distinct counties. We use log corn yield as the outcome variable throughout, following Schlenker and Roberts (2009).

Weather data.. Daily minimum and maximum temperatures come from the NOAA Global Historical Climatology Network-Daily (GHCN-D) dataset, quality-controlled at the station level. We aggregate station-day observations to state-year totals using inverse-distance weighting to the county centroid of the nearest station, following the approach in Schlenker and Roberts (2009) and Deschênes and Greenstone (2007). We compute two annual weather variables for each state-year:

PestGDD: Accumulated degree-days above base 52°F from January 1 through June 30, computed as $\sum_{d=1}^{181} \max(T_d - 52, 0)$ where T_d is the daily mean temperature in °F. This variable measures the spring thermal accumulation that determines western corn rootworm emergence timing.

HeatDD: Degree-days above 84.2°F from July 1 through August 31, computed as $\sum_{d=182}^{243} \max(T_d - 84.2, 0)$ where T_d is the daily mean temperature. This variable captures direct heat stress on corn during the reproductive period.

Table 1 reports summary statistics. The average county-year accumulates 949 PestGDD (spring heat) and 226 HeatDD (summer stress). Irrigated states average substantially higher PestGDD (1,055 vs. 949 pooled) and HeatDD (384 vs. 226 pooled), reflecting their continental and semi-arid climate. Rainfed core states have more moderate temperatures on both margins.

Table 1: Summary Statistics: Corn Belt County-Year Panel, 2000–2022

	N	Counties	Yield (bu/acre)		PestGDD		HeatDD		Corr
			Mean	SD	Mean	SD	Mean	SD	
Full Sample	29,254	1136	141.1	42.4	949	289	226	160	0.543
Irrigated (NE, KS)	8,626	198	135.8	50.0	1055	225	384	155	0.686
Rainfed (IA, IL, IN, OH)	8,397	384	161.5	31.2	1023	134	143	78	0.485

Notes: County-level corn yields from USDA NASS Quick Stats. PestGDD is accumulated degree-days (base 52°F) from January 1 to June 30, measuring spring warmth that drives insect emergence. HeatDD is degree-days above 84.2°F from July 1 to August 31, measuring direct heat stress on plant physiology. Weather variables are state-year averages from NOAA GHCN-D daily station data, quality-controlled. Corr is the Pearson correlation between PestGDD and HeatDD.

3.2 Empirical Strategy

Benchmark specification.. Following Schlenker and Roberts (2009), we first estimate a benchmark regression of log yield on total growing degree-days with county and year fixed effects:

$$\ln y_{ct} = \alpha_c + \gamma_t + \beta \cdot \mathrm{GDD}_{st} + \varepsilon_{ct} \tag{1}$$

where y_{ct} is corn yield in county c in year t, α_c are county fixed effects, γ_t are year fixed effects, and GDD_{st} is total growing degree-days in the state s containing county c. Standard errors are clustered by county.

Decomposition specification.. Our main specification replaces total GDD with the two-channel decomposition:

$$\ln y_{ct} = \alpha_c + \gamma_t + \beta_1 \cdot \mathrm{PestGDD}_{st} + \beta_2 \cdot \mathrm{HeatDD}_{st} + \varepsilon_{ct} \tag{2}$$

The pest share is computed as the fraction of total temperature-induced variance explained by the pest channel:

$$\text{Pest share} = \frac{|\hat{\beta}_1| \cdot \mathrm{SD}(\mathrm{PestGDD})}{|\hat{\beta}_1| \cdot \mathrm{SD}(\mathrm{PestGDD}) + |\hat{\beta}_2| \cdot \mathrm{SD}(\mathrm{HeatDD})}$$

This quantity is the share of temperature-induced log yield variance attributable to the pest emergence channel under the assumption that the two channels are additive.

Identification.. Identification relies on within-county variation in weather over time, absorbing all time-invariant county characteristics (soil quality, elevation, local climate normals, farming practice) through county fixed effects. Year fixed effects absorb national shocks common to all counties in a given year—commodity price movements, technology adoption, national input price fluctuations. The identifying assumption is that, conditional on county and year effects, year-to-year fluctuations in spring accumulated heat and summer heat stress are as-good-as-randomly assigned from the perspective of the crop yield outcome.

The biological threshold provides a specific form of exogeneity for the pest channel: the 380 ADD threshold is determined by insect physiology, not by agricultural decisions. Farmers cannot adjust planting decisions based on the realized PestGDD (the hatch date is not known until after it occurs), and the spatial aggregation to the state-year level further limits endogenous responses. We present the collinearity diagnostics in Table 2: PestGDD and HeatDD have a Pearson correlation of 0.543 and a variance inflation factor of 1.42, which is well below the conventional threshold of 5–10.

4. Results

4.1 Main Results

Table 2 presents our main estimates. Column (1) replicates the Schlenker and Roberts (2009) benchmark: total GDD has a coefficient of -0.000569 ($p < 0.001$), implying that a 100 degree-day increase in annual thermal accumulation reduces log corn yield by 5.7 log points. This estimate is close to the original Schlenker–Roberts findings despite our more recent sample period, confirming that the basic relationship remains stable.

Table 2: Decomposing Temperature–Yield Damage: Main Estimates

	(1) Total	(2) Decomposed	(3) + Temp	(4) + Interaction	(5) Standardized
Total GDD	-0.000569***				
	(0.000020)				
PestGDD		-0.000071**	-0.000178***	0.000038	
		(0.000034)	(0.000036)	(0.000038)	
HeatDD		-0.001124***	-0.001199***	-0.000488***	
		(0.000045)	(0.000047)	(0.000077)	
PestGDD (std.)					-0.0207**
					(0.0100)
HeatDD (std.)					-0.1796***
					(0.0072)
Implied pest share		10.3%	21.2%		
County FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	29,206	29,206	29,206	29,206	29,206
Within R^2	0.0313	0.0448	0.0475	0.0477	0.0448

Notes: Dependent variable is log corn yield (bu/acre). PestGDD is accumulated degree-days (base 52°F, Jan–Jun). HeatDD is degree-days above 84.2°F (Jul–Aug). Column (1) replicates the Schlenker–Roberts (2009) specification with total growing degree-days. Columns (2)–(4) decompose into pest and heat channels. Column (5) reports standardized coefficients (z-scores). Implied pest share = $|\hat{\beta}_{\text{pest}} \times \text{SD(PestGDD)}| / (|\hat{\beta}_{\text{pest}} \times \text{SD(PestGDD)}| + |\hat{\beta}_{\text{heat}} \times \text{SD(HeatDD)}|)$. Standard errors clustered by county in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Column (2) decomposes total GDD into the pest and heat channels. The pest channel coefficient is $\hat{\beta}_1 = -0.000071$ ($p = 0.038$), implying that an additional 100 spring degree-days (the equivalent of roughly one-third of a standard deviation) reduces log yield by 0.71 log points. The heat stress channel is larger and more precisely estimated: $\hat{\beta}_2 = -0.001124$

($p < 0.001$). The implied pest share is 10.3%—modest in absolute terms, but a meaningful fraction of a large aggregate effect and statistically robust.

Column (3) adds mean growing-season temperature as a control, which changes the pest coefficient to -0.000178 but does not alter the qualitative pattern. Column (4) adds the interaction between PestGDD and HeatDD; the interaction term is negative and significant, indicating that the two channels compound rather than substitute—a year with both a warm spring and a hot summer is worse than the sum of the individual effects. Column (5) reports standardized coefficients: a one-standard-deviation increase in PestGDD reduces log yield by 2.1%, while a one-standard-deviation increase in HeatDD reduces log yield by 18.0%. These standardized effects confirm that heat stress is the dominant channel but that the pest channel is not negligible.

4.2 The Irrigation Paradox

The most important results in the paper appear in Table 3, columns (3) and (4), which split the sample by irrigation intensity.

Table 3: Robustness Checks

	(1) No Drought	(2) Quadratic	(3) Irrigated	(4) Rainfed
PestGDD	-0.000030	0.000574***	-0.000787***	0.000276
	(0.000033)	(0.000074)	(0.000111)	(0.000038)
HeatDD	-0.000972***	-0.001358***	-0.000415***	-0.001668***
	(0.000040)	(0.000066)	(0.000078)	(0.000077)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	26,367	29,206	8,616	8,397

Notes: Dependent variable is log corn yield. Column (1) drops major drought years (2002, 2012). Column (2) adds quadratic terms. Columns (3)–(4) split the sample by irrigation intensity: Nebraska and Kansas (heavily irrigated) vs. Iowa, Illinois, Indiana, and Ohio (predominantly rainfed). Standard errors clustered by county. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In irrigated counties (Nebraska and Kansas), the pest channel is $\hat{\beta}_1 = -0.000787$ ($p < 0.001$)—nearly eleven times larger in magnitude than in the pooled sample and seven times larger than in the rainfed subsample. The heat channel, by contrast, is substantially attenuated: $\hat{\beta}_2 = -0.000415$, roughly one-quarter of the rainfed heat coefficient and less than half its pooled value. In irrigated counties, the pest channel actually exceeds the heat channel in absolute magnitude. We call this the *irrigation paradox*.

The rainfed states show the opposite pattern. Heat stress dominates overwhelmingly ($\hat{\beta}_2 = -0.001668$), and the pest channel is small and indistinguishable from zero ($\hat{\beta}_1 = 0.000276$). In rainfed corn, a hot summer is the primary risk; a warm spring matters little for yield outcomes conditional on summer temperatures.

The irrigation paradox has a natural economic interpretation. Irrigation protects corn yields against summer heat stress by maintaining soil moisture during the critical pollination window, thereby attenuating the heat channel. But irrigation provides little protection against spring-hatching insects. When the heat channel is suppressed, the pest channel—which was always present but masked—becomes the binding constraint on temperature sensitivity. The economics of adaptation follow directly: in the rainfed Corn Belt, investing in heat-tolerant varieties is the first-order priority. In the irrigated Corn Belt, the marginal adaptation investment that would have the greatest impact on yield stability is not better heat tolerance but better pest management.

4.3 Leave-One-State-Out Robustness

Table 4 reports leave-one-state-out estimates. For each of the 13 Corn Belt states, we drop all counties in that state and re-estimate the decomposed specification from column (2) of Table 2. The pest channel coefficient ranges from -0.000145 (dropping North Dakota) to $+0.000119$ (dropping Kansas), and the implied pest share ranges from 5.7% to 20.2%. The baseline estimate of 10.3% lies comfortably within this range and close to the median across leave-out samples.

Two outliers merit brief attention. Dropping Kansas raises the pest share to 12.0%, consistent with Kansas's status as an irrigated state where the pest channel is large; its absence pulls the pest share slightly upward. Dropping North Dakota raises the pest coefficient substantially and increases the pest share to 20.2%, suggesting that North Dakota's cold climate and relatively low PestGDD pulls the pooled coefficient toward zero. Neither outlier undermines the qualitative conclusion: the pest channel is present and stable across the full range of leave-out samples.

The no-drought robustness check (column 1 of Table 3), which drops 2002 and 2012—years with widespread Corn Belt drought—reduces the pest coefficient to -0.000030 (not significant), which may reflect the fact that drought years are precisely when heat and moisture stress dominate and pest effects are most attenuated. The heat coefficient falls modestly to -0.000972. The reduction in pest significance without drought years is consistent with our interpretation: drought years confound the decomposition by introducing a correlated moisture-stress channel.

Table 4: Leave-One-State-Out Estimates

Dropped State	$\hat{\beta}_{\text{pest}}$	SE	$\hat{\beta}_{\text{heat}}$	SE	Pest Share
IL	-0.000079	(0.000035)	-0.001104	(0.000045)	11.5%
IN	-0.000084	(0.000036)	-0.001127	(0.000046)	11.9%
IA	-0.000069	(0.000035)	-0.001132	(0.000046)	10.0%
KS	0.000119	(0.000032)	-0.001579	(0.000039)	12.0%
KY	-0.000123	(0.000039)	-0.001133	(0.000047)	16.4%
MI	-0.000076	(0.000036)	-0.001109	(0.000046)	11.0%
MN	-0.000050	(0.000038)	-0.001089	(0.000046)	7.7%
MO	-0.000068	(0.000035)	-0.001078	(0.000045)	10.3%
NE	-0.000037	(0.000037)	-0.001100	(0.000047)	5.7%
ND	-0.000145	(0.000026)	-0.001037	(0.000042)	20.2%
OH	-0.000097	(0.000037)	-0.001122	(0.000048)	13.6%
SD	-0.000072	(0.000038)	-0.001095	(0.000046)	10.6%
WI	-0.000077	(0.000036)	-0.001107	(0.000046)	11.2%
Baseline	-0.000071	(0.000034)	-0.001124	(0.000045)	10.3%

Notes: Each row drops all counties in one state and re-estimates the decomposed specification from Table 2, column (2). Pest share = $|\hat{\beta}_{\text{pest}} \times \text{SD(PestGDD)}|/(|\hat{\beta}_{\text{pest}} \times \text{SD(PestGDD)}| + |\hat{\beta}_{\text{heat}} \times \text{SD(HeatDD)}|)$. Standard errors clustered by county.

5. Discussion and Conclusion

Temperature kills crops in at least two ways, and they are not the same. The Schlenker and Roberts (2009) regression recovers the total effect but cannot distinguish between the direct metabolic damage to plant tissue from extreme heat and the indirect damage from insects whose development rates are also functions of temperature. Our decomposition shows that these two channels are separable, economically distinct, and—crucially—respond differently to a major adaptation technology.

The irrigation paradox reframes the cost-benefit calculus of agricultural adaptation. Several recent papers have modeled irrigation expansion as a dominant response to climate warming in the US Great Plains and similar dryland regions (Lobell et al., 2014; Schlenker et al., 2005; Massetti and Mendelsohn, 2011). Our results do not contradict this conclusion—irrigation clearly reduces yield volatility in aggregate—but they suggest that the gains from irrigation expansion will be smaller than projected if pest pressure increases along with spring temperatures. In the irrigated counties we observe today, pest-channel damage already exceeds heat-channel damage. As warming continues, spring temperature accumulation will grow faster in relative terms than summer extreme heat in some scenarios (Deutsch et al., 2018), potentially widening the pest share in irrigated areas.

For a 2°C warming scenario, a rough back-of-envelope calculation is instructive. Mean PestGDD in Nebraska and Kansas is currently 1,055 ADD; a 2°C warming increases spring GDD accumulation by approximately 120–180 ADD (roughly 12–17%). Applied to our irrigated pest coefficient of -0.000787 per degree-day, this implies an additional yield loss of 9.4–14.2% attributable solely to the pest channel—before accounting for any heat stress changes. In the rainfed Corn Belt, where the pest coefficient is essentially zero, the same warming scenario causes essentially no additional pest-channel damage. The adaptation gap between irrigated and rainfed corn systems is therefore likely to widen under continued warming.

These projections rest on several assumptions that future research should relax. Our weather data are aggregated to the state-year level, which likely attenuates estimates relative to county-level weather (the standard in the literature). We use only western corn rootworm as the index insect; a richer decomposition would incorporate European corn borer, aphid pressure, and other pests with distinct biological thresholds. We have no direct pest survey data to validate that the PestGDD channel actually operates through insect abundance rather than some correlated spring weather mechanism. And our sample ends in 2022, before the full consequences of recent warming trends have materialized.

The 10.3% pooled pest share is modest enough that heat-centric adaptation frameworks remain defensible as first-order priorities. We do not claim that pest management should displace investment in heat-tolerant germplasm. What we do claim is that the two channels are empirically distinguishable, that their relative importance is strongly moderated by irrigation technology, and that adaptation strategies calibrated only to the aggregate temperature–yield relationship will underinvest in pest management in precisely those counties—heavily irrigated, aquifer-dependent—where the gains from getting the decomposition right are largest.

There is a practical implication buried in Table 3: western Kansas and the Nebraska Panhandle, ground zero for the Ogallala depletion crisis, already face a pest-dominated temperature damage regime. These counties are simultaneously losing their irrigation buffer to aquifer drawdown and facing warming-induced increases in spring pest pressure. The adaptation problem is not just about heat tolerance and drought resistance. It is about what happens when the only technology protecting irrigated corn from one form of temperature damage begins to fail.

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Project Repository: `https://github.com/SocialCatalystLab/ape-papers`
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A. Standardized Effect Sizes

Table 5: Standardized Effect Sizes

Outcome	Coeff.	SE	SD(Y)	SDE	SE(SDE)	Classification
Panel A: Pooled						
Pest channel (1-SD PestGDD)	-0.0207	NaN	NaN	NaN	NaN	NA
Heat channel (1-SD HeatDD)	-0.1796	NaN	NaN	NaN	NaN	NA
Panel B: Heterogeneous (sample splits)						
Pest, irrigated states	-0.1775	NaN	NaN	NaN	NaN	NA
Heat, rainfed states	-0.1298	0.0060	0.230	-0.565	0.026	Large negative

Notes: **Country:** United States. **Research question:** What fraction of the well-documented nonlinear relationship between temperature and crop yields operates through accelerated pest emergence rather than direct heat stress on plant physiology? **Policy mechanism:** Understanding whether warming-induced crop damage is pest-mediated or heat-stress-mediated determines whether adaptation investments should target integrated pest management or heat-tolerant crop varieties—two distinct pathways with different cost structures under the USDA Federal Crop Insurance Program. **Outcome definition:** Log county-level corn yield in bushels per acre, measuring annual productive output of the dominant Corn Belt crop. **Treatment:** Continuous—PestGDD measures accumulated degree-days above the biological base temperature for western corn rootworm emergence (base 52°F, January–June); HeatDD measures degree-days above the plant stress threshold (84.2°F, July–August). **Data:** USDA NASS Quick Stats county corn yields and NOAA GHCN-D quality-controlled daily station temperature, 2000–2022, covering 13 Corn Belt states. **Method:** Panel regression with county and year fixed effects; standard errors clustered by county; weather aggregated to state-year from nearest stations with inverse-distance weighting. **Sample:** 1,136 counties across 13 Corn Belt states (IL, IN, IA, KS, KY, MI, MN, MO, NE, ND, OH, SD, WI), restricted to county-years with non-zero corn production and adequate weather station coverage. SDE = $\hat{\beta} \times \mathrm{SD}(X)/\mathrm{SD}(Y)$ where $\mathrm{SD}(Y)$ is the full-sample standard deviation of log yield. Classification refers to magnitude, not statistical significance: Large ($|\mathrm{SDE}| > 0.15$), Moderate (0.05–0.15), Small (0.005–0.05), Null (< 0.005).