

The Terror of History: Solar Eclipses and the Origins of Critical Thinking and Complexity



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Motivation

- Understanding of long-run economic growth based on
 - Geographical factors (Ashraf and Galor (2011), Nunn and Puga (2012)),
 - Caloric availability (Dalgaard et al. (2015), Galor and Özak (2016)),
 - Climatic variability (Waldinger (2015)).
- In modern time, *human capital* is a salient determinant of growth:
 - Galor and Moav (2006), Barro (2001), Hanushek and Woessmann (2012).
- However, little evidence about the importance of human capital for growth in the long run.
 - With some notable exceptions: Voigtlander and Squicciarini (2015), Mokyr (2018), Chen et al. (2020).

This Paper

Research question

Is human capital related to economic growth in pre-modern times?

- There is no data on human capital for pre-modern groups.
- Main idea:
 - Curiosity: precursor of human capital.
 - Explaining rare phenomena: intellectual endeavour, “early attempts at scientific explanation” (Ludwig et al. (2007)).
 - More rare phenomena → Comparative advantage in thinking.
- We exploit eclipse frequency to explain economic prosperity.
- Focus of the paper:
 - Pre-modern ethnic groups: Australian aborigens, African tribes, North-American natives, etc.

Solar Eclipses and Curiosity

- Solar eclipses are impressive even today, and more so during the past.
 - Day turns into night, temperature drops, animals change behaviour, winds change direction.
- For pre-modern groups: increase the demand for explanations:
 - Iwaniszewski (2014), Barale (2014)

Characteristics:

- A solar eclipse can be seen from a narrow path on Earth.
- Random, exogenous occurrence.
- Affects several locations simultaneously.

Competing Natural Events

- Alternative curiosity-catching phenomena have problems:
 - Cause massive destruction: retard growth.
 - Volcano eruptions, earthquakes, floods and tsunamis.
 - Are less impressive, harder to notice and more common:
 - Lunar and partial eclipses, lightning.
 - Affect the whole Earth:
 - Supernovae (extremely rare), comets.
- However, solar eclipses:
 - Do not destroy physical nor human capital.
 - Impressive effects: obscurity, wind, temperature.
 - Narrow area of effect: provides local variation.

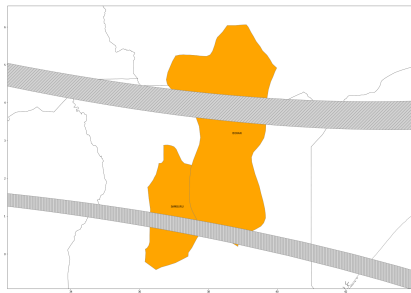
Empirical Strategy

- Relate the number of total solar eclipses to:
 - development and
 - human capital proxies.
- Most outcomes are ordered lists \rightarrow ordered logit regression.
- Unit of observation: the ethnic group.

$$y_{i,j} = f(\alpha \text{eclipses}_{i,j} + X_{i,j}\beta + \gamma_j + \epsilon_{i,j})$$

Data: Total Solar Eclipses

- Intersect eclipse paths with ethnic homelands.
- Time frame: 2000BCE to 1500CE.
- Count the number of total solar eclipses visible from ethnic homelands.



Data: Outcome Variables

- Proxies for economic development:
 - Social complexity (Ethnographic Atlas):
 - Jurisdictional Hierarchy Beyond Local Community.
 - Political Integration,
 - Class Stratification.
 - Other proxies of economic development (SCCS):
 - Technological level,
 - Population density.
- Proxies for human capital:
 - Presence of writing,
 - Play of strategy games,
 - Folkloric understanding of eclipses.

Preview of the Results

We find that a higher frequency of exposure to solar eclipses is associated with

- more economic development,
- and higher human capital.

Summary Statistics

	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max.
<i>Eclipses</i>								
Number of eclipses	69.117	54.483	13.000	883.000	Annual mean temp.	192.946	89.340	-166.522
Avg. time between eclipses(centuries)	0.658	0.300	0.040	2.560	Annual precipitation	1327.907	954.285	0.264
Min. Time between eclipses(centuries)	0.023	0.028	0.000	0.290	Ecological diversity	0.420	0.246	0.000
Max. Time between eclipses(centuries)	2.857	1.252	0.194	8.575	Dist. coast (km)	430.916	412.958	0.054
Number of lunar eclipses	1391.215	90.897	1336.000	2443.000	Dist. river (km)	248.096	836.981	0.198
<i>Jurisdictional Hierarchy</i>					Dist. Addis Ababa (km)	14.675	13.162	0.125
No levels	0.461	0.499	0.000	1.000	Ruggedness	86.664	32.505	0.000
One level	0.298	0.458	0.000	1.000	Elevation	162.953	26.374	0.000
Two levels	0.142	0.349	0.000	1.000	Malaria	0.173	0.206	0.000
Three levels	0.073	0.260	0.000	1.000	Caloric yield	1170.170	860.545	0.000
Four levels	0.026	0.159	0.000	1.000	Abs. latitude	21.443	17.700	0.017
<i>Class Stratification</i>					South (0/1)	0.203	0.403	0.000
Absence among freemen	0.487	0.500	0.000	1.000	Dependence on gathering (%)	24.149	128.998	2.500
Wealth distinctions	0.191	0.393	0.000	1.000	Dependence on agriculture (%)	45.249	26.581	2.500
Elite	0.035	0.184	0.000	1.000	<i>Intensity of Agriculture</i>			
Dual	0.213	0.410	0.000	1.000	No agriculture	0.206	0.404	0.000
Complex	0.074	0.262	0.000	1.000	Casual agriculture	0.036	0.187	0.000
<i>Political Integration</i>					Extensive agriculture	0.401	0.490	0.000
Absence	0.018	0.132	0.000	1.000	Horticulture	0.083	0.275	0.000
Autonomous local comm.	0.107	0.309	0.000	1.000	Intensive agriculture	0.166	0.372	0.000
Peace groups	0.007	0.083	0.000	1.000	Intensive irrigated agriculture	0.109	0.311	0.000
Minimal states	0.062	0.241	0.000	1.000	<i>Major Crop Type</i>			
Little states	0.023	0.151	0.000	1.000	None	0.213	0.410	0.000
States	0.034	0.181	0.000	1.000	Non food crop	0.002	0.041	0.000
<i>Technological Level</i>					Vegetables	0.003	0.050	0.000
Technological Level	9.536	1.492	7.194	13.378	Tree fruits	0.068	0.252	0.000
<i>Population Density</i>					Roots or tubers	0.197	0.398	0.000
Less than 1 / sq. mile	0.280	0.450	0.000	1.000	Cereal grains	0.517	0.500	0.000
1-5 / sq. mile	0.161	0.368	0.000	1.000	<i>Subsistence Economy</i>			
5-25 / sq. mile	0.181	0.386	0.000	1.000	Gathering	0.080	0.271	0.000
25-100 / sq. mile	0.197	0.399	0.000	1.000	Fishing	0.093	0.290	0.000
100-500 / sq. mile	0.124	0.331	0.000	1.000	Hunting	0.060	0.237	0.000
500 or more / sq. mile	0.057	0.232	0.000	1.000	Pastoralism	0.061	0.240	0.000
<i>Writing</i>					Extensive agriculture	0.372	0.484	0.000
Writing	0.212	0.410	0.000	1.000	Intensive agriculture	0.214	0.410	0.000
<i>Strategy Games</i>					Two or more above	0.051	0.220	0.000
Strategy games	0.169	0.375	0.000	1.000	Agriculture, unknown type	0.070	0.255	0.000
<i>Eclipse Explanation</i>								
No explanation	0.640	0.480	0.000	1.000				
Naive	0.258	0.438	0.000	1.000				
Involve Moon and Sun	0.102	0.303	0.000	1.000				

Results: Social Complexity

	Jurisdictional Hierarchy			Political Integration			Class Stratification		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Total number of eclipses	0.014*** (0.003)	0.015*** (0.003)	0.008*** (0.002)	0.011*** (0.003)	0.012*** (0.004)	0.011** (0.004)	0.008*** (0.003)	0.013*** (0.003)	0.008*** (0.003)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes	No	No	Yes
Pseudo- R^2	0.138	0.212	0.262	0.073	0.180	0.259	0.075	0.144	0.179
Observations	1111	911	911	307	255	255	1067	825	825

¹ Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Technology and Pop. Density

	Technology Level			Population Density		
	(1)	(2)	(3)	(4)	(5)	(6)
Total number of eclipses	0.003* (0.002)	0.004*** (0.001)	0.004** (0.002)	0.002 (0.002)	0.004 (0.003)	0.016*** (0.006)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes
Pseudo- R^2	0.345	0.577	0.706	0.090	0.276	0.454
Observations	129	108	108	166	139	139

¹ Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Size of the Effects

Jurisdictional Hierarchy (1)		Political Integration (2)		Class Stratification (3)		Technological Level (4)	Population Density (5)	
No levels	-0.046*** (0.013)	Absent	-0.019** (0.009)	Absent	-0.057*** (0.019)	0.175** (0.070)	Less than 1 / sq. mile	-0.040*** (0.014)
1 level	0.004** (0.002)	Local com.	-0.038** (0.015)	Wealth	0.005** (0.003)		1-5 / sq. mile	-0.008 (0.006)
2 levels	0.020*** (0.006)	Peace groups	-0.001 (0.001)	Elite	0.003** (0.001)		5-25 / sq. mile	-0.005 (0.005)
3 levels	0.016*** (0.004)	Min. states	0.008 (0.006)	Dual	0.031*** (0.011)		25-100 / sq. mile	0.016*** (0.004)
4 levels	0.006*** (0.002)	Little states	0.016** (0.007)	Complex	0.018*** (0.006)		100-500 /sq. mile	0.024** (0.011)
		States	0.033** (0.014)				500 or more / sq. mile	0.014*** (0.005)

¹ Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Competing Mechanisms

- Other rare events Rare events
 - Lunar eclipses,
 - Distance to volcanoes,
 - Distance to tectonic plates.
- Alternative drivers of social complexity Additional controls
 - Population density: scalar stress (Johnson, 1982)
 - Ecological diversity (Fenske, 2014).

Other Competing Mechanisms

- Bigger ethnic homelands experiences more eclipses.
- We tackle this by:
 - Control for area.
 - Redefine the main variable:
Predicted number of eclipses based on area, while controlling for the actual number.

Area

Robustness

- Validity of eclipses measure: Other times
 - Other time frames: -2000 to -1500, -1500 to -1000, etc.

Robustness: Other Ethnic Controls

- Other ethnic controls: Alt. ethnic
 - Reliance on agriculture,
 - Reliance on hunting and gathering,
 - Subsistence types.

Spatial Correlation

- Control for neighbour's number of eclipses,
- Different clustering,
- Control for language family.

Spatial cor.

The Mechanism

- We argue that eclipses raise human capital by prompting thinking.
- Test this hypothesis on variables indicative of human capital:
 - Writing,
 - Play of strategy games,
 - Folkloric understanding of eclipses.

The Mechanism

	Writing			Strategy Games			Eclipse Explanation		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Total number of eclipses	0.003*** (0.000)	0.003*** (0.001)	0.004** (0.001)	0.001*** (0.000)	0.001*** (0.000)	0.002*** (0.000)	0.001 (0.001)	0.002* (0.001)	0.004** (0.002)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geography	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Ethnic	No	No	Yes	No	No	Yes	No	No	Yes
Pseudo- R^2	0.212	0.520	0.573	0.486	0.599	0.653	0.061	0.142	0.158
Observations	139	117	117	448	336	336	567	437	436

¹ Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Concluding Remarks

- We study human capital and growth for pre-modern ethnic groups.
- Our results suggest that:
 - Exposure to inexplicable phenomena is related to economic growth.
- We provide evidence compatible with the hypothesis of human capital accumulation.
 - Solar eclipses call for an explanation.
 - Contributes to develop thinking and human capital.

APPENDIX

Results: Other Rare Events [Back](#)

	Jurisdic. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
Panel A: Volcanoes					
Total number of eclipses	0.008*** (0.002)	0.011** (0.004)	0.009*** (0.003)	0.004** (0.002)	0.016*** (0.006)
Dist. Volcano	0.000 (0.000)	-0.000 (0.000)	-0.001** (0.000)	-0.000 (0.000)	-0.000 (0.001)
R^2 Pseudo- R^2	0.262	0.259	0.185	0.706	0.455
Observations	911	255	825	108	139
Panel B: Tectonic Faults					
Total number of eclipses	0.008*** (0.002)	0.011** (0.004)	0.009*** (0.003)	0.004** (0.002)	0.016*** (0.006)
Dist. Tec. Fault	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.001 (0.001)
R^2 Pseudo- R^2	0.262	0.260	0.181	0.708	0.460
Observations	911	255	825	108	139
Panel C: Lunar Eclipses					
Total number of eclipses	0.007** (0.003)	0.009 (0.006)	0.007** (0.004)	0.007 (0.006)	0.017* (0.010)
Total number of lunar eclipses	0.001 (0.001)	0.002 (0.003)	0.001 (0.001)	-0.002 (0.005)	-0.001 (0.008)
R^2 Pseudo- R^2	0.262	0.259	0.179	0.706	0.454
Observations	911	255	825	108	139
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

¹ Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Alternative Drivers [Back](#)

	Jurisd. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
Panel A: Population Density					
Total number of eclipses	0.017* (0.009)	0.040*** (0.012)	0.019** (0.009)	0.002 (0.002)	
Pop. Density	Ref.	Ref.	Ref.	Ref.	
< 1 p. / sq. mile	Ref.	Ref.	Ref.	Ref.	
1-5 p. / sq. mile	-1.091** (0.521)	-0.807 (1.282)	0.104 (1.090)	0.502 (0.773)	
5-25 p. / sq. mile	2.980** (1.456)	4.316*** (1.635)	1.510 (1.274)	0.309 (0.932)	
25-100 p. / sq. mile	2.739 (1.706)	3.650*** (1.395)	1.696 (1.241)	1.104 (0.943)	
100-500 p. / sq. mile	3.656* (1.962)	4.629** (2.350)	2.712** (1.302)	0.803 (1.196)	
> 500 p. / sq. mile	5.414*** (1.898)	5.208* (2.940)	3.377 (2.242)	-0.142 (1.174)	
R ² Pseudo-R ²	0.433	0.533	0.310	0.740	
Observations	139	100	139	98	163
Panel B: Ecological Diversity					
Total number of eclipses	0.008*** (0.002)	0.010** (0.004)	0.008*** (0.003)	0.004* (0.002)	0.016*** (0.006)
Eco. diversity	0.580 (0.374)	0.731 (0.717)	0.932*** (0.304)	0.297 (0.740)	3.557*** (1.690)
R ² Pseudo-R ²	0.263	0.261	0.182	0.707	0.475
Observations	911	255	825	108	139
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

¹ Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

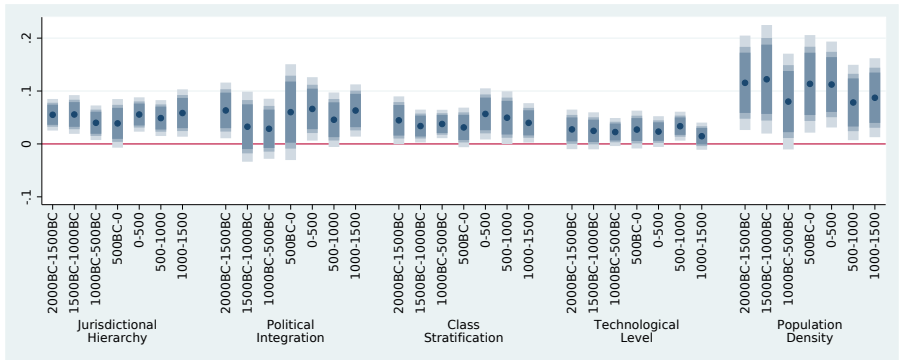
Results: Area [Back](#)

	Jurisdic. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
Panel A: Area					
Total number of eclipses	0.007** (0.003)	0.005 (0.004)	0.007*** (0.002)	0.005 (0.004)	0.016** (0.008)
Area	0.000 (0.000)	0.000*** (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
R^2 Pseudo- R^2	0.257	0.257	0.176	0.694	0.419
Observations	943	269	856	113	145
Panel B: Expected eclipses, 50 km radius					
Total number of eclipses	0.007*** (0.003)	0.006 (0.004)	0.007*** (0.003)	0.005 (0.004)	0.016** (0.007)
Expected eclipses 50 km radius area	0.001 (0.001)	0.005** (0.002)	0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)
R^2 Pseudo- R^2	0.257	0.256	0.176	0.694	0.419
Observations	943	269	856	113	145
Panel C: Expected eclipses, 100 km radius					
Total number of eclipses	0.007*** (0.003)	0.005 (0.004)	0.007*** (0.003)	0.005 (0.004)	0.016** (0.007)
Expected eclipses 100 km radius area	0.001 (0.001)	0.004*** (0.001)	0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)
R^2 Pseudo- R^2	0.257	0.257	0.176	0.694	0.419
Observations	943	269	856	113	145
Controls (common to all regressions)					
Fixed effects	Yes	Yes	Yes	Yes	Yes
Geography	Yes	Yes	Yes	Yes	Yes
Ethnic	Yes	Yes	Yes	Yes	Yes

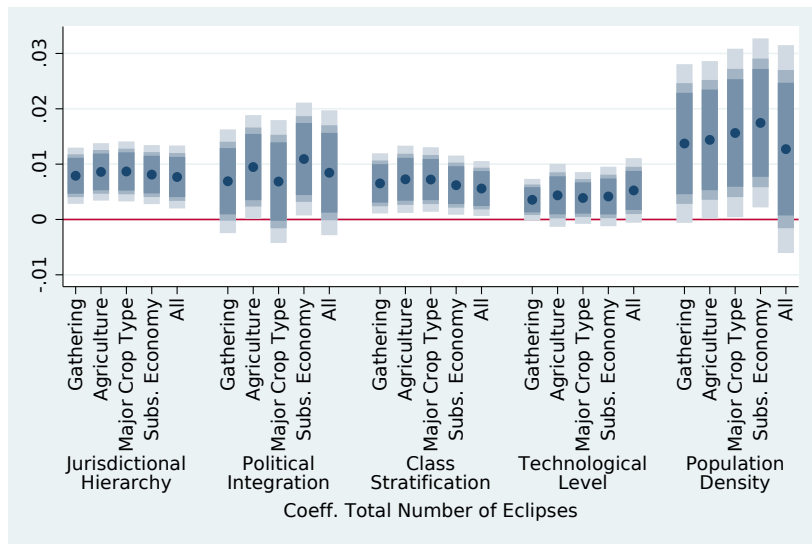
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² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results: Other Times [Back](#)



Results: Other Ethnic Characteristics [Back](#)



Results: Spatial Correlation [Back](#)

	Jurisdicht. Hierarchy	Pol. Int.	Class Strat.	Tech. Level	Pop. Den.
	(1)	(2)	(3)	(4)	(5)
A: Nearest Neighbour					
Total number of eclipses	0.009*** (0.002)	0.010* (0.006)	0.010*** (0.004)	0.006** (0.002)	0.015** (0.006)
Eclipses neighbour	-0.002 (0.002)	0.001 (0.003)	-0.004 (0.003)	-0.011 (0.006)	0.003 (0.004)
Pseudo- R^2	0.259	0.258	0.179	0.730	0.463
Observations	892	246	807	103	134
B: Clustering at ecoregions					
Total number of eclipses	0.008*** (0.002)	0.011*** (0.004)	0.008*** (0.003)	0.004** (0.002)	0.016*** (0.006)
Pseudo- R^2	0.262	0.259	0.179	0.706	0.454
Observations	911	255	825	108	139
C: Language Fixed Effects					
Total number of eclipses		0.021*** (0.007)	0.006*** (0.002)	0.016 (0.027)	-0.037 (0.023)
Language FE		Yes	Yes	Yes	Yes
Controls (common to all regressions)					
Fixed effects		Yes	Yes	Yes	Yes
Geography		Yes	Yes	Yes	Yes
Ethnic		Yes	Yes	Yes	Yes
R^2 Pseudo- R^2		0.381	0.235	0.926	0.718
Observations	703	255	825	108	139

¹ Geography: avg. temp., temp. seasonality, precipitation, precipitation seasonality, dist. to the coast, to rivers and to Addis Ababa, ruggedness, elevation, malaria, caloric yield, absolute latitude, south dummy, major habitat type dummies. Ethnic: major crop type (Fenske, 2014).

² * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.