Extreme Heat and Agricultural Productivity: The Case of Subsistence Farming in Nigeria

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Introduction

- 56% of the labor force in Sub-Saharan Africa works in farming (World Bank, 2018).
- Sub-Saharan Africa is the region with the lowest agricultural productivity (McCullough, 2017).
- The region is particularly vulnerable to climate change because:
  - Mean temperatures have increased (Dosio, 2017),
  - heat stresses plant growth (Lobell et al., 2012), and
  - rising temperatures potentially threaten agricultural productivity and production.
- It is critical to understand the impact of high temperatures on farming productivity to design policies to attenuate the impact of weather shocks on farmer household incomes.

Research Question

- Two of the main measures of agricultural productivity are yield and total factor productivity (TFP). Yield is equal to the value or volume of production over an area, while TFP is the ability of a farmer to produce a certain amount of output with a given set of inputs.
- Yield is a limited measure of productivity as it already accounts for adaptation while TFP is robust to adaptation.
- We know little about the impact of high temperatures on agricultural productivity at the farm level in Sub-Saharan Africa, or how to estimate the impact of high temperatures on TFP at the farm level without bias.
- This project estimates the impact of high temperatures on TFP at the farm level in Nigeria.

Farming in Nigeria

- Nigeria is the most populated country in Sub-Saharan Africa.
- Between 35% and 45% of the labor force works in agriculture (World Bank, 2021).
- Frequency and length of heatwaves will increase (Dosio, 2017).
- Land scarcity limits scope for short-term adaptation (Mueller and Thurlow, 2019).
- Lower agricultural productivity potentially implies lower aggregate farm output.

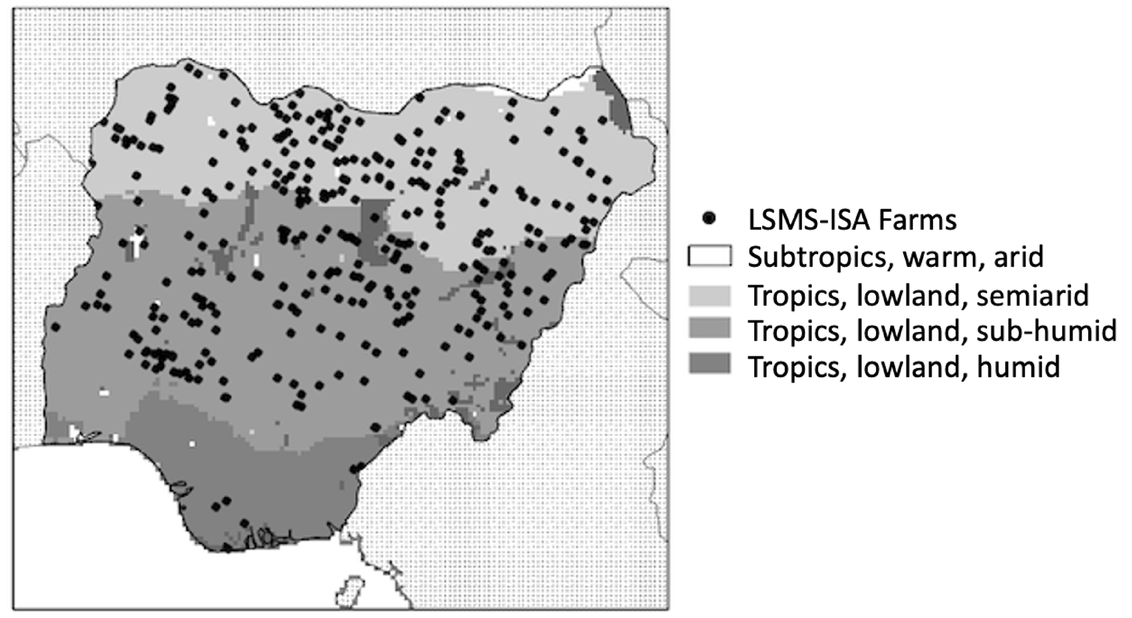
Figure 1. Figure 1: World Map

Data

- Nigeria LSMS-ISA: Nationally representative panel of households .
  - Waves: 2010, 2012, 2015, and 2018.
  - Demographic information at the individual and household level.
  - Agricultural production information at the farm, plot or crop-plot levels.
  - Soil type and quality, plot area, input use, and output value per crop.
- Final dataset has information at the farm level.
- Value of agricultural production in 2010 USD with Laspeyres Index.

- Daily land surface temperature and monthly rainfall data from MODIS and CHIRPS.
- Resolution: $0.05° \times 0.05°$ bins ($0.05° \approx$ 5.6 km or 3.5 miles at the Equator).
- The study links each household with the bin overlapping its coordinates.
- The final sample has 3678 farms.

Figure 2: Agroecological Zones and LSMS-ISA Clusters in the Study's Final Sample



Notes: The figure was made using data from Global Agroecological Zones (GAEZ) and the Nigeria LSMS-ISA.

Empirical Framework

Unit of observation: Farmer i in growing season t

$$Y_{it} = (L_{it})^{\alpha_L}(F_{it})^{\alpha_F}(H_{it})^{\alpha_H}e^{\omega_{it}} \tag{1}$$

$$\omega_{it} = g(\tau, X_{it}) + W_{it}^{Y}\beta_{it} + \omega_{it}^{Y} + \varepsilon_{it} \tag{2}$$

$$ln(Y_{it}) = g(\tau, X_{it}) + \alpha_L ln(L_{it}) + \alpha_F ln(F_{it}) + \alpha_L ln(H_{it}) + W_{it}^{Y}\beta_{it} + \omega_{it}^{Y} + \varepsilon_{it}. \tag{3}$$

Production function

- Y_{it}: Value of total production
- L_{it}: area planted in hectares
- F_{it}: # of HH members working on-farm
- H_{it}: # of worker-days of hired labor
- ω_{it}: TFP

TFP

- $g(\tau, X_{it})$: Function of temperature and rainfall
- W_{it}^{Y}: Non-weather determinants
  - HH head characteristics
  - Farm characteristics
  - Locality and region-by-year FE
- ω_{it}^{Y}: Unobserved component

- Endogeneity concerns if inputs and components of ω_{it}^{Y} are correlated.
- IV identification strategy by Gollin and Udry (2021).
  - Assumption 1: Farmers equalize input marginal product values to input shadow prices.
  - Assumption 2: Shocks faced to other farmers in the village impact input shadow prices.
- Typical instrument: average shock experienced by other farmers in the village × own-farm or own-household characteristics.
- Estimation with two-stage least squares (2SLS)

Extreme Heat Threshold

$$g(\gamma, \omega_{jt}) = \gamma_0 GDD_{jt} + \gamma_1 HDD_{jt} + \gamma_2 PP_{jt} + \gamma_3 PP_{jt}^2 \tag{4}$$

- Land surface temperature: h_d.
- Growing degree days: $GDD = \frac{1}{n}\sum_{d=1}^{n}(\min(h_d, \tau) - 8)\,\mathbf{1}(h_d \geq 8)$.
- Harmful degree days: $HDD = \frac{1}{n}\sum_{d=1}^{n}(h_d - \tau)\,\mathbf{1}(h_d > \tau)$.
- I estimate equation 3 for $\tau \in \{26, 27, ..., 44, 45\}$ similarly to Burke and Emerick (2016) and Aragón et al. (2021).
- Regression fit is highest when $\tau = 40°C$ or $104°F$.

Results

Table 1. Agricultural Production and Productivity

	Yield	TFP		Production
	(1)	(2)	(3)	(4)
	ln(yield)	ln(output)	ln(output)	ln(output)
GDD	0.125**	0.137***	0.136***	0.139***
	(0.0567)	(0.0380)	(0.0418)	(0.0452)
HDD	-0.363**	-0.358***	-0.387***	-0.336***
	(0.155)	(0.0958)	(0.114)	(0.104)
Input controls	No	Yes	Yes	No
Method	OLS	OLS	IV	OLS
First-stage F-stat			20.42	
Observations	3588	3588	3527	3588
R^2	0.386	0.468	0.147	0.349

Notes: Robust standard errors clustered at the village level are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. Input controls are the logs of the area planted in hectares, the number of household members working in the farm, and the number of worker-days of hired labor.

- An extra HDD decreases yield, TFP, and production by 30%, 32% and 28%, respectively.
- Nigerian farmers do not adapt area planted as a response to extreme heat.
- If temperature increases by 1°C throughout the growing season, aggregate agricultural output:
  - increases in humid or semihumid regions,
  - decreases in semiarid region,
  - and decreases by 3% at the national level.

Conclusion

- Extreme heat substantially impacts agricultural productivity in Nigeria.
- Evidence of limited attenuation of shock.
- Limitations of the study: Long-term effects, and how farmers get information on shocks.

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