Maize Yield Response to Fertilizer under Differing Agro-Ecological Conditions in Burkina Faso

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Motivation

• Achieving food security depends on smallholder productivity

• Intensification the only option:
  • High population density
  • Aged, degraded soils need mineral fertilizer

• Fertilizer policy: “blanket recommendations”

• Diverse agro-ecologies → variable economic incentives
Research hypothesis

- *Response* of maize yields to fertilizer and *profitability* of fertilizer use on maize varies by agro-ecological factors

- Contribution to a sparse regional literature
Context

3 agro-ecological zones

- Sahelian (< 600 mm)
- Sudano-sahelian (600-900)
- Sudanian (900-1200)

10 soil types

- 2/3 of the country is covered by soils that are iron-rich and low in organic matter

Maize area ↑ by 700% in 40 years
Data

• Continuous farm household survey from the General Research and Sectoral Statistics Department (DGESS), 2009/10-2011/12
  - 2,321 households (out of 2,700) and 9,526 maize plots

• National Oceanic and Atmospheric Administration’s Climate Prediction Center

• European Union’s Soil Atlas of Africa
## Methods

### Yield response function
- Control function approach with correlated random effects
- Quadratic term for N
- Interaction of N with agro-ecological factors
- Agro-ecological factors measured at several scales

### Profitability
- Marginal product of N
- Marginal value-cost ratio (MVCR)
- Average value-cost ratio (AVCR)
- Low, average, and high farm gate prices
- Market, official subsidized, and transacted-subsidized fertilizer prices
Yield Response

\[ \text{Yield}_{ijt} = \alpha N_{ijt} + \beta X_{ijt} + U_{ijt} \]

- \( N_{ijt} \): application rate
- \( X_{ijt} \): vector of other covariates
- \( U_{ijt} \): is composed of
  - \( V'_{ijt} \): unobserved plot characteristics correlated with N application
  - \( E_{ijt} \): random errors
  - \( C_{j} \): unobserved household time-invariant characteristics

\[ c_{j} = \overline{X'j}\delta + \alpha_{j} + \omega, \quad \alpha_{j} \mid X_{j} \sim N(0, \sigma_{\alpha}^{2}) \]

\[ N_{ijt} = \pi Z_{ijt} + V_{ijt} + C_{j} \quad (Z_{ijt} \text{ is a set of covariates & instrumental variable}) \]
Profitability

Parameters

1. Agronomic optimum
\[ \frac{\partial E(Y|X)}{\partial N} = 0 \]

2. \[ E(\text{MVCR}_{ijt}) = E(\text{MP}_{ijt}) * \frac{P_{\text{maize}}}{P_N} \]

3. \[ E(\text{AVCR}_{ijt}) = E(\text{AP}_{ijt}) * \left( \frac{P_{\text{maize}}}{P_N} \right) \]

Sensitivity

• Average low, mean, and high farmgate price for maize
• Fertilizer prices
  • Market
  • Official, subsidized (50% of \( P_f \))
  • Transacted, subsidized
    • 23% of urea price
    • 28% of NPK price
Variables

Agroecological factors at three scales of analysis:

• Plot
  • size (ha), location (in/outside of compound), and toposequence (lowland, plain, slope)
  • Presence of soil or water conservation structures, agroforestry, intercropping, and fallow

• Village
  • Total rainfall, coefficient of variation of rainfall (village)
  • Excellent, good, or poor/marginal soils (village)

• Zone
  • Sudano-sahelian or Sudanian zone

• Other productive inputs, plot manager, plot management type and tenure, household characteristics
## Estimated maize yield response functions

<table>
<thead>
<tr>
<th>Variables</th>
<th>CRE</th>
<th>CFA-CRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2.91***</td>
<td>22.46***</td>
</tr>
<tr>
<td>N*N</td>
<td>-0.014***</td>
<td>-0.016***</td>
</tr>
<tr>
<td>Intercropping</td>
<td>-235.24***</td>
<td>-155.90***</td>
</tr>
<tr>
<td>SWC</td>
<td>70.28**</td>
<td>78.85**</td>
</tr>
<tr>
<td>Excellent soils</td>
<td>16.26</td>
<td>52.52*</td>
</tr>
<tr>
<td>Good soils</td>
<td>178.75***</td>
<td>239.20***</td>
</tr>
<tr>
<td>Sudanian zone</td>
<td>-198.46</td>
<td>-65.62</td>
</tr>
<tr>
<td>N*excellent soils</td>
<td>-1.82**</td>
<td>-1.68**</td>
</tr>
<tr>
<td>N*good soils</td>
<td>-3.12***</td>
<td>-2.09***</td>
</tr>
<tr>
<td>N*sudano-sahelien zone</td>
<td>1.22***</td>
<td>1.44***</td>
</tr>
</tbody>
</table>

Controlling for other productive inputs, plot manager and household characteristics, household time-averages and crop years.
### Average partial effect of N and optimum

<table>
<thead>
<tr>
<th></th>
<th>Average partial effect of N-hat</th>
<th>Average partial effect of N-95% CI</th>
<th>Unconditional N (kg/ha)</th>
<th>Conditional N (kg/ha)</th>
<th>Agronomic optimum N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>22</td>
<td>13-31</td>
<td>16</td>
<td>38</td>
<td>722</td>
</tr>
</tbody>
</table>

Net loss of ~700 kg/ha of N over a 30 year period (World Bank, 1996)
Nutrient depletion can even reach 100 kg NPK/ha/year (Henao 1992)

Our results suggest a continuous soil fertility depletion in maize farming
## Value-cost ratios

<table>
<thead>
<tr>
<th>Price Scenario</th>
<th>Fertilizer at market price</th>
<th>Subsidized fertilizer price</th>
<th>Subsidized + TC price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MVCR</td>
<td>AVCr</td>
<td>MVCR</td>
</tr>
<tr>
<td>Low</td>
<td>1.6</td>
<td>1.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Average</td>
<td>1.7</td>
<td>1.8</td>
<td>3.5</td>
</tr>
<tr>
<td>High</td>
<td>1.9</td>
<td>2.0</td>
<td>3.9</td>
</tr>
</tbody>
</table>

Profit maximization at MVCR=1

Incentive if AVCR >2 (Morris et al. 2007); AVCR >3-4 (Kelly 2006)
Conclusions

• Maize yield response to N is ~ 22 kg/ha

• Agro-ecological factors, at the scale of plot, village soil type and climatic zone, do affect maize yield response to fertilizer and productivity

• Optimal N rates > maximum N application rates

• Not always profitable to use fertilizer
Policy implications

• Caution when generalizing across agroecologies
• Does a crop targeted fertilizer subsidy program make sense?
• Importance of reducing transaction costs
• Location-specificity vs. scale
Descriptives

• 40% of maize plots fertilized (all years)
• Unconditional mean of N kg/ha = 16
• Conditional mean of N kg/ha = 38
• Mean yield w/out fert = 970 kg/ha
• Mean yield w/fert = 1314 kg/ha
• Recommended rate = 45.5-53 N/ha