The Impact of Ecosystem Health on Rural Livelihoods: An Analysis of Land Degradation and Living Standards Surveys in Tanzania

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Four broad categories of climate change impacts and adaptation:

1. Erratic climate and weather patterns

2. Altered ecosystems and habitats

3. Risks to human welfare and society

4. Human adaptive capacity and resiliency
This research focuses on the second two linkages.

1. Altered ecosystem impacts on human welfare:
   Q. How much and under what conditions does soil degradation affect farmer profits?
   => Barrett, Bellemare and Hou (2010) - soil does not explain yield differences in Madagascar

2. If and how humans have adapted or responded:
   Q. What agricultural practices are being adopted to achieve sustainable intensification?
   Q. How to target policies based on these results?
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Preview of results

- Using a farmer fixed effects model, I find 18-23% reductions in agricultural returns per percent loss in soil organic carbon (SOC) content.
- Farm input responses to poor soil are extremely low.
- How to target policies based on these results?
  - In the short run, increase awareness of soil quality’s role in agricultural production before addressing markets.
  - In the long run, address drivers of land quality changes:
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Identification problem: We want to know effect of soil on agricultural outcomes.

- But there is a major concern of unobserved sources of bias (i.e., omitted variable bias) since better farmers may have both better soil and higher returns.
- How to determine whether productivity is higher because of soil or farmer ability?
Fixed effects regression model accounts for confounding farmer characteristics. For plot $i$ of farmer $j$,

$$y_{ij} = \alpha + \beta soc_{ij} + \gamma X_{ij} + \delta Y_j + \eta_j + \varepsilon_{ijv},$$  \hspace{1cm} (1)

- $y$ is the outcome of interest
- $\beta$ is the coefficient of interest
- $X$ and $Y$ are vectors of time-varying farmer- and plot-level observable characteristics, respectively
- $\eta$ are farmer fixed effects.
Fixed Effects Estimation

Household fixed effects:
- control for unobserved, time-invariant farmer characteristics that contribute to farm productivity (e.g. ability, risk)
- control for household-specific factor market imperfections

Household and plot control variables:
- account for observable time-varying farmer and farm factors, such as non-agricultural income, wealth, fertilizer, pesticides, irrigation, slope, fallowing, and more.

No plot fixed effects:
- cannot include unobserved, time-invariant plot characteristics, as the key variable of interest, SOC, does not vary over this period

=> Yields within estimator of SOC impacts on agricultural outcomes
Data: Land Degradation Surveillance Framework

Remote sensing soil data, ground-truthed scaled to national level

Figure: SOC density estimate in Tanzania. Source: LDSF and LSMS
Data: Land Degradation Surveillance Framework

Region Key
1. DODOMA
2. ARUSHA
3. KILIMANJARO
4. TANGA
5. MOROGORO
6. PWANI
7. DAR ES SALAAM
8. LINDI
9. MTWARA
10. RUVUMA
11. IRINGA
12. MBeya
13. SINGIDA
14. Tabora
15. RUKWA
16. KIGOMA
17. SHINYANGA
18. KAGERA
19. MWANZA
20. MARA
21. MANYARA

SOC
Data: Living Standards Measurement Study

Integrated Surveys on Agriculture (LSMS-ISA):
- nationally representative multi-period panel datasets in SSA
- detailed agricultural production statistics, as well as household and community surveys

Tanzania:

<table>
<thead>
<tr>
<th>Source</th>
<th>Share in HH Income</th>
<th>Source of HH income</th>
<th>Only source of HH income</th>
<th>Avg HH Income (Real USD)</th>
<th>Avg HH Income if positive</th>
<th>Share in HH Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.4172</td>
<td>0.82</td>
<td>0.17</td>
<td>277.48</td>
<td>378.51</td>
<td>(0.3894)</td>
</tr>
<tr>
<td>Wage Labor</td>
<td>0.2456</td>
<td>0.46</td>
<td>0.04</td>
<td>407.75</td>
<td>1,376.66</td>
<td>(0.3483)</td>
</tr>
<tr>
<td>Enterprise</td>
<td>0.2275</td>
<td>0.40</td>
<td>0.02</td>
<td>772.52</td>
<td>2,792.02</td>
<td>(0.3438)</td>
</tr>
<tr>
<td>Remittances</td>
<td>0.0698</td>
<td>0.49</td>
<td>0.15</td>
<td>2766.03</td>
<td>(45004.15)</td>
<td>(0.2032)</td>
</tr>
<tr>
<td>Non-Ag Rental</td>
<td>0.0109</td>
<td>0.06</td>
<td>NA</td>
<td>32.44</td>
<td>494.47</td>
<td>(0.0688)</td>
</tr>
<tr>
<td>Aid</td>
<td>0.0101</td>
<td>0.13</td>
<td>0.00</td>
<td>5.17</td>
<td>47.20</td>
<td>(0.0774)</td>
</tr>
<tr>
<td>Pension</td>
<td>0.0041</td>
<td>0.01</td>
<td>0.00</td>
<td>48.66</td>
<td>6,823.13</td>
<td>(0.0702)</td>
</tr>
<tr>
<td>Total Income</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1,675.19</td>
<td>1,675.19</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Note: standard deviations in parentheses. All statistics weighted according to sampling method. Wage labor aggregated from the individual to the household level. All figures in real 2012 USD. Income statistics winsorized on the right-tails at the 99th percentile, except aid, non-ag rental and remittances.
### Agricultural practices, by plot size and SOC

<table>
<thead>
<tr>
<th>Variable:</th>
<th>2012 Low SOC (&lt;11 g/kg)</th>
<th>2012 Medium SOC (11-22 g/kg)</th>
<th>2012 High SOC (&gt;22 g/kg)</th>
<th>2012 Small Plots (&lt;0.5 acres)</th>
<th>2012 Medium Plots (0.5 - 3 acres)</th>
<th>2012 Large Plots (&gt;3 acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot area (acres)</td>
<td>3.2</td>
<td>2.92</td>
<td>1.85</td>
<td>19.73</td>
<td>17.87</td>
<td>15.49</td>
</tr>
<tr>
<td>Landholdings</td>
<td>7.39</td>
<td>7.16</td>
<td>4.44</td>
<td>2.44</td>
<td>4.26</td>
<td>13.78</td>
</tr>
<tr>
<td>Agricultural returns per acre</td>
<td>171.7</td>
<td>187.69</td>
<td>121.69</td>
<td>26.89</td>
<td>117.57</td>
<td>403.94</td>
</tr>
<tr>
<td>Value harvested per acre</td>
<td>186.02</td>
<td>203.60</td>
<td>143.57</td>
<td>53.74</td>
<td>133.34</td>
<td>412.98</td>
</tr>
<tr>
<td>Irrigated</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Good soil (subjective)</td>
<td>0.42</td>
<td>0.48</td>
<td>0.51</td>
<td>0.47</td>
<td>0.48</td>
<td>0.46</td>
</tr>
<tr>
<td>Years since fallow</td>
<td>0.14</td>
<td>0.12</td>
<td>0.1</td>
<td>0.09</td>
<td>0.13</td>
<td>0.18</td>
</tr>
<tr>
<td>Organic fertilizer value per acre</td>
<td>0.5</td>
<td>0.27</td>
<td>0.47</td>
<td>0.47</td>
<td>0.32</td>
<td>0.16</td>
</tr>
<tr>
<td>Inorganic fertilizer value per acre</td>
<td>3.91</td>
<td>4.23</td>
<td>5.02</td>
<td>7.7</td>
<td>3.11</td>
<td>1.55</td>
</tr>
<tr>
<td>Agricultural income</td>
<td>350.66</td>
<td>291.97</td>
<td>201.02</td>
<td>139.67</td>
<td>219.82</td>
<td>504.54</td>
</tr>
<tr>
<td>Total income</td>
<td>1,441.53</td>
<td>1,492.39</td>
<td>1,553.89</td>
<td>1,286.14</td>
<td>1,765.07</td>
<td>1,822.05</td>
</tr>
</tbody>
</table>

Notes: Landholdings, agricultural income and total income are at the farmer level. SOC and plot area categories were created at 25th, 50th, and 75th percentiles. All monetary values in 2012 USD.
FE Results: Agricultural Production and Land Value

Impacts of soil organic carbon (g/kg)

- Agricultural Returns
- Value Harvested
- Land Value
- Land Value per Acre

$ (2012 USD)

-15
-10
-5
0
5
10
15

100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
### FE Results: Agricultural Production and Land Value

<table>
<thead>
<tr>
<th>(1) Agricultural Returns</th>
<th>(2) Value Harvested</th>
<th>(3) Land Value</th>
<th>(4) Land Value per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(2.027)</td>
<td>(2.019)</td>
<td>(25.29)</td>
</tr>
<tr>
<td>Plot area</td>
<td>13.33***</td>
<td>12.80***</td>
<td>108.6***</td>
</tr>
<tr>
<td></td>
<td>(1.622)</td>
<td>(1.676)</td>
<td>(21.00)</td>
</tr>
<tr>
<td>Most recently fallow</td>
<td>63.82**</td>
<td>64.37**</td>
<td>-528.4</td>
</tr>
<tr>
<td></td>
<td>(31.41)</td>
<td>(31.34)</td>
<td>(392.7)</td>
</tr>
<tr>
<td>Nitrogen Phosphate Potassium (N)</td>
<td>4.216***</td>
<td>1.450</td>
<td>5.734</td>
</tr>
<tr>
<td></td>
<td>(1.028)</td>
<td>(1.191)</td>
<td>(14.92)</td>
</tr>
<tr>
<td>Inorganic fertilizer cost</td>
<td>2.814***</td>
<td>10.02**</td>
<td>21.50</td>
</tr>
<tr>
<td></td>
<td>(0.320)</td>
<td>(4.008)</td>
<td>(25.46)</td>
</tr>
<tr>
<td>Organic fertilizer cost</td>
<td>0.988</td>
<td>52.36***</td>
<td>142.5***</td>
</tr>
<tr>
<td></td>
<td>(1.074)</td>
<td>(13.45)</td>
<td>(27.73)</td>
</tr>
<tr>
<td>Observations</td>
<td>3,979</td>
<td>3,979</td>
<td>3,978</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.730</td>
<td>0.764</td>
<td>0.934</td>
</tr>
</tbody>
</table>

Notes: standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Sloped indicates slightly sloped or very steep, as opposed to flat top or flat bottom. Most recently fallowed is the negative of the number of years since the plot was last fallowed. Other controls include soil type, irrigation, input amounts and costs, and intercropping.
FE Results: Input Use

Anil K. Bhargava, University of Michigan
Ecosystems and Livelihoods in Tanzania
If and how much inherent soil quality matters to agricultural production is not well-understood by researchers or farmers. Here, we quantify it using high-resolution SOC data and control spatially for confounding farmer characteristics and plot management. We find a significant increase in agricultural returns of 18–23% due to soil quality. But no effect on land values or input use, suggesting a lack of understanding or underestimate by farmers of SOC’s role in production.
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  - Subjective valuation of land quality matters
  - Inputs and soil quality can separately and interactively determine agricultural and welfare outcomes
- In the long run, address drivers of land quality changes.
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  - Deforestation, irrigation, and crop & livestock choices all matter to soil quality and could be dimensions on which to target environment and development policies
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Thank you.