SOIL HEALTH,  
PRODUCTIVITY,  
and  
PROFITABILITY

Example on the spatial patterns of fertilizer profitability in maize production systems in East Africa

Zhe Guo, Jawoo Koo, Stanley Wood, Carlo Azzarri, and Ho-Young Kwon
International Food Policy Research Institute, Washington, DC
**Production System & Market Access Analysis**
**MESO SCALE**
Pixels as Units of Analysis

**Household Characterization**
**MICRO SCALE**

**Investment/Policy Analysis**
**MACRO SCALE**
Aggregate, market-scale (geo-political) units

Change (e.g., policy)

Change (e.g., climate, technologies)

**Fixed Geographies of Analysis**
e.g., IMPACT/WATER, GTAP derivatives

**Flexible Geographies/Units of Analysis**
e.g., DREAM, MM models

Aggregation By Commodity

Region | Urban/Rural | Income tertile | Consumption | Production | Inputs
--- | --- | --- | --- | --- | ---

Infrastructure/Market Access

Production System

Ecosystem Services
HarvestChoice CELL5M (700+ 10 km spatial layers)

Data harmonization

Bio-physical: land use, soil, climate, aez (IIASA, CRU, USGS)

Production: SPAM (admin records, suitability)

Socio-eco: pop. poverty, factor productivity (LSMS, ag. census, DHS, FAO)

Markets: infrastructure, transportatio n, market access

Up/down scaling

Calibration

Try: harvestchoice.org/mappr
harvestchoice.org/tablr
Bio-physical data layers are used to run process-based **crop models**

**WEATHER**
- Radiation
- Temperature
- Precipitation
- CO2

**SOIL**
- Water
- N-P-K
- pH
- SOM

**CULTIVAR**
- Phenology
- Max # of kernels
- Kernel filling rate

**MANAGEMENT**
- Planting window
- Irrigation
- Inorganic fertilizer
- Organic manure
- Tillage
- Residue
CROP MODEL SIMULATES A LOT MORE THAN YIELDS

- Productivity
- Nutrient balances
- Water balance
- Soil organic carbon

\[ \rightarrow \text{SOIL HEALTH (or SOIL QUALITY) INDICATOR} \]

YIELD LEVELS (esp. low-input)
YIELD VARIABILITY (esp. water stress)
YIELD RESPONSES to interventions

Continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans

USDA-Natural Resources Conservation Service
WHAT HEALTHY SOIL DOES

- Tighten soil nutrient cycles
- Increase nutrient and water use efficiency
- Suppress diseases and pests, including weeds
- Resist degradation
- Buffer environmental constraints
- Produce healthy plants, people and animals

Illustration from National Geographic
How important is Soil?

The Soil Renaissance: Knowledge to Sustain Earth’s Most Valuable Asset

The Soil Renaissance seeks to reawaken the public to the importance of soil health in vibrant, profitable and sustainable natural resource systems. It seeks to make maintenance and improvement of soil health the cornerstone of land use management decisions.

A Soil Renaissance Strategic Plan has been developed with input from thought leaders working in production agriculture, agribusiness, the academic community, NGOs and government agencies. The Soil Renaissance Strategic Plan outlines goals and work plans in four key areas: Measurement, Economics, Research and Education.

“This Strategic Plan is a starting point that will evolve and expand as work is completed, new challenges are identified and more
Why the need for a Soil Renaissance?

Experts forecast the world's food demand will double by 2050. The average rate of soil erosion on U.S. cropland is 7 TONS/ ACRE/YEAR.

The world's 7 billion people today are fed by arable land that comprises 10.6% of the world's land area. Globally, about 40% of the soil used for agriculture is classified as degraded or seriously degraded. At current degradation rates, the world has about 60 years of topsoil left.

Half of the topsoil on the planet has been lost in the last 150 years.

Soil Erosion globally costs an estimated $400 billion per year.

Soil loss of soil and water from U.S. cropland decreases productivity by about $37.6 billion per year.

More than 90% of the fruits and 78% of the vegetables produced in the U.S. are grown on farms located closest to cities - directly in the path of development.

Soils are...

The surface on which we live and build.

Storage for water and carbon. Just 1 percent of organic matter in the top 6 inches of soil would hold approximately 27,000 gallons of water per acre.

Recycling and purification for air, water, and nutrients. Healthy soils can reduce nutrient loading and sediment run-off, increase efficiencies, and sustain wildlife habitat.

Housing for a variety of microbes, organisms, and animals.

Soils provide...

The dynamic skin of the earth, formed by the interaction of minerals, organic material, organisms, water and air.

A non-renewable resource. It can take hundreds to thousands of years to create 1 inch of topsoil.

Fertility to grow the plants and forests that nurture and shelter humans and animals.

The Soil Renaissance will...

Make soil health a priority among all stakeholders.

Identify a standard approach to measuring soil health.

Develop tools to demonstrate the return generated by soil health investments.

Support soil health education and outreach programs for all stakeholders.

Identify knowledge gaps and lay the groundwork for needed research.

Celebrate the miracle of soils.

How to be a part of the Renaissance...

Neil Condon, president, Farm Foundation, NFP, neil@farmfoundation.org
William Buckner, president, Noble Foundation, wbuckner@noble.org
Tim Brennan, Farm Foundation, NFP, tim@farmfoundation.org

"No civilization has outlived the usefulness of its soils. When the soil is destroyed, the nation is gone."

—Lloyd Noble, Nov. 18, 1949
WHERE ARE THE HEALTHY SOILS, AND WHAT ARE THEIR YIELD IMPACTS? **IT’S COMPLICATED.**

**OUR APPROACH** for **SIMULATING YIELDS** in **FARMERS’ FIELDS** with (MODELED) **SOIL FERTILITY**

1. Use the soil property maps to set initial conditions
2. Model soil quality degradation under low-input monoculture scenario.
3. Simulate yield responses over time, on the initial and degraded soil properties.

- Interpolated, static surface using observations.
- Great resource for **initializing models** and understanding the **representative soil characteristics**.
- Does **not** necessarily represent the soil health status in farmers’ fields (dynamic process, depending on the current/historic management practices, as much as the chemical properties).
FERTILIZER POLICY OPTIONS in EAST AFRICA and THEIR IMPACTS on FERTILIZER PROFITABILITY

AGRA requested IFPRI an impact assessment study of:

1. Reducing the landed cost of fertilizer through collective bulk purchasing.
2. Reducing transport costs through improved road and related transportation infrastructure.
3. Reduced transactions costs through improved harmonization and streamlining of border crossing/customs procedures.

plus, SOIL FERTILITY IMPLICATIONS?
Assessing Farmgate Prices: 1. Imported Inputs

Farmgate Fertilizer Price:

\[ P_{\text{fert, farm}} = P_{\text{fert, port}} + \text{Build-up costs} \]

(Handling + “Barriers” + Transport Costs)
Assessing Farmgate Prices: 2. Output Surplus to Local Markets

Farmgate Fertilizer Price:
\[ P_{fert, farm} = P_{fert, port} + \text{Build-up costs} \]
   \[ \text{(Handling + “Barriers” + Transport Costs)} \]

Farmgate Maize Price
\[ P_{maize, farm} = P_{maize, market} - \text{Transport Costs} \]
ON-SITE FERTILIZER RESPONSES

Farm Households

- LOCATION & PRODUCTION
  - SYSTEM SPECIFIC FERTILIZER RESPONSES
  - CLIMATE/WEATHER,
    - SOIL FERTILITY,
    - MANAGEMENT PRACTICES

- FARMGATE OUTPUT PRICES
- FARMGATE FERTILIZER PRICES

- Markets

- Transport Costs
  - (on & off road)

- Fertilizer Import Costs
Fertilizer Delivery Cost
Maize Transport Cost
Maize Farm-gate Price
“Fertilizer markets have failed in Africa”

- Scattered and small size of local market
- Weak demand for use with food staple crops
- High transportation cost – poor road and rail infrastructure, particularly in landlocked countries
- Low profitability

Value-Cost Ratio (VCR)

\[
VCR_{x,y} = \frac{\Delta y(N)_{x,y}}{N \times Price_{fertilizer}} \times Price_{maize}
\]

- \(N\) = fertilizer application rate (kg/ha)
- \(y(N)\) = maize yield with fertilizer at \(N\) rate (t/ha)
- \(\Delta y(N) = y(N) - y(0)\) (t/ha)

“...IFDC suggests VCR>2 to accommodate price and climatic risks and still provide an incentive to farmers”
VALUE-COST RATIO

40 kg N VCR

Value cost ratio

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Color</th>
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<tbody>
<tr>
<td>&lt; 0</td>
<td>Red</td>
</tr>
<tr>
<td>0.1 - 1</td>
<td>Orange</td>
</tr>
<tr>
<td>1.1 - 2</td>
<td>Yellow</td>
</tr>
<tr>
<td>2.1 - 4</td>
<td>Green</td>
</tr>
<tr>
<td>4.1 - 8</td>
<td>Light Green</td>
</tr>
<tr>
<td>&gt; 8</td>
<td>Dark Green</td>
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Yield response with 40 kgN/ha

<table>
<thead>
<tr>
<th>Yield response (kg/ha)</th>
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<tbody>
<tr>
<td>&lt; 500</td>
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<tr>
<td>501 - 1,000</td>
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<tr>
<td>1,001 - 1,500</td>
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<tr>
<td>1,501 - 2,000</td>
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<tr>
<td>&gt; 2,000</td>
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</tbody>
</table>
Highlands: Yield by Country and Agroecological Zone

Lowlands: Yield by Country and Agroecological Zone

Fertilizer application rate (N kg ha⁻¹)

Yield (kg ha⁻¹)

Highlands: Yield by Agroecological Zone

Lowlands: Yield by Agroecological Zone

Yield (kg ha⁻¹)

Arid  Humid  Semi-Arid  Sub-Humid

Arid  Humid  Semi-Arid

Arid  Sub-Humid  Total

Humid  Semi-Arid  Total
CONCLUDING REMARKS

- Soil carbon is key indicator to understand the various aspects of crop productivity, especially under low-input systems.
- Good understanding of soil carbon content in the field can explain the yield level, yield variability, and yield responses to interventions.
However, use of static soil carbon data may potentially be misleading. Soil carbon content is highly dependent on farmers’ management practices and dynamic in nature; static soil property maps may not adequately inform the actual soil quality status.

Process-based modeling framework, whose initial conditions to be set with soil property databases, can dynamically simulate the dynamics of soil carbon changes and its effects on crop growth and yields.
CONCLUDING REMARKS

- As shown in the profitability study example, single assumption of soil fertility in a given location can potentially mislead the impact of intervention.

- To take into account the heterogeneity of soil fertility in farmers’ fields, model-estimated crop yield responses under various scenarios may need to be disaggregated based on soil fertility classes.