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Economics of Soil Health: A Conceptual Framework

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A model of soil health

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- Services that soils provide:
  1. Medium for crop growth.
  2. Channel through which agriculture affects environmental quality.
- Consider a landscape divided into I parcels of uniform characteristics, each of a possibly different size a_i.
  - Each parcel has J possible types of output per acre at time t $\mathbf{y_{it}} = \{y_{i1t}, \ldots, y_{iJt}\}$.
  - Each parcel also generates M possible environmental services $\mathbf{q_{it}} = \{q_{i1t}, \quad , q_{iMt}\}$.
  - We apply a vector of K inputs per acre to each parcel $\mathbf{x}_{it} = \{x_{i1t}, \ldots, x_{Kt}\}$.
  - Each parcel has a vector of N soil characteristics $\mathbf{s_{it}} = \{s_{i1t}, \ldots, s_{sNt}\}$.
- Crop production per acre: $f^i(\mathbf{y_{it}}, \mathbf{q_{it}}, \mathbf{x_{it}}, \mathbf{s_{it}}, u_t) \leq 0$.
- Environmental services per acre: $g^i(\mathbf{y_{it}}, \mathbf{q_{it}}, \mathbf{x_{it}}, \mathbf{s_{it}}, u_t) \leq 0$.
- Evolution of soil characteristics: $s_{in,t+1} = h^{in}(\mathbf{y_{it}}, \mathbf{x_{it}}, \mathbf{s_{it}}, u_t)$.

Manage landscape to maximize the expected present value of returns, both agricultural and environmental:

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$$\max_{\boldsymbol{y},\boldsymbol{q},\boldsymbol{x},\boldsymbol{s}} E\left\{\sum_t \delta^t \sum_i \left(\left\{\sum_j p_{jt}\, y_{ijt} - \sum_k w_{jt}\, x_{ijt} - \sum_m v_{mt}\, q_{imt}\right\} + \lambda_{it} f^i(\boldsymbol{y_{it}}, \boldsymbol{q_{it}}, \boldsymbol{x_{it}}, \boldsymbol{s_{it}}, u_t)\right.\right.$$
$$\left. + \mu_{it}\, g^i(\boldsymbol{y_{it}}, \boldsymbol{q_{it}}, \boldsymbol{x_{it}}, \boldsymbol{s_{it}}, u_t) + \sum_n \theta_{int}\left[h^n(\boldsymbol{y_{it}}, \boldsymbol{x_{it}}, \boldsymbol{s_{it}}, u_t) - s_{in,t+1}\right] + \psi_{iT} W(\boldsymbol{s_{iT}})\right) a_i$$
$$\left. - C(a_i)\right\}$$

What do we mean by "soil health"?

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- Does crop productivity alone matter?
  - Which crops?
  - What levels of output?
- Does a combination of crop productivity and environmental services matter?
  - If so, what combination?
  - What levels of crop output and environmental services?
- Do the benchmarks we use vary over time?
  - Price-induced changes in crop mix?
  - Climate-change-induced changes?

Specifying a model of soil health

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- What combinations of physical, chemical and biological properties are of first order importance? Which can be ignored?
  - What do we know about interactions between soil properties and outputs ($\partial^2 f/\partial y_{ijt}\partial s_{int}$)? Environmental services ($\partial^2 g/\partial q_{ijt}\partial s_{int}$)? Inputs ($\partial^2 f/\partial x_{ijt}\partial s_{int}$, $\partial^2 g/\partial x_{ijt}\partial s_{int}$)?
- Can we construct one or more indices of soil health?
  - Can we construct subaggregates of soil characteristics that interact with crop production in a uniform way?
  - Can we construct subaggregates of soil characteristics that interact with crop production in a uniform way?
  - Are the subaggregates for crop production and environmental services the same?
- Nonlinearity in u_t: randomness influences decisions even in absence of insurance value. Variance, skewness and thus resilience matter.

Dynamics: soil as natural capital

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- The value of an individual soil characteristic equals the present value of all future increments to crop productivity and environmental services due to a marginal change in that soil characteristic, adjusted for the impact on the future accumulation or depletion.
- Optimal to invest in "soil health capital" up to the point where the rate of return equals the rate of return on a marginal dollar invested anywhere else in the economy.
- Questions:
  - The long run: Is a steady state optimal? Is cyclic exploitation optimal?
  - The short run: What is the optimal transition time? Transition strategy?

Progress to date

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- Static analyses using nonparametric methods (Jaenicke and Lengnick *AJAE* 1999, Zago *AJAE* 2009, Hailu and Chambers *JProdAnal* 2012).
  - Nonparametric avoids a priori functional form restrictions but does not permit general inferences about functional relationships, formation of soil quality indices, etc.
- Limited dynamic analysis (Kim, Barham, and Coxhead *AgEcon* 2001).
  - Restricted to nitrogen carryover.
  - Static optimization of fertilizer application.
  - Dynamics of recovery under alfalfa following continuous corn grown for 5, 10, 20, 30 years.

Data needs

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- We need agronomic studies featuring
  - Multiple soil characteristics and crops
  - Different crop rotations and management regimes
  - Conducted in different agro-climatic zones
  - Over extended periods of time
- To be able to determine:
  - Which soil characteristics are important?
  - How those soil characteristics interact (can we aggregate?).
  - How those soil characteristics/indices evolve over time.
  - The influence of rainfall, solar radiation, temperature, and other random factors on crop productivity and the evolution of soil health indicators.
  - How soil characteristics influence environmental services.

And to conclude …

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- Concreteness matters because “health” is in the eye of the beholder—and different beholders have different interests and different perspectives.
- We make progress only by being concrete in discussing what soil health consists of and how we should be investing in it.
- So let’s have some concrete discussions!