AREC 615 Project

Agricultural Productivity and Soil Carbon Dynamics: A Bioeconomic Model

Sushil Khatri

Department of Agricultural and Resource Economics
Colorado State University

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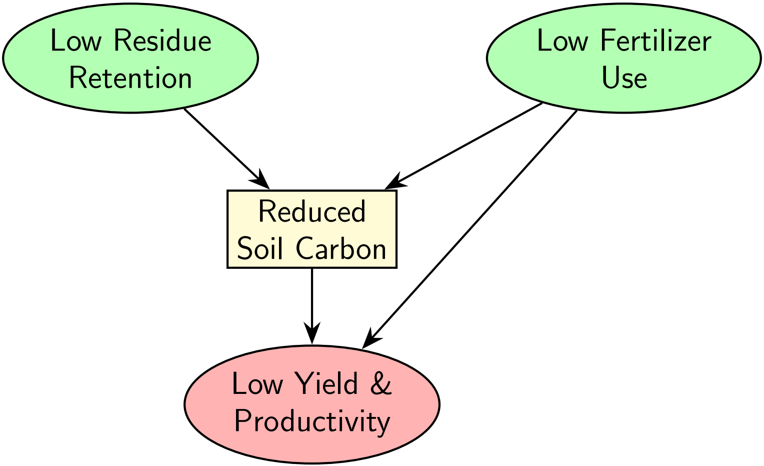
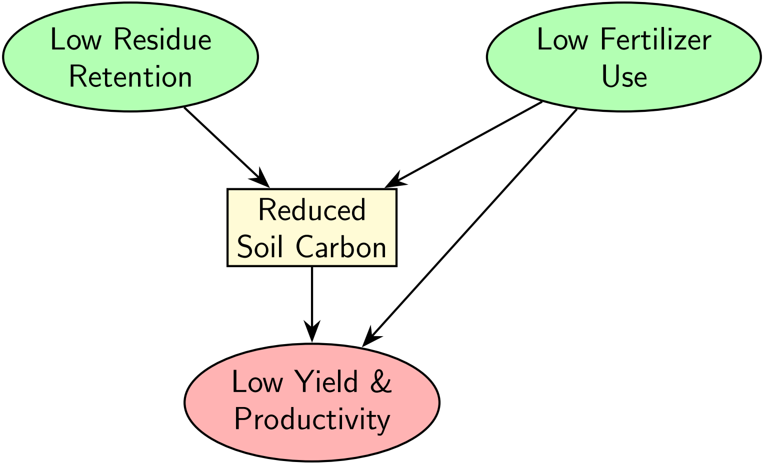
Paper Information

- **Paper Title:** Agricultural Productivity and Soil Carbon Dynamics: A Bioeconomic Model
- **Authors:** J. Berazneva, J. M. Conrad, D. T. Güereña, J. Lehmann, and D. Woolf
- **Journal:** American Journal of Agricultural Economics (AJAE)
- **Year:** 2019

Problem


Low Residue Retention
Low Fertilizer Use
Reduced Soil Carbon
Low Yield & Productivity

Problem



Research Question: *What fertilizer–residue choices maximize long-run soil carbon and yield?*

Model Components

Control Variables

- f_t : fertilizer applied (Mg/ha)
- a_t : fraction of crop residue retained (0–1)

State Variable

- c_t : soil organic carbon stock (Mg/ha)

Yield Function

$$y_{kit} = \alpha_0 + \alpha_c\, c_{kit} + \alpha_{cc}\, c_{kit}^2 + \alpha_f\, f_{kit} + \alpha_{ff}\, f_{kit}^2 + \alpha_{cf}\, c_{kit} f_{kit}$$

$$+ \underbrace{\gamma_k + \phi_i + \eta_t + \nu_{kt}}_{\text{Fixed Effects}} + \kappa_{kit}$$

Soil Carbon Dynamics

$$c_{t+1} = c_t - Dc_t + A\left(a_t F k\, y(c_t, f_t)\right)^B$$

- D : annual SOC decay rate
- A, B : accumulation parameters (soil science models)
- F : residue carbon fraction
- k : residue-grain ratio Replication

Optimization Structure

Objective Function

$$\max_{\{f_t, a_t\}} \quad \sum_{t=0}^{\infty} \beta^t \, \pi(c_t, f_t, a_t)$$

$$\text{s.t.} \quad c_{t+1} = c_t - Dc_t + A\left(a_t F k \, y(c_t, f_t)\right)^B$$

Profit Function

$$\pi(c_t, f_t, a_t) = \big(p_{maize} + q_R \, k_{rg} \, (1 - a_t)\big) \, y(c_t, f_t) \; - \; nP \, f_t \; - \; m_{fix}.$$

Results

Steady-State Optimal Values

$$f^* = 0.13 \quad \text{Mg/ha}$$

$$a^* = 0.54 \quad \text{(54\% residue retention)}$$

$$c^* = 25.63 \quad \text{Mg C/ha}$$

Optimal Yield

$$y^* \approx 3.9 \text{ Mg/ha}$$

Shadow Value of Soil Carbon

$$\lambda^* \in [95, 168] \text{ \$/Mg C}$$

Replication

Built model

- Set horizon $(T = 100)$
- Paper consistent discounting, prices, costs, and parameters were used.
- Adjusted intercept b_0 to match the paper's steady-state yield.

Soil Carbon Dynamics

- Calibrated A so paper's steady state (c^*, f^*, a^*) satisfies the equation.

Back to Model

Open-loop Optimization

- Decision vector: $x = [f_1..f_{100}, a_1..a_{100}]$.
- Used L-BFGS-B to maximize present value of profits.
- Added terminal and tail penalties to enforce convergence.

Simulation Results

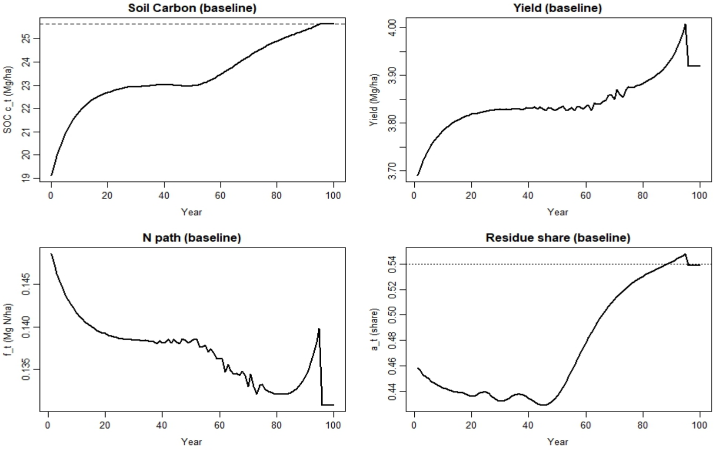


Figure: Soil carbon, Yield, Fertilizer (Nitrogen), and Residue paths (replication)

Extension

Motivation

- **The original model assumes:**
  - No policy intervention
  - Does not explore how carbon subsidies affect human behavior.

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- **Extension Idea (flow Subsidy):**
  - The government pays a subsidy for annual gains in soil carbon.

Motivation

- **The original model assumes:**
  - No policy intervention
  - Does not explore how carbon subsidies affect human behavior.
- **Extension Idea (flow Subsidy):**
  - The government pays a subsidy for annual gains in soil carbon.
- **Key questions for extension:**
  - **RQ 1:** How do carbon incentives (i.e., $ per Mg of carbon gained) affect decisions?
  - **RQ 2:** How do carbon subsidies affect overall welfare and carbon gain?

Extension Model

Carbon-Flow Subsidy Term

$$\text{Subsidy}_t = p_C\,(c_{t+1} - c_t)$$

p_C : carbon payment ($/Mg of SOC increase)

New Profit Function

$$\pi^{new}(c_t, f_t, a_t) = \pi(c_t, f_t, a_t) + p_C(c_{t+1} - c_t)$$

New Objective Function

$$\sum_{t=0}^{T} \beta^t \left[\pi(c_t, f_t, a_t) + p_C(c_{t+1} - c_t)\right]$$

RQ 1 Extension Results

Table: Effect of Carbon Incentives on Optimal Decisions

Carbon price ($)	Tail residue [1]	Tail fertilizer [2](Mg N/ha)	Soil Carbon (Mg/ha)
0	0.54	0.13	25.60
50	0.56	0.13	26.41
100	0.60	0.13	27.69
150	0.78	0.11	31.49
200	0.78	0.11	31.60

[1] Average residue retention in final 10 years

[2] Average fertilizer use in final 10 years

RQ2: Welfare and yield gain

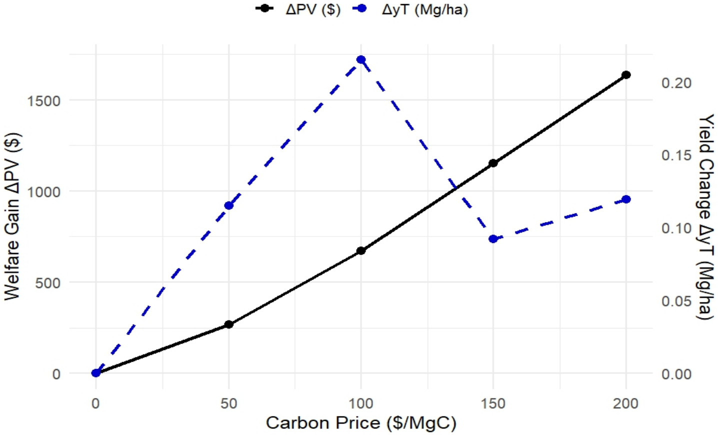

Figure: Welfare and Yied gain

RQ2: Carbon gain

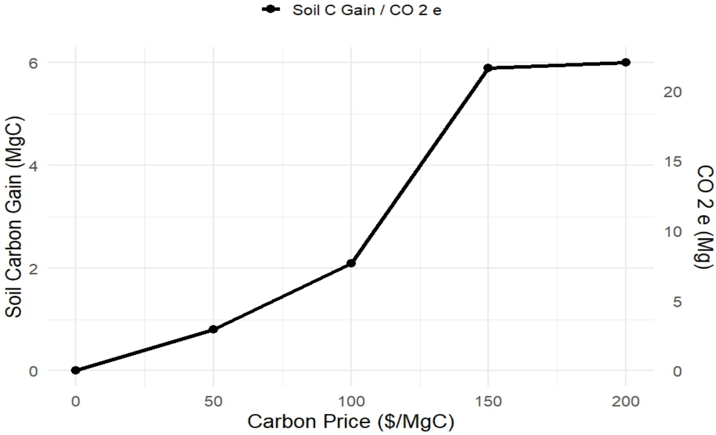

Figure: Soil Carbon Gain and CO_2e Response

Conclusion

- Carbon incentives increase residue retention and soil carbon in the long run.
- The higher the carbon price, the greater the SOC gains and welfare improvements.
- Therefore, carbon payment can increase profitability and promote sustainable agriculture.

Thank You!

Questions?

https://github.com/khatris04/AREC-615-Project