Bilevel Optimization of Conservation Practices for Agricultural Production

Brad Barnhart[1], Moriah Bostian[2], Manoj Jha[3], Luba Kurkalova[4], Gerald Whittaker[5]

[1]Department of Applied Economics, Oregon State University

[2]Department of Economics, Lewis & Clark College

[3]Department of Civil, Architectural, and Environmental Engineering, North Carolina A&T State University

[4]Department of Economics, North Carolina A&T State University

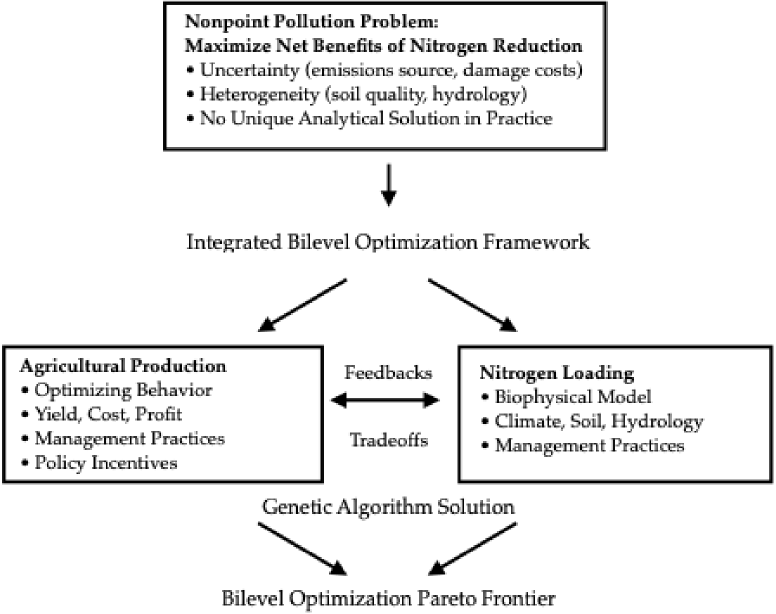
[5]Department of Applied Economics, Oregon State University

Bilevel Multiobjective Optimization Problem

Bilevel optimization to solve nested problems (Bard, 1998).

- The solution set of optimal policy incentives and management practices depends on the profit maximizing behavior of individual producers.
- Basin-level policy cost and Nitrogen minimization is the outer optimization (upper level).
- Farm-level profit maximization in response to the policy incentive is nested (lower level).
- Transforms single objective (max social surplus) to multiobjective problem: minimize economic cost, minimize pollution level

Schematic Overview

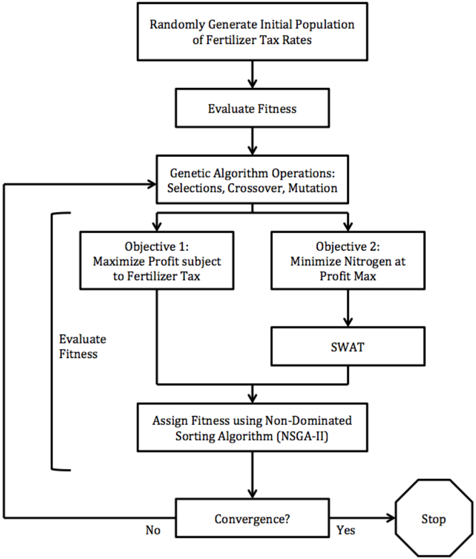


Bilevel Multiobjective Optimization Problem

$$
\begin{aligned}
\max_{\tau, r, s, x_N} \quad & \mathrm{F}(\tau, x, r, s) = \big(- C(\tau, r, s, x_N),\ B(r, s, x_N) \big) \\
\text{s.t.} \quad & (r^k, s^k, x_N^k) \in \operatorname*{argmax}_{x^k,\ y^k, r^k, s^k} \{ \pi^k(p^k, w^k, \tau^k) : \\
& \qquad (\tau^k,\ x^k,\ y^k, r^k, s^k) \in \Omega^k \} \\
& \qquad \forall\ k \in \{1, \ldots, K\}, \\
& x_n^k \geq 0,\ \forall\ k \in \{1, \ldots, K\}, n \in \{1, \ldots, N\}, \\
& y_m^k \geq 0,\ \forall\ k \in \{1, \ldots, K\}, m \in \{1, \ldots, M\}, \\
& \tau_j^k \geq 0,\ \forall\ k \in \{1, \ldots, K\}, j \in \{1, \ldots, J\}, \\
& r^k \geq 0,\ \forall\ k \in \{1, \ldots, K\}, \\
& s^k \geq 0,\ \forall\ k \in \{1, \ldots, K\},
\end{aligned}
$$

for policy scheme, τ, for tillage, s, and Nitrogen fertilizer use, $x_N = x_N^1, ..., x_N^K$.

Bilevel Optimization Solution Process



Model Calibration Iowa Raccoon River Watershed

Economic Production Model:

- Production model parameters estimated from agronomic data (Secchi et al., 2011; Randall, 2012)
- Price data drawn from 2002 Census of Agriculture

SWAT Biophysical Model:

- SWAT model calibrated following Jha et al.(2007; 2010)
- 2002 Land Use Land Cover data (IDNR 2002)
- 1996-2004 Climate data, calibrated for 2001-2004 (Jha et al., 2009)

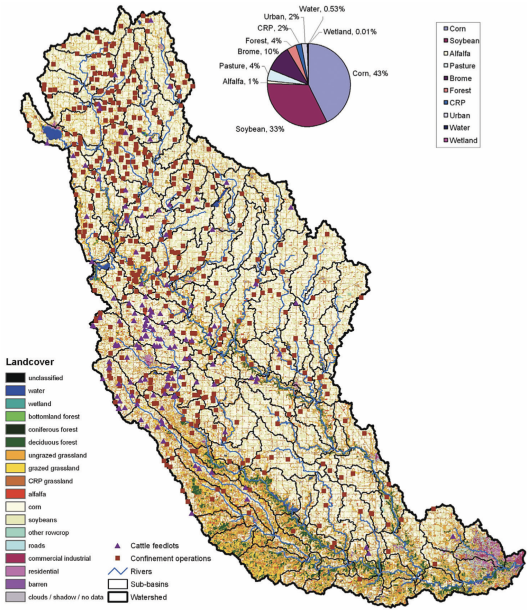
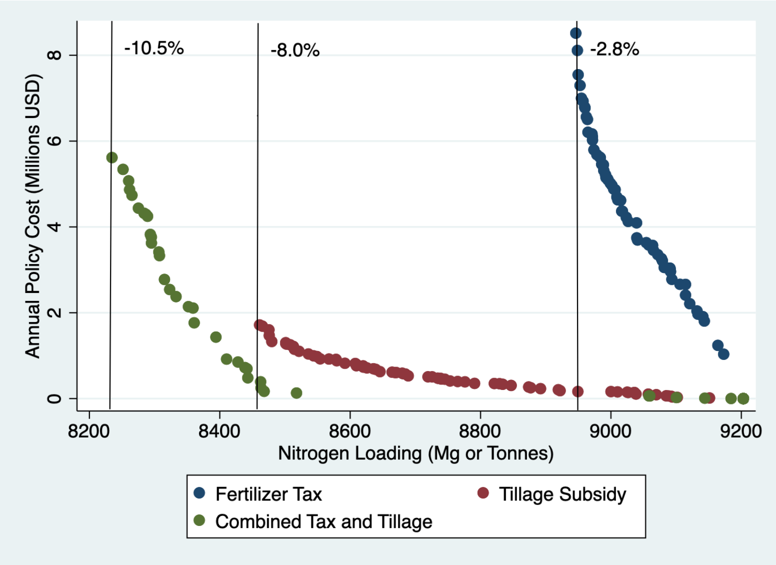


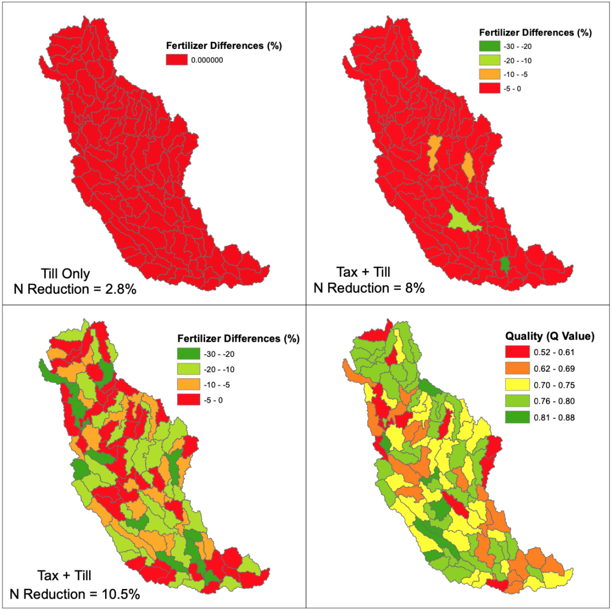
Figure: The Raccoon Watershed, SWAT Delineation (Jha et al., 2010)

Combined Policy Results

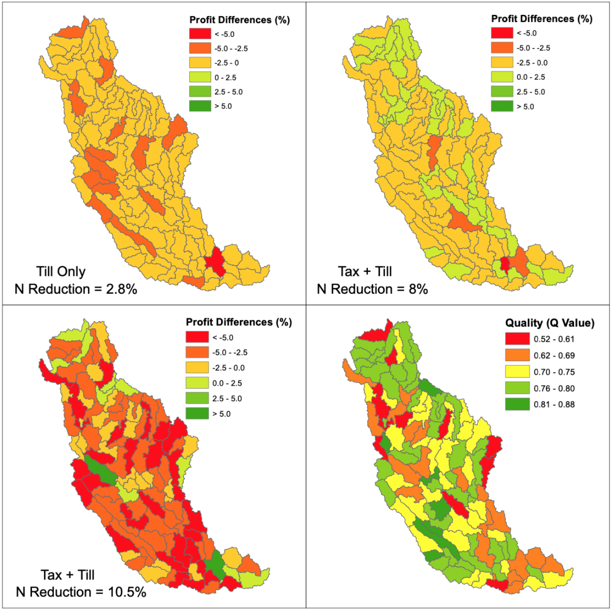


*Note, vertical lines indicate maximum feasible nitrogen reduction levels for each policy scenario, in percent of the baseline load.

Fertilizer Spatial Results



Profit Spatial Results



Next Steps

Future extensions of this framework include:

- Expand geographic scale to UMRB, connect to Gulf Hypoxia
- Update with more recent data
- Inclusion of additional environmental objectives, such as biodiversity measures or water flow
- Analyze changing tradeoffs over time (technology growth, climate change)
- Incorporate other management practices (tiling, terracing, etc.)