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Optimal Nitrogen Applications: A Stochastic Dynamic Model of Irrigated Corn in the Southern High Plains

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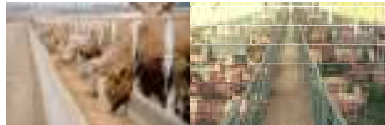
Optimal Nitrogen Applications: A Stochastic Dynamic Model of Irrigated Corn in the Southern High Plains

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Introduction

- Regional importance of livestock production
 - Swine production, along with beef cattle, generated \$636.7 million in revenue and was the major source of employment, providing nearly 16 000 jobs within this area (Oklahoma Pork Council, 2009, unpublished data).
- Economic feasibility of animal manure as a substitute for commercial fertilizers
 - The proper management is costly and labor intensive (Carreira, 2004).
 - Not as efficient as commercial fertilizers since some nutrients in animal manure are not available for plant uptake (Zhang, 2003).
- Best management practices of animal manure applied to land
 - Imperative in the semi-arid areas where crop and animal production is heavily dependent on limited water resources.



Previous studies

- Non-market valuation methods
 - Animal manure as a substitute for commercial fertilizer (Ruter et al., 2004; Nunez and McCann, 2004).
- Few classical primal approach to utilization of nutrients in the animal manure
 - Lack of the multi-year soil data (Carreira, 2004).

Objective

- Using a stochastic dynamic programming (SDP) model, this study determines optimal nitrogen fertilizer rates in continuous irrigated corn according to sources of nitrogen (anhydrous ammonia, beef, and swine manure).
- Estimated corn response and soil nutrients (N, P, pH) carryover functions for each source of nitrogen are used in a SDP model

Optimization Model

- Maximize expected utility of net return over time
- A set of equations for state (carryover) variables
- Soil nitrogen, Soil phosphorus, Soil pH
- Power utility function defined as $\frac{(x_i)^{1-\theta}}{1-\theta}$
 - θ is the coefficient of relative risk aversion
- Modified Mitscherlich-Baule response function
- Nitrogen loss function through ammonia volatilization for swine effluent
- Nitrogen application cost
 - assumed to be linearly related with Na

Data

- Multi-year data with yield of irrigated continuous corn and soil characteristics
 - Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, OK
- Three sources of nitrogen fertilizer
 - Anhydrous ammonia (AA), Beef manure(BM), and swine effluent (SE)
- Four different application rates of nitrogen fertilizer
 - 0, 56, 168, and 504 kg ha⁻¹ yr⁻¹
- Randomized complete block design with repeated measures.

Numerical Algorithm

- Stochastic Dynamic Optimization :

- Dimensions and bounds of discrete grids

| | State Variable Grids | | | Control Variable |
|---------------|----------------------|--------------|-----|--------------------|
| | N (Kg N /ha) | P (Kg N /ha) | pH | Opt. NA (Kg N /ha) |
| Min Value | 10 | 27 | 5 | 0 |
| Max Value | 200 | 800 | 8.5 | 200 |
| No. of points | 8 | 8 | 8 | 12 |

- Four random shocks: Fourth-order Gaussian approximation of the distribution was used

- A Markov transition matrix
 - the stochastic nature of the state-transitions and the linear interpolation to approximate $EV_{t+1}(N_{t+1}, P_{t+1}, pH_{t+1})$

- A complete conditional Markov transition matrix for each of the 12 value
 - A 512x512x12 array of possible dynamics
 - A 512x12 array of possible expected utility
 - In each iteration of a successive approximation approach to find the optimal NA for each of the 3 N sources.

- Bellman's equation

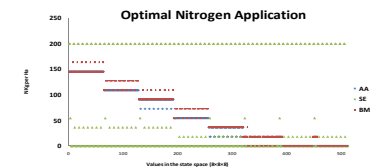
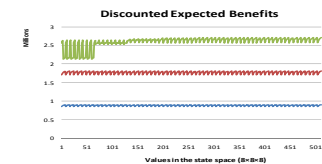
$$V^{k+1}(N_t, P_t, pH_t) = \max_{N_{t+1}} R(N_t, P_t, pH_t, N_{t+1}) + \beta EV^k(N_{t+1}, P_{t+1}, pH_{t+1})$$

- where β is the discount factor, $\beta = \frac{1}{1+r}$ if r is the discount rate.

- $k+1^{th}$ approximation of the value function is found by finding the NA_t that solves the Bellman's equation

- Solved for each of the 512 points in the state space and then the process is repeated recursively until a fixed point is reached until $V^{k+1}(\cdot) \approx V^k(\cdot)$

Results



Conclusion

- Best source of nitrogen is swine effluent
 - Consistent with previous findings (Park et al 2010, Park 2009).
- For anhydrous ammonia and beef manure, the optimal NA rate depends only on the soil Nitrogen levels.
 - No variation w/r/t soil pH or soil Phosphorus levels.
- For swine effluent, soil pH seems to be a driving force
 - Optimal NA rates move between max and min values

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