Dynamic Optimization of Fertilizer Application With Carryover and Runoff

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Introduction

Lower input use and reduced nutrient runoff are often-cited benefits to the production of bioenergy crops. Properly accounting for these benefits requires an understanding of the temporal dynamics of fertilizer application, carryover, and runoff. Fertilizer carryover measures the amount of fertilizer applied in the previous period available for crops in the current growing period (Kennedy et al., 1973). Fertilizer runoff refers to fertilizer that has flowed or leached into adjacent water bodies and is no longer available to growing crops.

Objective

The objective of this research is to create a modeling framework to aid in simulation and empirical analyses of crop choice and optimal fertilizer application rates for bioenergy and conventional crops over lands of varying quality.

Methods

We first construct an intertemporal model that maximizes the net benefits of fertilizer application given choice of crop. Using this model, net benefits and optimal nitrogen application rates for the production of switchgrass and corn at the University of Tennessee Research and Education Center in Milan, Tennessee are simulated over differing fertilizer carryover and runoff rates.

Farmer's Net Benefit Model

$$V_t\{X_t\}=\max_{I_t}[\rho P_t Y_t - r_t I_t - \rho H_t - C_t + \rho V_{t+1}\{\theta(X_t+I_t-R_t)\}$$

Subject to: $I_t \geq 0$

$$Y_t=\beta_0(t)+\beta_1(X_t+I_t-R_t)-\beta_2(X_t+I_t-R_t)^2 \text{ with } \beta_1, \beta_2>0$$

$$R_t=\varphi(X_t+I_t) \text{ with } 0\leq\varphi<1$$

$$X_{t+1}=\theta(X_t+I_t-R_t) \text{ with } X_0=a \text{ and } 0\leq\theta<1$$

$$V_{T+1}\{\theta(X_t+I_t-R_t)\}=0$$

- X_t is the amount of fertilizer in the soil and available for crop production at the beginning of period *t* and it is a state variable
- I_t represents the amount of fertilizer applied in period *t* and it is a control variable to be solved in the model
- R_t is the quantity of fertilizer runoff in period *t*
- Y_t is crop yield in period *t* and it is a function of the amount of fertilizer available in period *t*, or $X_t+I_t-R_t$
- r_t is price of the fertilizer in period *t*
- P_t is price of the crop in period *t*
- θ is the proportion (0, 1) of fertilizer that carries over from one period to the next
- φ ($0\leq\varphi<1$) is the runoff rate , or the proportion of fertilizer that runs off and is not available for crop production in the current or future periods
- ρ denotes the discount rate
- H_t represents per-acre fixed harvest cost
- C_t represents per-acre cost of crop establishment and maintenance

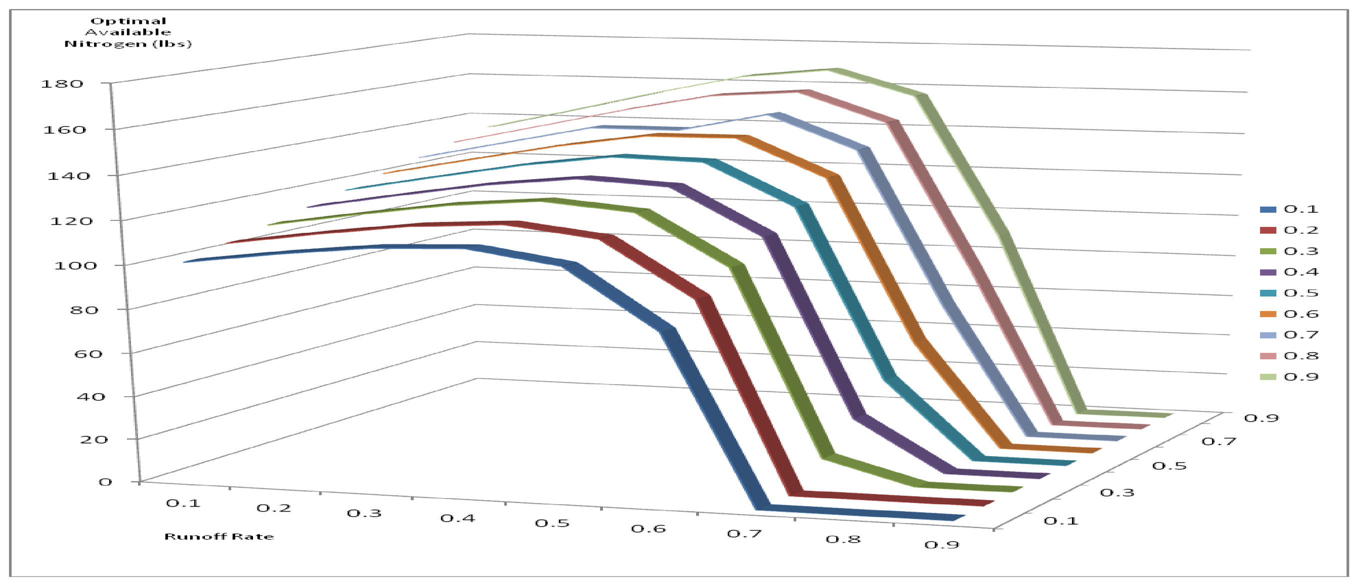

The optimal available amount of fertilizer before and after runoff occurs at period *t* is represented by Q_t^* as follows:

$$Q_t^*=(X+I_t)^*=\frac{-r_t+\rho r_{t+1}\theta(1-\varphi)+\rho P_t\beta_1(1-\varphi)}{2\beta_2\rho P_t(1-\varphi)^2}$$

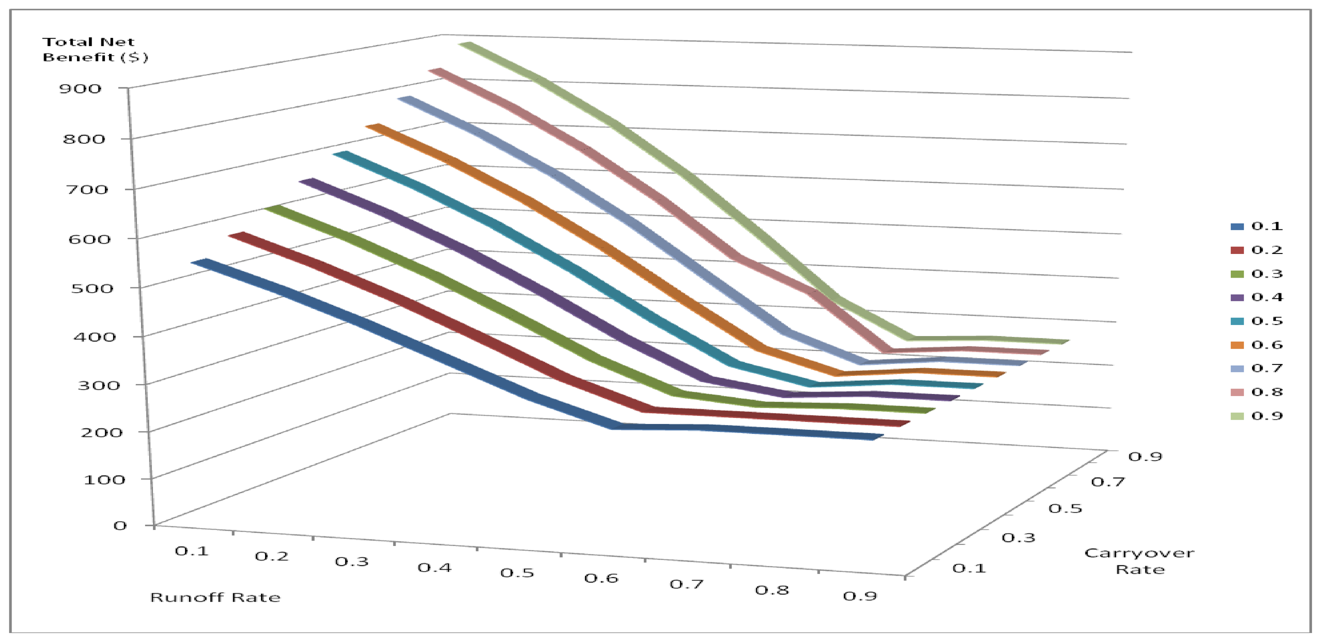
Data

- Parameters for Switchgrass Yield Function - Mooney et al, 2010
- Parameters for Corn Yield Function - UT Ag Extension
- Budgets and Prices for Switchgrass and Corn - UT Ag Extension

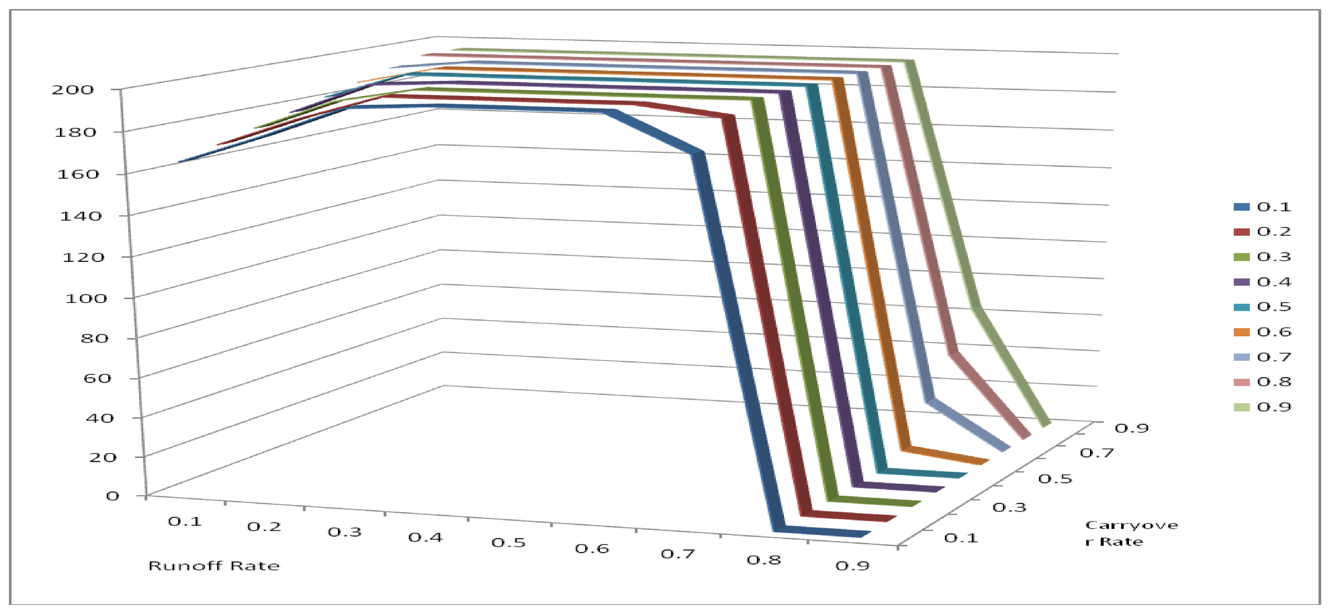
Results



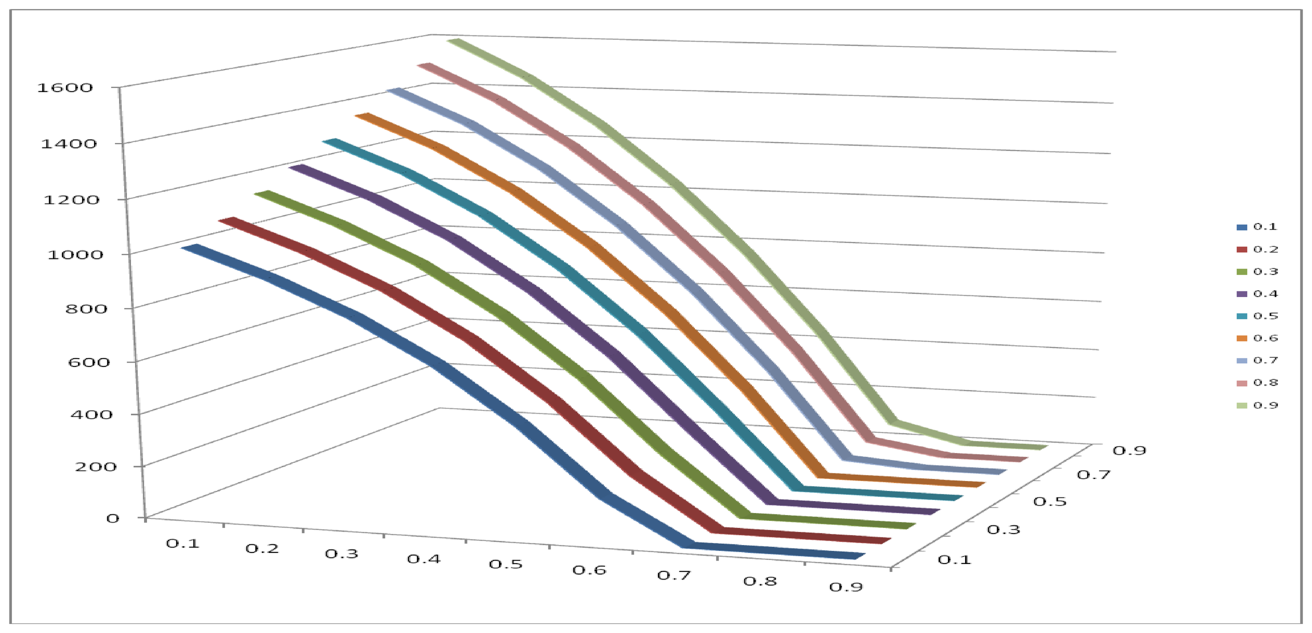
Optimal Available Amount of Nitrogen (Q_t^*) for Switchgrass (lbs/acre)



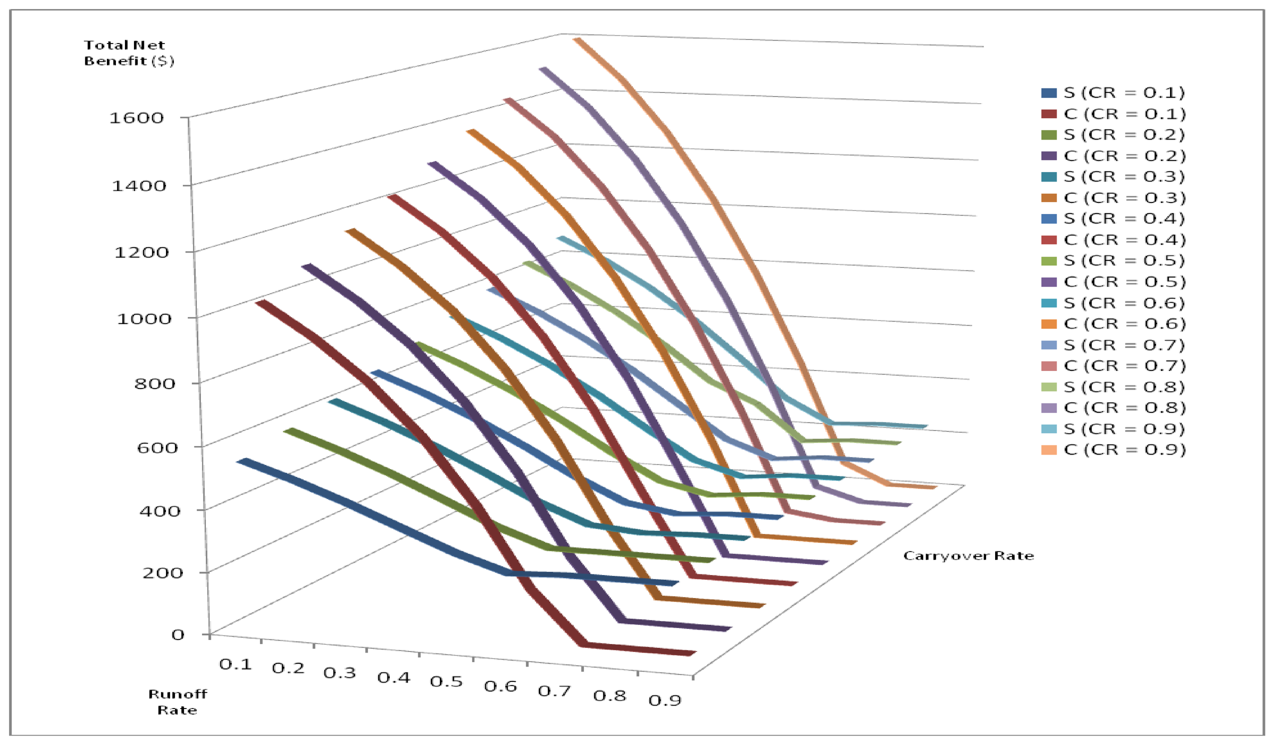
Ten Years of Total Net Benefits for Switchgrass ($/acre**)**



Optimal Available Amount of Nitrogen (Q_t^*) for Corn (lbs/acre)



Ten Years of Total Net Benefits for Corn ($/acre)



Ten Years of Net Benefits for Switchgrass and Corn ($/acre)

Conclusions

The optimal available and applied amounts of nitrogen along with ten years of net benefits are simulated for switchgrass and corn. The optimal available amount of nitrogen increases as the carryover rate increases; and the total net benefit increases as the carryover rate increases and decreases as the runoff rate increases. Total net benefits of corn production exceed those for switchgrass when the runoff rate is less than 0.6, but fall below those for switchgrass when the runoff rate exceeds 0.6. Thus, at the assumed prices and costs and estimated yield parameters, switchgrass is more profitable than corn only on the most marginal lands where fertilizer runoff exceeds 60% of the available fertilizer.

Future Direction

This paper provides a modeling framework for simulation and empirical analyses of optimal fertilizer application rates and relative net benefits associated with the production of bioenergy and conventional crops. Future research may be directed at using the framework to analyze the effect of a runoff constraint or other nutrient management strategies on the relative profitability of bioenergy and conventional crops.

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