Risks in Potato Production: Fertilizer, Water, and Producers' Decision Making

Serhat Asci, Tatiana Borisova, and John J. VanSickle

The authors are (respectively): Former graduate student, Assistant Professor, and Professor, Food and Resource Economics Department, University of Florida

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Abstract

This study focuses on the challenge of developing fertilizer best management practices (BMPs) for agricultural producers that would both optimize the crop production and minimize water quality impacts from agricultural operations. The overall objective is to develop recommendations to improve BMP development process by allowing for a more comprehensive consideration of production and marketing risks affecting farmers' production choices. Specifically, we use linear stochastic plateau production function to evaluate risks associated with the alternative levels of fertilizer application and prices for Florida potato production. Such analysis helps us to determine under what conditions alternative fertilizer BMP recommendations can be too restrictive, and how likely these conditions to occur. The results of the study are summarized in the form of recommendations for BMP development process in Florida and other states that use BMP as the primary tool to address nutrient water quality issues in agricultural areas.

Keywords: Nitrogen fertilizer use decision, water quality, stochastic plateau production functions, risk analysis.

Introduction

Nutrient management is a key decision for an agricultural producer. The amount of nitrogen fertilizer and its placement, type, and timing can have a direct impact on the crop yield and hence, profitability of a farm. Nutrient management also has important implications for water quality in local streams and rivers, helping to reduce fertilizer runoff from

[1] This article is partially based on Dr. Serhat Asci's PhD dissertation at the University of Florida.

agricultural fields. The State Cooperative Extension Service and USDA Natural Resource Conservation Service (NRCS) develop fertilizer use recommendations, referred to as Best Management Practices (BMPs), to advice producers on optimizing fertilizer use to achieve highest yields / profits while minimizing pollution runoff. In Florida, BMP implementation is mandatory for agricultural producers operating in the watersheds with impaired water bodies where Total Maximum Daily Load (TMDL) plans were established. Such mandatory requirement for BMP implementation requires a precise BMP definition, acceptable to all stakeholder groups, and providing for economically viable agricultural production and water quality protection.

Agricultural producers often deviated from fertilizer BMP recommendations, likely due to one of the three reasons: (1) producers' beliefs about the excessively significant effect that additional fertilizer has on their crops' yield and/or yield variability (Feinerman et al. 1990; Huang et al. 1998); (2) systematic biases in Extension production experiments used to develop recommendations; or (3) the lack of considerations of socio-economic factors in the development of the Extension recommendations, which leads to overly restrictive recommendations. In this study, we focus on the third potential reason. The overall objective of the study is to provide recommendations for BMP definition and development process to better account for the economic factors influencing the producers' fertilizer use decisions.

Existing studies identified a variety of economic and non-economic factors affecting fertilizer use (see, for example, Antle 2010, Babcock and Blackmer 1994, Babcock and Pautsch 1998, Feinerman et al. 1990, Isik 2002, Paudel et al. 2008, Pope and Kramer 1979, Prokopy et al. 2008, Rajsic et al. 2009, and SriRamaratnam et al. 1987). Overall, it has been shown that the BMP implementation and maintenance costs, perceived benefits of BMP, as well as the farm's financial performance (e.g., farm's debt-to-asset ratio) are key determinants of BMP adoption rate. However, BMP development largely relies on agronomic research and stakeholder discussions, while a comprehensive economic analysis of the impact of BMP implementation on producers' long-term profitability is rarely conducted. As a result, there is a room for debates among producers, researchers, and the state agencies about the fertilizer BMP rates that is practical for producers, and at the same time protective for water resources (Asci et al. 2013).

In this study, the economic factors important for fertilizer BMP definition are explored by considering (a) variability in yield driven by uncertainty in weather and fertilizer input use; (b) alternative levels of input and output prices; (c) various decision criteria that can be used by producers (i.e. maximizing profits or expected utility); and (d) various levels of producers' risk-aversion. Florida potato industry around Lower St Johns River Basin is used as a case in this study. Contested fertilizer BMP requirement for the potato production, sandy soils that facilitate fertilizer leaching, and potato farms located in close proximity to waterways make this region attractive for this study. The study shows that the fertilizer BMP level depends on the assumptions about the decision criteria, producers' risk aversion, and the market prices. Since the decision criteria and risk aversion varies among producers, and the prices vary from year to year, developing a unique optimal fertilizer rate BMP applicable for all producers and all production and market conditions is impossible.

Study Area

The study area is the Tri-County Agricultural Area (TCAA) in the Northeast portion of the State, most of which is located in the Lower St. Johns River Basin (TCAA, Figure 1). The BMAP for the Lower St Johns River Basin was the third BMAP developed in Florida, and it has been one of the most detailed and still one of the most contested BMAPs developed in Florida (US-EPA, 2009). The importance of the region and the increased attention to the region of the stakeholders in the state make it an interesting case study.

[INSERT FIGURE 1 HERE].

The main stem of the Lower St. Johns River is classified as impaired with respect to the narrative biologic water quality standard and the numeric DO standard (FDEP, 2013). Agriculture is identified among the main causes of impairment, especially in the up-stream, southern portion of the Basin, which is largely rural (FDEP, 2013). Agriculture is an important economic sector for the Basin. Along with potato (the major crop), farmers grow sod, cabbage, and other vegetables. The total value of agricultural production in the region was $126.1 M in 2007 (USDA, 2007). Implementation of BMPs is currently mandatory for agricultural producers in the Basin.

The rate of agricultural BMP implementation, as well as signing the Notices of Intent (NOIs) to implement BMPs, varies among Florida's regions and agricultural crop types. For a long time, the rates of signing NOIs and implementing fertilizer BMP were also relatively low in TCAA. In 2010 – 2012, large discrepancies between BMP recommendations and actual fertilizer use were observed, with the BMPs being 200 lb/acre, while growers were using up to 300 lb N/acre. Such a discrepancy between past BMP and the actual producers' practice make TCAA an interesting case study for this research.

Data

The land area, per acre yield and prices specifically for Hastings potato production in each of TCAA counties were obtained from potato statistics published by USDA – NASS for 1949 to 2006. Data for additional years (2007-2010) were obtained from USDA potato annual summary reports. Finally, NOAA' National Climatic Data Center was used to collect temperature and precipitation data for the study region. Information for Hastings area climatic station (COOP: 081978) was available only for the period of 1952 to 2010. Thus, this analysis focuses on this time period (Table 1). The precipitation data indicates the distribution of the number of rains over 1 inch during production season of TCAA (this precipitation level is based on the definition of the "leaching rain" event used in the fertilizer BMP definition).

[INSERT TABLE 1 HERE].

County level fertilizer sale data for the three counties in TCAA were obtained from US Geological Survey (USGS, 2012), National Oceanic and Atmospheric Administration (NOAA, 2012), and Florida Department of Agriculture and Consumer Services (FDACS, 2012). Time series data for the changes in acreage of different agricultural operations was not available, and hence, the total fertilizer use could not be adjusted to account for the use in specific crops. Potato production was considered to be the primary agricultural land use type in TCAA that requires fertilizer use, and hence, all county-level agricultural fertilizer sales were attributed to potato production.

Methodology

To examine the effect of economic factors on fertilizer use decisions, this study develops a comprehensive model that integrates various production and risk analysis methods. First, linear stochastic plateau potato production functions is estimated using the maximum likelihood technique. Next, financial analysis model is developed to assess profits for a typical potato farm in the study area. The financial model and the estimated potato production function are then combined to simulate ten-year net present value of profits using Monte Carlo technique. The simulations are conducted given alternative weather conditions, nitrogen fertilizer and potato sale prices, and nitrogen fertilizer application rates.

Linear stochastic plateau production function

Heady and Dillon (1961) stated that the majority of production functions have a plateau where yield does not increase in response to additional input use. Following Tembo et al. (2008), assuming single input model, the plateau response function in general form is expressed as follows

$$y = \min(g(N), y_p) + \varepsilon \tag{1}$$

where *y* is the yield, *N* is the level of nitrogen, *g*(*N*) is the production function and y_p is the plateau level and ε is the random error term. This function comes from a mathematical model called the plateau principle in which input contribution to the yield eliminated by time (Spillman 1933). Tembo et al. (2008) described a univariate linear response function and the optimum level of nitrogen as follows:

$$y_t = \min(\alpha_0 + \alpha_1 N_t, \mu_p + v_t) + \varepsilon_t \tag{2}$$

where N refers to nitrogen use at the time *t* , µ is a plateau level, ε and *v* are random variables. The random shift of the plateau is represented by weather variance for which $v_t \sim N(0, \sigma_v^2)$. The stochastic variable for weather and random error term for the whole function are assumed to be independent and the production function and v_t are not linearly dependent.

As stated above, assuming a risk-neutral producer that faces only the weather risk, the producer aims at maximizing the expected profit:

$$E(\pi_t \mid N_t) = p \cdot E(y_t) - w_N \cdot N_t \tag{3}$$

where *p* is the output price and the w_N is the input price. If we use non-stochastic plateau model, the optimum input level is obtained from the first order condition as

$$N_t = \begin{cases} N_p, & if \;\; p \cdot \alpha_1 > w_N \\ 0, & otherwise \end{cases} \tag{4}$$

where N_p represents the nitrogen level at the plateau. We add distribution function to this solution to determine input level for stochastic plateau. The censored normal distribution theorem developed for Tobit models can be used to find the optimum input level for stochastic plateau model (Greene 2000). SAS NLMIXED procedure was used to estimate the coefficients in the production function, and the optimal fertilizer use (Brorsen 2013).

Financial Analysis Model

The analysis described above employs expected profit maximization criterion to find the optimal fertilizer rate. While this analysis accounts for the production risks associated with variability in yield, it ignores the market risk, i.e., the risk associated with the variability in sale prices. Furthermore, this analysis is based on the assumption that the producer is risk-neutral, and is primarily concerned with the expected profits as opposed to the profit variability.

To account for the effects on fertilizer use decisions of both production and market risks, financial analysis model is developed. The model allows calculating total costs, revenues, and the annual present values (PV) of a business enterprise. For this study, ten-year net present value is computed as follows:

$$NPV = -(\text{Start}-\text{up Equity Value}) + \sum_{1}^{10} \frac{PV_t}{(1+r)^t} + \frac{\text{Terminal Value}}{(1+r)^{10}} \quad (5)$$

The NPV for a typical potato producer in TCAA is estimated based on discussions with industry experts and the latest financial and business literature (Richardson et al. 2007a; Richardson et al. 2007b; Palma et al. 2011).

To reflect production and price risks faced by the potato producers in the region, yield level and sale prices used in NPV estimation for each year are assumed to be stochastic. NPV levels are then estimated for a variety of fertilizer and sale prices, and fertilizer use levels (using Monte Carlo simulation method implemented in Simetar© add-in for MS Excel [Richardson, Schumann and Feldman, 2008]).

Simulation scenarios

Two set of simulation scenarios are developed in this study. In the first set of scenarios, potato production returns are simulated for three different potato sale prices: at the mean of $12/cwt, $14/cwt, and $16/cwt. Note that the fertilizer rates at these sale price levels are used to ensure the expected profit maximization from stochastic production function (as described in the section above).[2] These scenarios allow one to explore the profit loss associated with different price expectation for determining optimum nitrogen level.

In the second set of scenarios, the fertilizer application rate is assumed to vary between 150 lb N/acre to 207 lb N/acre, and then to 250 lb N/acre. For these scenarios, potato sale prices are assumed to be at the mean of $14/cwt. Note that for all scenarios NPV is calculated on per acre basis. These scenarios help to evaluate preferred level of fertilizer application depends on the risk aversion level of the producer.

The key outputs of the scenarios are ranked using the mean variance method, first level stochastic dominance analysis, and stochastic dominance with respect to a function (SDRF) to incorporate producers' risk aversion. All these risk ranking tools are available in the Simetar© add-in.

Results

The estimation results for linear response stochastic plateau as well as non-stochastic plateau function (for comparison purposes) show that:

- The hypotheses that the production function as non-stochastic plateau function is rejected at the 5% level (by log likelihood ratio test) by taking linear response stochastic plateau function as a base function.

- The expected plateau estimated in linear response stochastic function is higher than the estimated plateau level in the non-stochastic plateau function.

[2] As described below, this level is 207 lb N/acre, see table 3. The optimum is based on the assumption of $14/cwt potato sale price and $0.6/lb N input price

- The optimum level of nitrogen is found as 207.26 lb N/acre in linear stochastic plateau functions when potato price is assumed to be $14/cwt and the price of nitrogen is $0.6/lb.

[INSERT TABLE 2 HERE].

Optimum fertilizer level given stochastic response functions is calculated by using the equation (7) for linear stochastic plateau function. These equations are derived from the profit maximization function for specific nitrogen input price and output price. Therefore, we include sensitivity analysis to determine the different optimum nitrogen levels given both production functions. The sensitivity analysis shows that high output price results in high optimal fertilizer levels for a profit maximizing producer. Therefore, different price expectation of growers leads to various fertilizer rates among the growers. Similarly, a policy maker can have low price expectations, and in this case, BMP fertilizer level recommended by the regulators will be lower than the optimal.

[INSERT TABLE 3 HERE].

The estimated coefficients of the stochastic plateau functions can be used to simulate (or forecast) yields and use the simulated values in the financial analysis. Stochastic terms allow fluctuation to be included in the forecasted yield values. In contrast to the expected profit maximization described above, this analysis presents a more comprehensive model of the farmers' behavior by explicitly considering the output and input price variability in the financial analysis.

First, NPVs are compared for three different fertilizer levels: 150, 207, and 250 lb N/acre (Table 4). Recall that 207 lb N/acre was found to be the optimal fertilizer use level given the expected profit maximization criterion (see the previous section and fixed output and nitrogen prices). Note that this level is approximately equal to the fertilizer BMP level used in 2008 - 2012. The high nitrogen use scenario is selected to represent the current BMP level that allows producers to add extra fertilizer if required (FDACS, 2011). The low nitrogen use scenario is selected hypothetically to represent exceptionally low fertilizer use requirement. The summary statistics for the three fertilizer use scenarios is summarized in Table 4. The mean variance technique does not reveal the clear dominance of one fertilizer level, since the levels with higher mean NPV (i.e. 250 lb N / acre) is also associated with higher variability of the NPV (with the standard deviation equal to 1,054.13).

[INSERT TABLE 4 HERE].

As a second step in ranking scenarios, PDFs and CDFs of the 10-year NPV are drawn for alternative fertilizer use levels (Figure 2).

[INSERT FIGURE 2 HERE]

The figure indicates that fertilizer application at 207 and 250 lb N/acre level robustly dominates fertilizer application at 150 lb N/acre level given the first degree stochastic dominance criterion. However, the comparison of NPV distributions for 207 lb N /acre and 250 lb N / acre is not so straightforward. The CDFs of 'Fertilizer Applied-207' and 'Fertilizer Applied-250' cross each other, and the first degree stochastic dominance does not allow selecting the preferred fertilizer use level.

At last, the role of farmers' risk aversion on the fertilizer use decision is examined. SDRF is applied to incorporate various degrees of risk aversion into the ranking of alternative fertilizer use rates. The absolute risk aversion coefficients ranged from 0 to 0.00131 in the analysis. The absolute risk aversion coefficients, a, are based on the relative risk aversion, r, and are calculated as $a(w)=r(w)/w$ where w is the level of wealth, which is taken as the mean NPV value in this analysis. The relative risk aversion coefficients considered in this study are 0.0, and 2.0, which, respectively, indicating risk-neutral and moderately risk-averse producers (Richardson and Outlaw 2008). For example, for a moderately risk-averse producer, $a(w) = 2.0/1{,}524=0.00131$ where \$1,524 is the expected worth (i.e. 10-year NPV).

Table 5 presents the results of the SDRF ranking. The results show that the preferred level of fertilizer application depends on the risk aversion level of the producer. Specifically, Risk-neutral producers would prefer the scenario with fertilizer rate of 250 lb N / acre ('Fertilizer Applied-250'). In contrast, a producer who is moderately risk-averse prefers 'Fertilizer Applied-207' and avoid the downward risk caused by the high fertilizer expense and low yields.

[INSERT TABLE 5 HERE].

Different price expectation leads to various optimal fertilizer rates selected by the growers. In the second set of scenarios, different output price expectations are compared (Table 6). Note that the prices are kept stochastic, and hence, the difference in the price expectations is captured in the shifts in the price distributions. The reduction in NPV profits is then estimated for the case when the recommended fertilizer BMP level is set below the optimal level for a given output and fertilizer prices. Specifically, a policy maker can have low price expectations, and in this case, BMP fertilizer level recommended by the regulators will be lower than the optimal.

[INSERT TABLE 6 HERE].

Figure 3 shows the PDF approximations of simulated NPVs of optimum nitrogen levels at various output prices. The graphs illustrate the mean values and the distribution around the mean. As illustrated in the figure, the mean value increases when the output prices are high; however, high output prices decreases the risk. For instance, 'Mean Output Price-$16' has the highest mean and the lowest risk.

[INSERT FIGURE 3 HERE].

Conclusion

This study aims at exploring the socio-economic factors that should be considered in the development of the fertilizer best management practices (BMPs). Specifically, the study examined various decision criteria used by producers, alternative specifications of crop production function, alternative levels of input and output prices and various levels of producers' risk-aversion. The analysis focuses on TCAA region in northeast Florida.

The latest BMP regulation developed for TCAA allows farmers to adjust fertilizer application if necessary; therefore, it gives the farmers the flexibility to avoid reductions in profits associated with too restrictive BMP recommendations. Overall, this is consistent with the conclusion derived from this study that no single fertilizer BMP can be recommended for all growers and all market conditions.

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Table 1. Descriptive statistics summary for TCAA potato production, 1952-2010

Variables	Average	Standard Deviation	Minimum	Maximum
Potato Yield (cwt/acre)	209.9	55.1	110.0	330.0
Planted Potato Area (acre)	22.9	4.1	15.5	30.5
Fertilizer Sale (lb N /acre)	117.0	57.0	34.4	235.1
Precipitation (Number of rain events over 1 inch per potato production season)	5.3	2.6	1.0	12.0
Total Potato Production (1000 cwt)	4,605.8	1,223.6	2,376.0	6,930.0
Potato Price ($/cwt)	6.9	4.1	1.9	18.0

Table 2. Production functions and the optimum nitrogen levels

Estimated Parameters		Linear Response Stochastic Plateau	Linear Response Non-Stochastic Plateau
α_0	Intercept	113.38 (10.55)	103.79 (10.96)
α_1	Linear term	0.88 (0.07)	1.03 (0.09)
μ_p	Plateau level	257.80	260.54 (7.69)
σ_v^2	Variance of year random	N/A	1061 (34)
σ_ε^2	Variance of error term	1240 (218)	1034 (214)
N^*	Optimum Nitrogen Level	163.36	207.26 (2.79)
-2 Log Likelihood		588.50	590.70

Note: The expected price of nitrogen is $0.6/lb, the price of potato is $14/cwt.

Table 3. Sensitivity analysis of optimum nitrogen level for linear function (in pounds of nitrogen per acre)

Sale Prices -	Nitrogen Prices - $ / lb		
$/cwt	$ 0.55	$ 0.60	$ 0.65
$ 12	206.26	204.94	203.71
$ 14	208.54	207.26	206.07
$ 16	210.46	209.22	208.05

Note: Nitrogen levels are provided in lb N/acre.

Table 4. Summary statistics for 10-year NPV simulations for various fertilizer rates

Linear Stochastic production Function, Output price = $14, various N fertilizer rates			
	Fertilizer Applied-207	Fertilizer Applied-150	Fertilizer Applied-250
Mean	1,524.00	706.62	1,608.32
Standard Deviation	997.96	968.25	1,054.13
Coefficient Var.	65.48	137.03	65.54
Minimum	(1,516.84)	(2,083.70)	(1,912.51)
Maximum	5,128.98	3,708.96	4,325.47

Table 5. Analysis of Stochastic Dominance with Respect to a Function (SDRF)

Rank	Name	Level of Preference
Lower Risk Aversion Coefficient: 0 (Risk-neutral)		
1	Fertilizer Applied-250	Most Preferred
2	Fertilizer Applied-207	2nd Most Preferred
3	Fertilizer Applied-150	3rd Most Preferred
Upper Risk Aversion Coefficient: 0.00131 (Moderately Risk-averse)		
1	Fertilizer Applied-207	Most Preferred
2	Fertilizer Applied-250	2nd Most Preferred
3	Fertilizer Applied-150	3rd Most Preferred

Table 6. Summary statistics for 10-year NPV simulations for various output prices

Linear Stochastic production Function, optimum N fertilizer rates, various output prices

	Mean Output Price-$14	Mean Output Price-$12	Mean Output Price-$16
Mean	1,508.97	(345.67)	2,893.31
Standard Deviation	1,004.01	1,079.03	996.38
Coefficient Var.	66.54	(312.16)	34.44
Minimum	(1,516.84)	(3,596.91)	(361.44)
Maximum	5,128.98	2,505.62	5,991.60

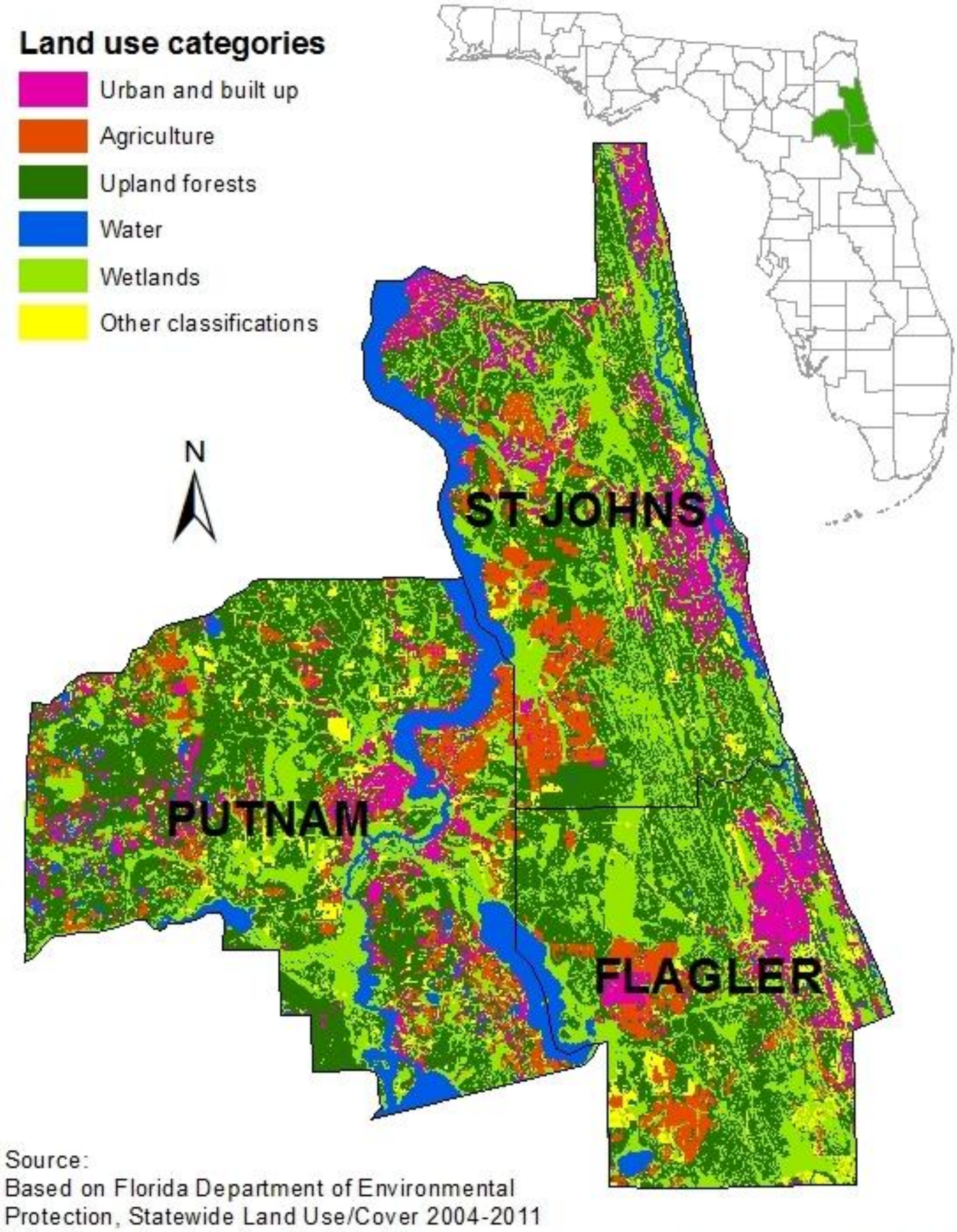

Figure 1. The counties of Tri-County Agricultural Area and agricultural areas

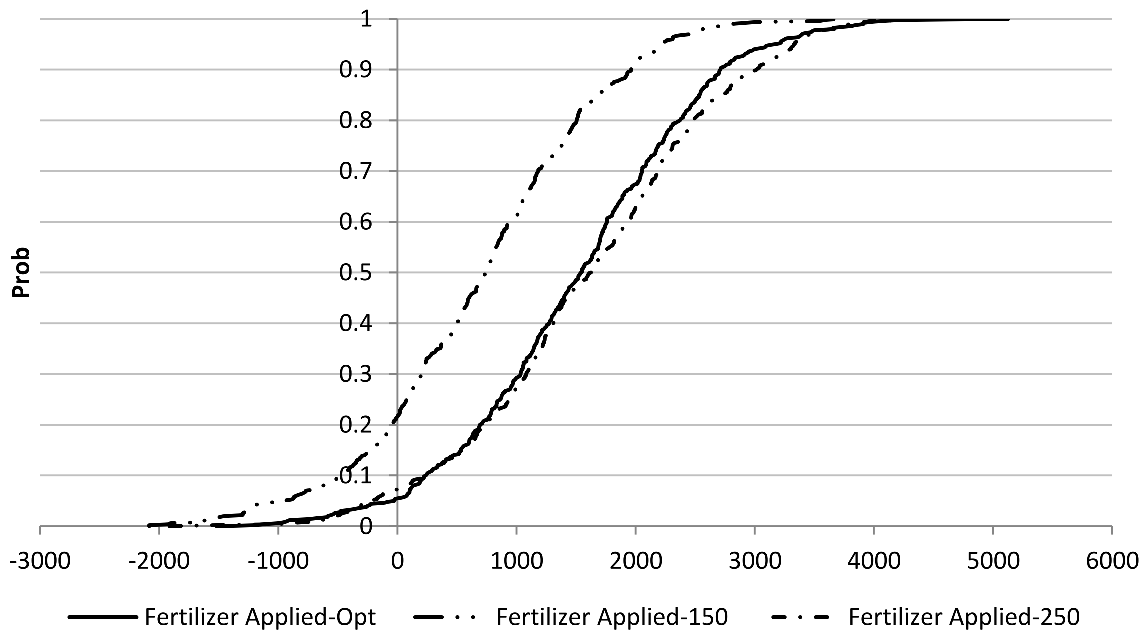

Figure 2. CDFs of simulated net present values for various fertilizer use decisions

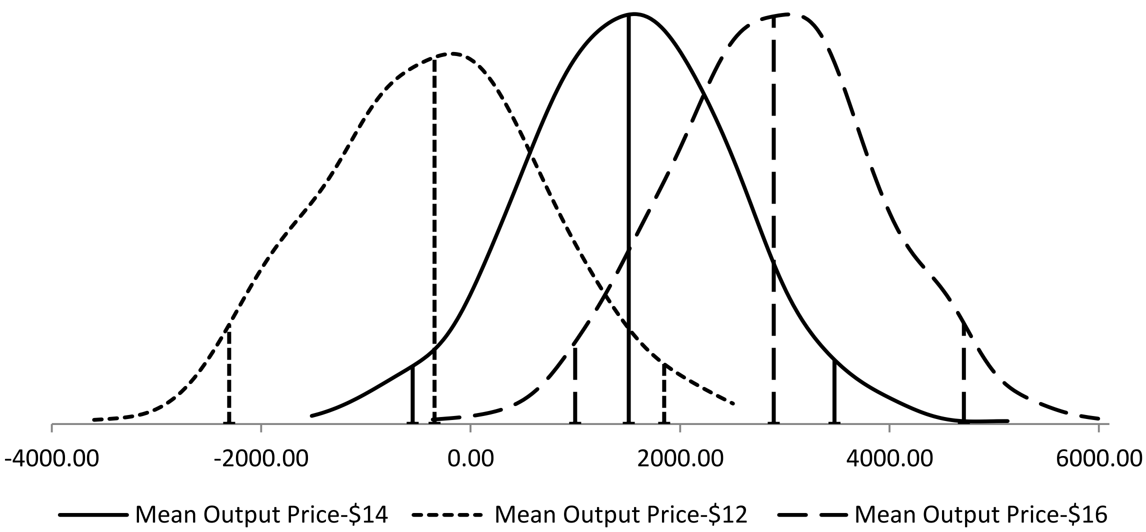

Figure 3. PDF approximations of simulated net present values of optimum nitrogen levels at various output prices