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Role of economics in developing fertilizer best management practices

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ABSTRACT

To reduce agricultural water quality impacts, many US states and other countries rely on agricultural best management practices (BMPs). Although fertilizer BMP rates are supposed to ensure the economic viability of agricultural production, BMPs are frequently based on agronomic, rather than economic, research; moreover, some producers resist BMP adoption, citing profit reductions. In this study, we examine the effect of production and market risks, as well as producers' risk aversion, on producers' fertilizer rate and BMP adoption decisions. We focus on potato production in the Lower St. Johns River Basin, northern Florida. Using historical data, we estimate the linear stochastic plateau production function that explicitly incorporates production risks related to weather. We develop a financial model and use Monte Carlo simulation and empirical fertilizer and potato sale price distributions to estimate the distributions of ten-year net present values (NPVs) for alternative fertilizer rates. The results show that the preferred fertilizer rate depends on the assumption about potato sale prices and producers' risk aversion levels. Risk-neutral producers prefer lower fertilizer rates than do risk-averse producers to avoid the downward risk caused by the high fertilizer expense and low yields. BMP adoption can also lead to profit loss when the BMP is designed for a low price scenario while market conditions are favorable. Hence, BMP development should be based on comprehensive analysis of production and market risks, as well as producers' risk perceptions. It should also be recognized that to achieve water quality targets, BMP adoption may lead to reductions in profits if a subset of possible production and/or market conditions are realized. Insurance-type policies to compensate agricultural producers for the profit losses may be developed.

1. Introduction

Forty years after passing the federal Clean Water Act, restoring and maintaining the integrity of the nation's waters still remains a challenge in the United States (US). Nationwide, 253 thousand kilometers of assessed rivers, 2 million hectares of assessed lakes and reservoirs, and 15.5 thousand square kilometers of assessed bays and estuaries are being classified as having nutrient-related impairments. In some US states, such as Florida, Kansas, and Delaware, more than fifty percent (%) of all assessed rivers, lakes, and reservoirs are impaired due to nutrient-related causes, which are often related to leaching from agricultural areas (US EPA, 2014, 2000).

In 2011, 11.7 million tons of nitrogen were used in the United States, and this level is near an all-time high, despite the recent increase in nitrogen fertilizer prices (USDA/ERS, 2013). The overall efficiency of applied fertilizers is generally less than 50% for nitrogen (Baligar et al., 2001; Fageria et al., 2008). Despite the advances in precision technologies, there is still substantial uncertainty in the factors affecting the nutrient uptake of plants, as well as the loss of nutrients due to leaching and other processes, leaving room for subjective judgment about the amount of fertilizer to be applied.

Given the profound uncertainty in the plants' uptake and nutrient fate in the environment, agricultural best management practices (BMPs, also referred to as conservation practice) are usually seen as the primary strategy to protect local water resources. BMPs are generally defined as research-based practices that allow for maximizing yields and profits while minimizing the negative impacts on the environment. For example, the Natural Resource Conservation Service (NRCS), an agency within the United States Department of Agriculture (USDA) that provides conservation assistance to US farmers, defines nutrient management BMP as a practice that "achieves realistic production goals while minimizing movement of nutrients and other potential contaminants to surface and/or ground waters" (NRCS, 2006). Similarly, in Florida, agricultural BMPs are defined as "practical, cost-effective

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actions that agricultural producers can take to reduce the amount of. . .pollutants entering our water resources. . .while maintaining or even enhancing agricultural production" (FDACS, 2011a). Similar definitions are used in other US states (GSWCC, 2013; LDNR, 2008; MRSC, 2013; NHG, 2005; Hardy et al., 2003) and in some countries (D'Arcy and Frost, 2001; Greiner et al., 2009). While BMPs are developed based on agronomic studies (Dechmi and Skhiri, 2013; Naramngam and Tong, 2013), a comprehensive economic analysis is rarely part of the BMP development or evaluation process.

In this paper, we develop a farm-level economic model, and we use it to show that the failure to consider production and market risks, as well as producers' risk perceptions, in the BMP development process results in significant, yet unaccounted for, production costs associated with BMP implementation.

Improved agricultural water management is a primary strategy for reducing pollution runoff; however, changes in irrigation and drainage systems can be prohibitively expensive. Nationwide, 30% of farms that identified barriers to energy and/or water conservation improvements mentioned inability to finance improved irrigation systems among the barriers (Schaible and Aillery, 2012). Given potential challenges faced by producers, alternative strategies for reducing nutrient pollution runoff and improving fertilizer use efficiency are considered. Better tailoring of the nutrient supply to the plants' needs can be achieved through BMPs related to soil testing, timing of fertilizer application, fertilizer application rates, or the use of controlled-release fertilizers (Hartz, 2006). In this paper, we focus on fertilizer application rates, although similar arguments about the importance of risks and risk perceptions can be made for other BMPs.

While reviewing past economic studies focused on defining the optimal fertilizer rates, we found none that directly connected the optimal fertilizer rate research with existing or proposed fertilizer BMPs. Early economic studies used profit maximization models to determine the optimal fertilizer rate given specific fertilizer and crop sale prices, as well as a specific relationship between fertilizer rate and crop yield. This relationship is referred to as production function (Anderson, 1973; Bullock and Bullock, 1994; Cerrato and Blackmer, 1990). In more recent studies, it was recognized that the key parameters in the profit maximization model are not perfectly known at the time the decision about fertilizer use is made.[3] Specifically, there is uncertainty about crop sale prices and the prices of fertilizer and other inputs caused by fluctuations in demand and supply (generally referred to as price risks), as well as future yields (referred to as production risk). Yield varies due to the stochastic parameters related to weather, soil quality, disease presence, and other conditions (Antle, 2010; Babcock and Pautsch, 1998; Claassen and Just, 2011; Tembo et al., 2008). Moreover, fertilizer rates often increase yield variability (Feinerman et al., 1990; Huang, 2002; Rajsic et al., 2009; Roosen and Hennessy, 2003). To account for the risks and uncertainties of production profits, economists focus on maximizing expected profits (Tembo et al., 2008) and expected utility, which reflects producer preferences over risky events (Richardson and Outlaw, 2008). Generally, if the increase in fertilizer use leads to a higher profit variability, then farmers who dislike the risks (i.e., more risk-averse) are expected to apply less fertilizer, compared with farmers who like risky enterprises (i.e., less risk-averse or risk-neutral). Hence, accounting for the degree of producers' risk aversion helps explain the range of fertilizer rates used by agricultural producers.

Significant attention has also been paid in economic literature to the adoption of agricultural BMPs. Farmers' net benefit has been identified as a critical determinant of producers' adoption decision, where along with financial concerns, net benefits can include considerations of the BMPs' compatibility with producers' value systems, perceived impacts upon family lifestyle, or loyalty to a brand (Pannell et al., 2006; Rogers, 2003). Given that the production function and financial payoffs can be fairly flat for a range of production practices, non-financial concerns can have significant impact on the choice of the practices (Pannell, 2006; Sheriff, 2005). Farmers' subjective beliefs related to the probability of uncertain production outcomes can also influence farmers' decision to adopt alternative production practices (Pannell et al., 2006; Marra et al., 2003).

Surprisingly, the economic studies that investigated optimal agricultural input use decisions and the adoption of innovations have not been linked with the BMP development literature. Instead of maximizing producers' expected profit, utility, or net benefit, BMP development studies focus on yield maximization, and primarily include agronomic studies estimating production functions (Hochmuth et al., 2011; Mikkelsen and Hopkins, 2008; Rosen and Bierman, 2008). No studies were found that considered variability in input and sale prices, as well as the role of price and yield variability and producers' risk preferences in the context of developing agricultural BMPs.

This study contributes to the production economics and the agronomic and horticultural BMP development literature by exploring the impacts of production and price risks, and producers' risk preferences on the costs associated with BMP implementation. Unlike the previous economic studies that focused on expected profits or utility maximization, we develop empirical distributions of profits associated with alternative fertilizer rates. We then apply economic ranking criteria to identify the profit distributions that are most preferred by the producers with alternative risk aversion levels. The distribution of profit is driven by stochastic fertilizer prices, produce sale prices, and crop production conditions. To capture the stochastic relationship between fertilizer rates and yield, we use the most recent economic literature that develops the stochastic plateau production function (Tembo et al., 2008), and we explicitly relate the variability in yields to stochastic seasonal weather conditions. We also use historical data to account for the correlation between stochastic yields and sale prices, and estimate BMP cost by calculating the difference between the expected profits given the BMP fertilizer use level and the optimal fertilizer rate. We demonstrate that the selection of a fertilizer rate BMP without considering price and production risks and producers' risk preferences can result in BMP recommendations that are unacceptable to some farmers or specific production and market conditions impacting BMP adoption rates.

2. Materials and methods

2.1. Study area

Florida is a remarkable area to study BMP development and agricultural water quality policy. Current Florida water quality policy reflects the delicate balance between the goals of protecting water resources and allowing for economic stability and growth. Florida is one of the few US states where BMPs are mandatory for agricultural producers to implement. Following federal requirements, Total Maximum Daily Loads (TMDL) set caps on the total amount of pollution discharged to impaired water bodies. In turn, state-recommended Basin Management Action Plans (BMAPs) are implementation plans describing strategies to achieve TMDL caps, with mandatory agricultural BMPs being one of the key strategies (FDACS, 2011a). To formally comply with the state BMP program, agricultural producers are required to use the BMP manuals

[3] Economists distinguish risk and uncertainty such that risk refers to future events with measurable probability, while uncertainty characterizes future events with indefinite or incalculable probability (Knight, 1964).

adopted by the Florida Department of Agriculture and Consumer Services (FDACS) that are appropriate to their operations and geographical regions. Agricultural producers are required to identify the applicable BMPs on a formal Notice of Intent, and submit the Notice of Intent to FDACS. Producers who sign Notices of Intent receive the presumption of compliance with the state of Florida's water quality standards, but they still may be subject to inspections to verify BMP implementation and maintenance. Cost-share programs are available for BMP implementation. Producers who decide not to implement BMPs and/or not sign Notices of Intent have the option of monitoring runoffs from their fields to prove that they are not causing water quality problems (with monitoring costs often being prohibitively high). Producers who do not sign Notices of Intent and do not monitor runoffs may be subject to enforcement actions from state agencies.

BMPs included in the FDACS BMP manuals are based on agronomic research conducted by the University of Florida. The manuals are reviewed by industry representatives and other experts to ensure that BMPs are "economically and technically feasible" (FDACS, 2014). The definition of agricultural BMPs and the process of their development receive special attention from both the agricultural producers (that are mandated to implement the BMPs) and the environmental community (that consider the BMPs as the only strategy available for protection of waterways from impacts of agricultural activities). Both stakeholder groups raise questions about the environmental effectiveness and economic feasibility of individual BMPs, largely due to the lack of economic and water quality data related to BMP implementation in the fields. The lack of agreement between the two stakeholder groups affects the rate of BMP adoption. For example, only 37% of agricultural producers in north-central Florida signed Notices of Intent, and the signature rate for the program in northeast Florida has also been low (Katz, 2013).

The Lower St. Johns River (LSJR) Basin in northeast Florida (Fig. 1) was one of the first regions in Florida where BMAPs were adopted to address excessive nutrient loading to the St. Johns River, and where agricultural BMPs became mandatory for the producers (in 2008). Florida is the leading supplier of potatoes in the nation during the spring harvesting season (National Potato Council, 2014), and most of the Florida potatoes are grown in the Lower St. Johns River Basin, specifically in Putnam, St. Johns, and Flagler Counties (which are referred to as the Tri-County Agricultural Area, or TCAA). Agriculture is an important economic sector for the TCAA, with the total value of agricultural production equal to $130.8 million in 2012 (USDA, 2012).

The limit on nitrogen fertilizer rate is one of the primary BMPs included in the FDACS BMP manual for the row crop producers in northeast Florida, and it is subject to mandatory implementation. The first fertilizer BMP rate for potato production in the TCAA was set at 224 kilograms of nitrogen per hectare (kg N/ha). Although the BMP rate was selected based on field experiments conducted by University of Florida researchers, some stakeholders argued that this BMP rate was economically unfeasible since it would reduce producers' profits, and hence could not be called a BMP (FDACS, 2011a). Indeed, a large discrepancy between the BMP recommendation and actual fertilizer use was observed, with the growers using up to 336 kg N/ha. Recognizing the discrepancy and responding to stakeholder requests, FDACS revised the BMP for potato growers in the TCAA to allow up to 280 kg N/ha while keeping 224 kg N/ha as the recommended BMP level (FDACS, 2011b). This new rule gives growers some flexibility to respond to changing markets and weather conditions.

While the revision in the BMP fertilizer rate illustrates the adaptive nature of BMP development in Florida, the discrepancy in BMP recommendations and the actual producers' practices indicates the need to accurately account for the economic factors driving fertilizer use. In this paper, we argue that the BMP is currently set without explicitly considering production and price risks, as well as risk preferences of the producers. As a result, BMP adoption can result in significant costs for producers with specific levels of risk aversion and some market conditions. Hence, the "economic viability" criterion used in the BMP definition needs to be defined more explicitly, describing the limit on the costs associated with BMP adoption and economic criteria (and processes) for periodic BMP revisions.

2.2. Model description

2.2.1. Potato production function

In contrast to traditional BMP research that relies on deterministic production functions, this study explicitly models the stochastic production function in which the stochasticity is driven by seasonal weather conditions. Following Tembo et al. (2008), a linear stochastic plateau response function is used:

$$y_t = \min(\alpha_0 + \alpha_1 N_t, \mu_p + \nu_t) + \varepsilon_t \tag{1}$$

where N_t refers to nitrogen use at the time t, μ_p is a plateau level, ε and ν are random variables, and α_0 and α_1 are the parameters. The random shift of the plateau is represented by weather variance for which $\nu_t \sim N(0, \sigma_\nu^2)$ (Fig. 2). Maximum likelihood estimation enables us to estimate the parameters of the linear plateau production function using the SAS NLMIXED procedure (Asci, 2013; Brorsen, 2013; SAS Institute Inc., 2008).

2.2.2. Expected profits for risk-neutral producer, deterministic prices, and stochastic yields

As a starting point, we consider a risk-neutral producer facing only the production risk. The producer aims at maximizing the expected profit:

$$E(\pi_t|N_t) = p \cdot E(y_t) - w_N \cdot N_t \tag{2}$$

where p is the output price and w_N is the fertilizer price, with both prices assumed to be fixed and perfectly known. Based on the censored normal distribution theorem developed for Tobit models and applying chain rule, one can derive the optimum level of nitrogen value as

$$N_t^* = \frac{1}{\alpha_1}\left[\Phi^{-1}\left[1 - \frac{w_N}{p\alpha_1}\right] \cdot \sigma_\nu + \mu_p - \alpha_0\right] \tag{3}$$

where Φ^{-1} shows the inverse standard normal cumulative distribution function at $\Phi = \Phi((a - \mu_p)/\sigma_\nu) = \text{prob}(y_p \le a)$ (Asci, 2013; Greene, 2000; Tembo et al., 2008).

BMP costs can then be estimated as the difference between the expected profits given the BMP fertilizer use level (N_{BMP}) and the optimal level in Eq. (3). If they coincide, the costs are zero:

$$\text{BMP Cost} = E(\pi_t|N_t^*) - E(\pi_t|N_{\text{BMP}}) \tag{4}$$

Note that the optimal fertilizer use in (4) depends on the sale price p and fertilizer price w_N. Prices are often unknown at the time when the fertilizer rates are decided, and producers' price expectation may be determined by their past production experiences, perceptions of market conditions and policies, and producers' socio-demographic characteristics (Choi and Helmberger, 1993; Lobell et al., 2009). Sensitivity analysis is used to determine the dependence of the BMP costs and optimum nitrogen levels given alternative fertilizer and potato sale prices. Based on the range of historical prices, three potato sale prices are considered: low ($242.6/ton), medium ($308.7/ton), and high ($352.8/ton).[4]

[4] The medium is calculated as the price distribution mean when trend is included. The low and high prices are the values in the 90% confidence interval to the mean.

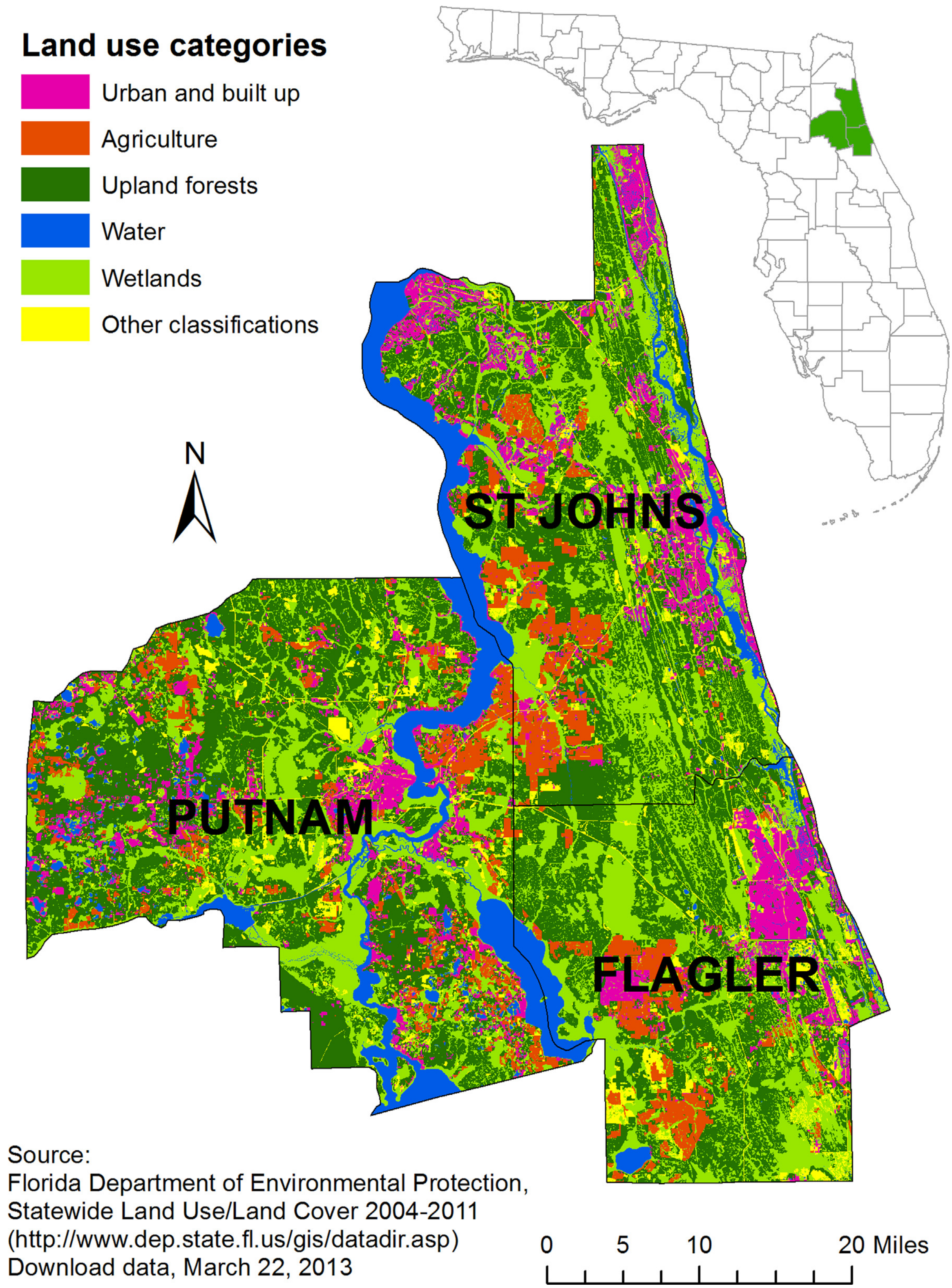

Fig. 1. The counties of Tri-County Agricultural Area and agricultural areas.

2.2.3. Financial performance given stochastic yield and prices

To make the model developed above more realistic, we consider the situation when yield y and the prices p and w_N are stochastic. Given the number of stochastic variables affecting production profits, simulations are used to find the empirical distributions of the ten-year production profits (i.e., net returns) given alternative fertilizer rates (with one rate reflecting the fertilizer BMP). The distributions are then ranked to account for the preferences of the producers with different risk aversion levels.

To derive empirical distribution of the ten-year production profits, a farm financial analysis model is developed. The financial model includes an income statement, a cash flow statement, and

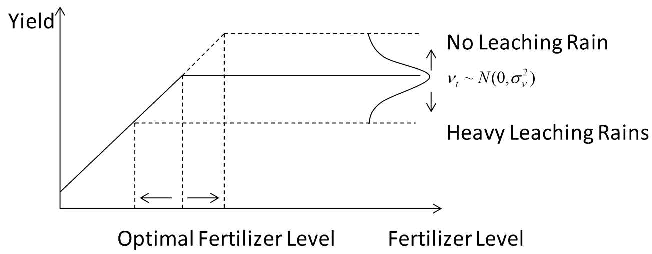

Fig. 2. Plateau shift for the stochastic function due to weather effect. *Note*: Based on Tembo et al. (2008).

a balance sheet, which are the basic accounting tools in any agricultural enterprise. The model allows calculating the total costs, revenues, and net present values (NPV) of a business enterprise. The ten-year NPV is computed as

$$\text{NPV} = -(\text{Start-up Equity Value}) + \sum_{1}^{T} \frac{\text{FCF}_t(N_t|p, w_N)}{(1+r)^t} + \frac{\text{Terminal Value}}{(1+r)^T} \tag{5}$$

where NPV gives us the sum of the discounted annual difference between cash inflows and cash outflows, referred to as free cash flow (FCF), over T years (with $T = 10$ in this study). A business enterprise starts with an equity value that ensures that the average cash flow never falls below zero for a rational investment. Additionally, the terminal value of the enterprise is also discounted at the end of T years. Values are discounted by using rate of return, represented by r.

In this study, NPV is calculated on a per acre basis. The Monte Carlo simulation method is used to obtain the distribution of NPV based on the distributions of stochastic yield and prices (Palma et al., 2011). A sample of values for all stochastic variables is selected simultaneously, and the process is repeated 500 times to estimate the probability density functions (PDF) and cumulative distribution functions (CDF) for the stochastic outcomes. The simulations are conducted using Simetar© add-in for MS Excel (Richardson et al., 2008).

The following stochastic variables are used to model production and price risks: yield, output price, and fertilizer price. Potato yield is simulated by using estimated linear stochastic plateau production function coefficients and the stochastic terms (1). Various fertilizer use levels are considered (as described below in Section 2.2.3.1). Potato sale prices are simulated jointly with the yields, since historical price and yield data show negative correlation between the prices and yields. A multivariate empirical (MVE) probability distribution is used for the joint simulation of stochastic output prices and yields (Richardson et al., 2000) given the correlation between potato price and yield. Finally, nitrogen input price is simulated with the GRKS distribution (named after Gray, Richardson, Klose, and Schuman) (Richardson et al., 2007). This distribution uses mean, maximum, and minimum value information to generate a distribution that can also account for rare events outside the minimum and maximum values. Specifically, GRKS distribution provides for the probability of unforeseen events (Richardson et al., 2007).

2.2.3.1. Alternative fertilizer application rates. To show that BMP development should account for production and price risks, the distribution of the ten-year NPV described above is compared given the BMP fertilizer rates and the alternative rates that may be chosen by producers. Specifically, three fertilizer rates are considered: low, medium, and high. The low nitrogen rate is selected hypothetically to represent exceptionally low fertilizer use based on historical data. The medium level is selected as the level representing the optimal fertilizer use level given the expected profit maximization criterion (N^*, see Section 2.2.2). As shown in Section 3, this level approximates the fertilizer BMP rate used by FDACS between 2008 and 2012. Finally, the high nitrogen use scenario is selected to represent the revised FDACS BMP rate that allows producers to add fertilizer if required (FDACS, 2011b). Alternative fertilizer rates result in distinct NPV distributions that are then ranked to determine the relationship between the risk aversion of the producer and the preferences for the nitrogen rate, as described in Section 2.2.4.

2.2.3.2. Fertilize rates and alternative output prices. Since price expectations can be subjective and depend on past experiences and socioeconomic characteristics of the decision-maker (Choi and Helmberger, 1993; Lobell et al., 2009), in the second set of simulation scenarios, NPV distributions for different output price expectations and fertilizer rates are compared. Note that the prices are kept stochastic, and hence, the difference in the price expectations is captured in the shifts of the price distributions. Based on the range of historical prices, three distributions of potato sale prices are selected based on historical data: low (mean of \$242.6/ton), medium (mean of \$308.7/ton), and high (mean of \$352.8/ton).

NPV distributions are then compared for the different price scenarios, as well as for the scenarios with alternative fertilizer use. A policy maker can have lower price expectations than the producers, and in this case, the BMP fertilizer level recommended by the regulators will be lower than the level preferred by the producers. To reflect this situation (when the BMP level is fixed by the regulatory agency based on a lower price assumption), we fix the fertilizer rate on the medium level. We then examine whether higher fertilizer use may be more preferable given different price scenarios.

2.2.4. Farmers' risk aversion levels and ranking NPV distributions

The distributions of NPVs derived for the different fertilizer rates, and output price scenarios are ranked using the mean variance method, first-degree stochastic dominance, and stochastic dominance with respect to a function (SDRF) to incorporate producers' risk aversion.

The mean variance method simply looks for the highest coefficient of variation for ranking the risky alternatives, and it does not account for producers' risk aversion levels. First-degree stochastic dominance compares cumulative distribution functions (CDFs) of the NPVs, and identifies whether there is a distribution that is more preferable for producers given all the stochastic variables and risk aversion levels (Richardson and Outlaw, 2008). If the first-degree stochastic dominance criterion fails to determine the most preferred distribution of NPV, this implies that the choice of the NPV distribution depends on the producers' risk aversion level. SDRF criteria are then defined as follows:

$$\sum U(x, r_i(x))F(x) \leq \sum U(x, r_i(x))G(x) \tag{6}$$

where x is NPV for the simulated scenario, and $F(x)$ and $G(x)$ are the distribution functions. $F(x)$ is preferred to $G(x)$ under the given absolute risk aversion coefficient ($r_i(x)$) of the decision maker (Richardson and Outlaw, 2008), where i refers to the upper and lower limits of absolute risk aversion coefficients, respectively, represented as ($r_U(x)$) and ($r_L(x)$), and U refers to utility. The absolute risk aversion coefficient is calculated based on the relative risk aversion coefficient and the expected worth of an average potato producer. In this study, the relative risk aversion coefficient is scaled from zero (for the risk-neutral decision maker) to two (for the strongly risk-averse decision maker) (Richardson and Outlaw, 2008).

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

Variables	Units	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 (>1 in.)	# of rain/season	5.3	2.6	1.0	12.0
Total potato production	1000 cwt	4605.8	1223.6	2376.0	6930.0
Potato price	$/cwt	6.9	4.1	1.9	18.0

Note: This table is constructed by authors (NOAA, 2012; FDACS, 2012; USDA/ERS, 2012; USGS, 2012).

2.3. Data

The potato production area, per acre yield, and fertilizer and potato sale prices specifically for Hastings potato production in the TCAA were obtained from potato statistics published by USDA/ERS for 1949–2006 (USDA/ERS, 2012). Data for additional years (2007–2010) were obtained from USDA potato annual summary reports. Finally, NOAA's National Climatic Data Center data were used to estimate precipitation for the study region, specifically focusing on the number of precipitation events over one inch during the potato production season. Such events are defined as "leaching rains" and are used to characterize rainy weather conditions conducive for fertilizer losses.[5] Information for the Hastings area climatic station (COOP: 081978) was available only for the period of 1952–2010, and this time period is used in this study (Table 1). Based on historical data, estimated correlation between potato sale prices and yield is −0.14.

County-level fertilizer sales data for the three counties in the TCAA were obtained from the US Geological Survey (USGS, 2012), National Oceanic and Atmospheric Administration (NOAA, 2012), and Florida Department of Agriculture and Consumer Services (FDACS, 2012). Specifically, NOAA data cover the period from 1952 to 1991, USGS data span the period from 1987 to 2001, and FDACS reports the data for 1997–2010. Potato production was considered to be the primary agricultural land use type in the TCAA that requires fertilizer use, and hence, all county-level agricultural fertilizer sales were attributed to potato production. It is important to acknowledge that this assumption is an over-simplification. For example, the most recent US Agricultural Census showed that in 2012, 9803 ha were devoted to vegetable production in the TCAA, and potatoes was grown on 67.5% of this area (i.e., 6566 ha) (USDA, 2012).[6] The percentage of agricultural area devoted to potato production varies over time, and it would be important to account for this variation in estimating fertilizer use. However, the time series data on the proportion of potato production area in the total vegetable production area were unavailable. The average fertilizer use analyzed in this study ranges from 168 kg N/ha to the revised highest fertilizer use of 280 kg N/ha, which is close to the levels historically observed in potato production in the area.

Production cost values (variable, marketing, and durable costs) are taken from the most recent potato budget produced by the University of Florida (Smith and VanSickle, 2009) and adjusted for recent changes in prices based on discussions with industry experts. The production budget allows us to construct a financial model parallel to one used in the agribusiness literature (Palma et al., 2011; Richardson et al., 2007). The start-up equity value (beginning wealth) for potato production is approximately $803.06/ha. This amount is chosen as the minimum amount to ensure that the farmer does not run out of cash over the ten-year period. Based on actual loan rates in the United States, farmers use operating loans which account for 90% of the total variable cost at a 5% interest rate annually; in addition, 80% of the fixed costs are financed at an 8% interest rate over a seven-year period (Briggeman, 2010). These levels of operating loans for variable and durable expenses, the annual interest rates, and the loan periods are based on the literature and discussions with experts. The rate of return to this enterprise is assumed to be 10% for farmers at the end of each year. The rate of return on investment refers to farmers' annual return from the positive net income, and the 10% level is assumed based on similar existing studies (Richardson and Mapp, 1976).

Table 2
Linear production stochastic plateau production function estimates and the optimum nitrogen levels.

Estimated parameters		Estimates	Standard errors
α_0	Intercept	103.79	10.96
α_1	Linear term	1.03	0.09
μ_p	Plateau level	260.54	7.69
σ_v^2	Variance of year random	1061	34
σ_ε^2	Variance of error term	1034	214
N^*	Optimum nitrogen level	207.26	2.79

Notes: The model was estimated using US customary measurement units. In metric units, the price of nitrogen is $1.32/kg ($0.6/lb) and the price of potato is $308.7/ton ($14/cwt). The optimum nitrogen level is 232.00 kg N/ha.

3. Results and discussion

3.1. Potato production function

The estimation results for linear stochastic plateau production function are reported in Table 2. The maximum likelihood estimation method gives the estimates for production function parameters, plateau level, year random variable, error term, and optimum nitrogen level. Standard errors for each term are also given. All parameter and estimated variance components are significant at the 1% level. The linear term indicates that an additional pound (0.454 kg) of nitrogen fertilizer increases the yield by 1.03 cwt/acre (0.12 ton/ha) until the plateau level reaches 261 cwt/acre (29 tons/ha). Yield is higher for the drier seasons (with smaller number of leaching rain events), and it is lower for the rainy seasons.

3.2. Expected profit maximization for risk-neutral producer, deterministic prices, and stochastic yield

The optimum fertilizer level given linear stochastic plateau production function and deterministic prices is calculated using Eq. (3). The optimum level of nitrogen is 232 kg N/ha given the mean potato price of $309/ton and the mean nitrogen price of $1.32/kg. For comparison, the BMP level used in the 2008–2010 period was 224 kg N/ha, which is close to the estimated optimum.

[5] FDACS BMP manual defines "leaching rains" as a minimum rain amount of three inches in three days, four inches in seven days, or over one inch in one day, given Florida's sandy soils (Cantliffe et al., 2006; Fraisse et al., 2010).

[6] In addition to vegetable production, other types of agriculture included woodland, pasture, and other uses, along with a relatively small percentage of sod and floriculture crops (USDA, 2012).

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

Sale prices ($/ton)	Nitrogen prices ($/kg)		
	$1.21	$1.32	$1.43
$264.6	231.22	229.74	228.36
$308.7	233.77	232.00	231.00
$352.8	235.93	234.54	233.22

Note: Nitrogen levels are provided in kg N/ha.

We conducted a sensitivity analysis to explore the effect of fertilizer and potato sale prices on the optimum nitrogen levels (Table 3). Given the historical prices used in the sensitivity analysis, the optimal ranges from 228 kg N/ha to 236 kg N/ha (i.e., the difference is 7.6 kg N/ha). As expected, a combination of high output prices and low fertilizer prices results in high optimal fertilizer levels for a profit maximizing producer. Therefore, a different price expectation may lead to various fertilizer rates being chosen by the growers. Similarly, a policy maker may have low price expectations, and in this case, the BMP fertilizer level recommended by the regulators will be lower than the producers' optimal level, leading to a non-zero cost of BMP adoption for the producers. The sensitivity of fertilizer application to sale price changes (Table 3) is reported on a per-hectare basis. For a 162 ha farm (which is the average size of potato farms in the TCAA), the 7.6 kg N/ha difference in the estimated optimal fertilizer use translates into total 1226 kg N, indicating the importance of accounting for the price variation in BMP development. For the range of prices examined, BMP costs (Eq. (4)) reach $4569/ha ($1849/acre) given the optimal fertilizer use level is 236 kg N/ha (selected for high sale price and low fertilizer price) and the BMP fertilizer rate is 228 kg N/ha (set for low sale price and high fertilizer price).

3.3. Financial model and Monte Carlo simulations

The distributions of NPV allow us to examine scenarios for different fertilizer rates and output price scenarios while accounting for producers' risk aversion levels. The NPV distributions are ranked using the mean variance method, first-degree stochastic dominance, and stochastic dominance with respect to a function (SDRF) criteria to incorporate producers' risk aversion.

3.3.1. Alternative fertilizer application rates

Table 4 shows the summary statistics for the simulated NPVs for three different fertilizer levels: low (168 kg N/ha), medium (232 kg N/ha, approximating the BMP level used in 2008–2012), and high (280 kg N/ha, BMP level after 2012). The CDFs of the ten-year NPVs are shown in Fig. 3. The mean variance technique and the first-degree stochastic dominance criterion do not reveal the clear dominance of one fertilizer level. The level with the highest mean NPV (i.e., 280 kg N/ha) is also associated with a higher variability of the NPV and, hence, may be unattractive for risk-averse producers.

Table 4
Simulated NPV for various fertilizer rates for a 0.4 ha potato plot.

At the output price = $308.7/ton, for various *N* fertilizer rates			
	Medium fertilizer – 232	Low fertilizer – 168	High fertilizer – 280
Mean	1524.00	706.62	1608.32
Standard Dev.	997.96	968.25	1054.13
Coefficient Var.	65.48	137.03	65.54
Minimum	(1516.84)	(2083.70)	(1912.51)
Maximum	5128.98	3708.96	4325.47

Note: 0.4 ha is equivalent to 1 acre.

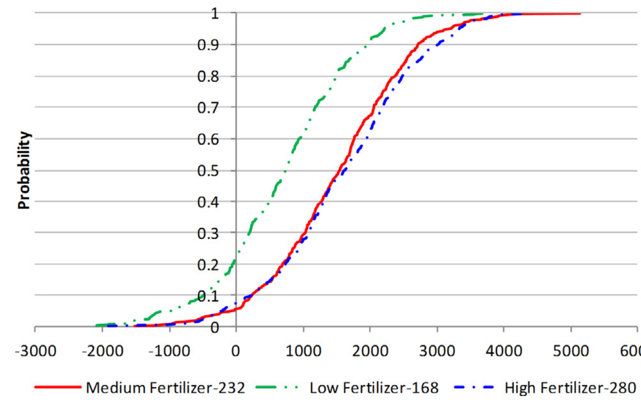

Fig. 3. CDFs of simulated net present values for various fertilizer use decisions.

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	High Fertilizer – 280	Most preferred
2	Medium Fertilizer – 232	2nd most preferred
3	Low Fertilizer – 168	3rd most preferred
Upper risk aversion coefficient: 0.00131 (strongly risk-averse)		
1	Medium Fertilizer – 232	Most preferred
2	High Fertilizer – 280	2nd most preferred
3	Low Fertilizer – 168	3rd most preferred

A corollary is that for medium fertilizer rate, the chance of receiving the highest NPVs is lower, making this rate less attractive for producers who are more willing to take risks to achieve higher payoffs. Hence, the SDRF ranking criteria is needed to identify the ranking of the NPV outcomes for medium and high fertilizer rates given alternative degrees of producers' risk aversion.

To use SDRF ranking, two relative risk aversion coefficients are examined: 0 for risk-neutral and 2 for strongly risk averse[7] (Richardson and Outlaw, 2008). Table 5 presents the results of the SDRF ranking and shows 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 the high fertilizer rate (280 kg N/ha). In contrast, a producer who is strongly risk-averse prefers the medium rate (232 kg N/ha) to avoid the downward risk caused by the high fertilizer expense and low yields given unfavorable production and market conditions. Given that the medium fertilizer rate approximates the BMP level used in the 2008–2012 period, this result shows that the adoption of this BMP would depend on the level of risk aversion of the producer, and risk-neutral producers would likely violate the BMP requirement. It can also be concluded that if 100% of BMP adoption is expected by state agencies, then the recommended rate should be based on the preferences of a risk-neutral producer, or a system of compensations should be set up to create additional incentives for risk-neutral producers to comply with lower fertilizer rate requirements.

[7] Following Richardson and Outlaw (2008), the absolute risk aversion coefficient (ARAC) was calculated as a ratio of relative risk aversion coefficients and the worth of the enterprise. The latter is taken as $1524/acre, or $3766/ha, based on 10-year NPV given mean, potato sale price of $309/ton, mean fertilizer price of $1.32/kg, and fertilizer rate of 232 kg N/ha. Resulting ARACs are 0 for risk-neutral producers, and 0.00131 for strongly risk-averse producers.

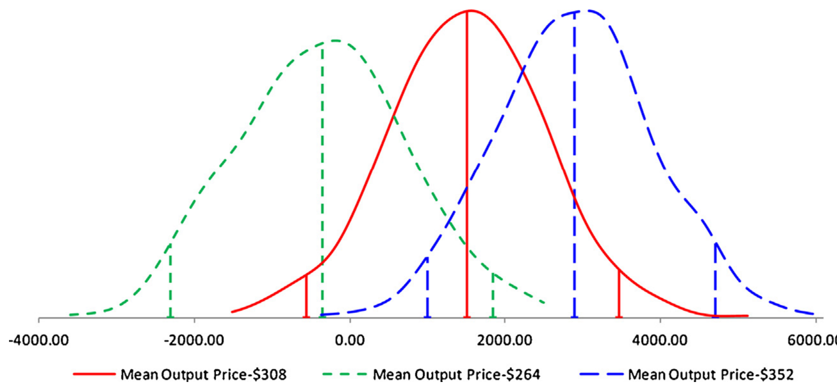

Fig. 4. PDF approximations of simulated net present values of optimum nitrogen levels at various output prices.

Table 6
Simulated NPV for various output prices for a 0.4 ha potato plot.

At their profit maximizing N fertilizer rates based on output prices			
	Mean output price-$308.7/ton	Mean output price-$264.6/ton	Mean output price-$352.8/ton
Mean	1508.97	(345.67)	2893.31
Standard Dev.	1004.01	1079.03	996.38
Coefficient Var.	66.54	(312.16)	34.44
Minimum	(1516.84)	(3596.91)	(361.44)
Maximum	5128.98	2505.62	5991.60

Note: 0.4 ha is equivalent to 1 acre.

Table 7
Simulated NPV given high mean output price of $353/kg and 0.4 ha potato plot.

	Fert. level = 230 (optimal for low sale price of $265/kg)	Fert. level = 235 (optimal for high sale price of $353/kg)
Mean	2868.02	2884.58
Standard Deviation	976.77	969.67
Coefficient Var.	34.06	33.62
Minimum	(199.51)	(192.27)
Maximum	6111.92	6249.46

Note: 0.4 ha is equivalent to 1 acre.

3.3.2. Differences in the output price expectations

Fig. 4 shows the PDF approximations of simulated NPVs at various output prices and nitrogen fertilizer rates. Specifically, each PDF is derived for a unique price–fertilizer rate scenario. These are 230 kg N/ha for the sale price distribution with the mean of $265/kg, 232 kg N/ha for the sale price distribution with the mean of $309/kg, and 235 kg N/ha for the sale price distribution with the mean of $353/kg.[8] Note that the stochastic fertilizer prices fluctuate around the medium level, $1.3/kg. As expected, the mean NPV increases with output prices, while the variance remains largely unchanged (Table 6).

What if a producer operates under a different price expectation as compared with policy makers prescribing BMPs? Assume that the sale price fluctuates around the high level, $353/ton, while fertilizer BMP is set for a lower expected price of $265/kg (Table 7). Then the loss to producers is $17/acre ($41/ha) at the mean, and this loss could increase to $138/acre ($340/ha) when weather and production conditions are favorable for a grower (i.e., when tales of the NPV distributions are compared).

[8] The fertilizer rates correspond to the optimal rates in Table 3.

4. Conclusions

In the United States and other countries, BMPs are developed to allow agricultural operations to remain economically viable while minimizing water quality impacts. Yet, comprehensive economic analysis is rarely part of BMP development, and most of the BMPs are based on agronomic research, with limited analysis of markets and producers' preferences. In this paper, we used a farm-level economic model of potato production in Florida to examine how lack of consideration of production and price risks in the fertilizer BMP development process can translate into non-zero costs for producers implementing BMPs. In other words, the risk perceptions and the price and production expectations will affect producers' willingness to adopt a BMP.

Specifically, we showed that given the stochastic input and output prices, as well as stochastic yields, the higher fertilizer rate is preferred by risk neutral producers, while the medium fertilizer rate is preferred by risk-averse producers. This result is consistent with other studies showing that risk-averse growers would prefer to apply less fertilizer than would risk-neutral growers if fertilizer increases profit variability (Antle, 2010). Given the historical fertilizer BMP rate for Florida's potato producers of 224 kg N/ha, this result implies that the rate of adoption of this BMP would depend on the risk aversion of the producers, and it is not surprising that some producers argued that this BMP was economically unfeasible.

We also showed that price assumptions strongly affect the choice of fertilizer rate. In our sensitivity analysis, depending on the price levels historically observed for the Florida's potato production, optimum nitrogen use varies between 229 kg N/ha and 236 kg N/ha, which translates into a 1226 kg N difference for an average 162-ha Florida potato farm (assuming a risk-neutral producer). When stochastic prices are simulated, BMPs developed for lower expected output prices result in the average reduction of producers' ten-year NPV by $41/ha (i.e., $6624 for a 162-ha farm). These costs can reach $340/ha (i.e., $55,016 for a 162-ha farm) when the maximum achievable NPV values are considered (i.e., given favorable market and production conditions). The simulation results are summarized in Table 8.

The latest BMP manuals developed for the TCAA allow farmers to apply up to 280 kg N/ha if necessary. This flexible BMP rate is consistent with the conclusion derived from this study that no single fertilizer BMP should be recommended for all growers (since they likely have different risk aversion levels) and for all market conditions (since market fluctuations lead to a range of fertilizer and potato prices). The flexibility in producers' response to production and market conditions and their risk preferences offered by the current BMP was achieved through extensive stakeholder

Table 8
Summary of the study results.

Assumptions	Analytical method and scenarios considered	Main results	Implications
Risk-neutral producer, deterministic prices, and stochastic yield.	Expected profit maximization; sensitivity analysis given historical range of nitrogen fertilizer and potato sale prices.	The optimal fertilizer rate ranges from 228 kg N/ha to 236 kg N/ha. This difference of 8 kg N/ha translates into the total difference of 1226 kg N for a 162 ha farm.	The importance of accounting for the price variation in BMP development (when a small difference in per acre fertilizer use translates into a large difference in farm-level revenues).
Risk-neutral and risk-averse producers, stochastic prices and yield.	Monte Carlo Simulation of ten-year net present value (NPV) given three fertilizer application rates: low (168 kg N/ha), medium (232 kg N/ha), and high (280 kg N/ha).	The medium and high fertilizer rate scenarios robustly dominate the low fertilizer rate scenario. Risk-neutral producers prefer the high fertilizer rate while risk-averse prefers the medium rate.	The importance of accounting for the producers' risk aversion levels in BMP development process and BMP adoption requirements.
Risk-neutral and risk-averse producers, stochastic prices and yield.	Monte Carlo Simulation of ten-year NPV given alternative output price expectations: low ($265/kg), medium ($309/kg), and high ($353/kg).	If the fertilizer rate BMP is set for low output price while high prices realize, the BMP cost to producers is in the range of $6624–$55,016 for a 162-ha farm.	The failure to account for the price variation in BMP development potentially translates into significant BMP cost to producers.

discussions and stakeholder conflicts sparked by disagreements about the economic and environmental impacts of the proposed BMP rates. The conflicts could have been avoided if the BMP development process included a comprehensive economic analysis of the proposed BMPs (Borisova et al., 2010). In Florida and in some other US states, BMPs are periodically revised and re-assessed. We suggest that a formal economic analysis should be required as part of such assessments. Such an economic analysis should include in-depth discussions with producers about their price expectations and yield expectations, and their perceived relationship between fertilizer use and yield levels, as well as the elicitation of producers' risk preferences. If producers' price or production expectations are different from the assumptions used in the BMP development, additional research should be conducted. It is possible that producers have better insights into the local production and market conditions than do the researchers developing the BMPs. Alternatively, it is possible that the producers are overly optimistic about the effect of fertilizers on yield, or about sale prices. In this case, Cooperative Extension could design and implement educational programs discussing the existing production and market data, and link them with producers' past experiences.

Further, as shown in the existing literature (e.g., Pannell et al., 2006), financial considerations are only one factor in the producers' decisions about specific production practices and BMP adoption. Such factors as the compatibility of the BMP with producers' beliefs, values, and self-image can play a decisive role, especially when the difference in the payoffs for alternative production practices is relatively small (i.e., the case with the flat payoff function) (Pannell, 2006; Pannell et al., 2006). BMPs are a cornerstone of agricultural water quality policy, and producers' perceptions about the development and administration of the policy can also affect the choice to adopt a specific production practice (Borisova et al., 2012; Lubell, 2004; Sabatier et al., 2005). For example, the fact that BMP adoption is mandatory in Florida implies that producers' beliefs about the role of government in regulation of private actions can affect the decision to comply or not with the BMP program (Lubell, 2004). In this case, producers' may use the economic unfeasibility of BMP implementation as a relatively easy motive to express their general disapproval of the water quality policy in a region. In line with the recommendations by Pannell et al. (2006), we conclude that along with agronomical and economic studies, BMP development should involve sociologic and behavioral analyses.

This paper does not discuss the environmental effectiveness of BMPs. In actuality, BMP development should be based on the comparative analysis of expected economic impacts and environmental outcomes of alternative BMP practices. An explicit analysis of economic and environmental tradeoffs will help refine the definition of a BMP and make it more operational. Current BMP definitions emphasize win-win solutions when water quality improvements can be achieved without affecting the profitability of agricultural enterprises. Is this expectation realistic? It is likely that water quality improvements will require agricultural producers to implement practices that are costly. There should be a wider discussion of how "economic viability" is defined for agricultural BMPs, and it should be recognized that BMP adoption may be associated with reductions in agricultural profits. If the definition of the economic viability is broadened from considering just the costs of a practice to agricultural producers to the costs and benefits of alternative agricultural practices for the society, then assessed outcomes of BMP adoption should include evaluation of potential shifts in agricultural crop production and related impacts on consumers of agricultural products, agricultural suppliers, employers, and other beneficiaries, along with potential reductions in such outcomes as amenity or cultural values provided by agricultural lands. These outcomes should then be compared with related improvement in environmental quality and associated benefits (such as increase in nature-based tourism revenues, or increased amenity value of water resources).

Where does this discussion leave us with a mandatory BMP implementation policy? The diversity of factors influencing BMP adoption and the variability in production and market conditions and producers' attitudes lead us to believe that it is unrealistic to expect BMP implementation by 100% of producers, even if (modest) incentive payments are offered. Alternative policy approaches have been discussed, such as performance-based strategies, where producers have the choice of a practice to adopt, as long as a specific performance indicator is achieved, or polluter-pay policies, where producers are paying a fee for an input associated with environmental degradation (Shortle et al., 2012). Developing BMPs that provide significant economic benefits to the producers have also been proposed (Pannell et al., 2006). In addition to economic programs and benefits, there may be opportunities for non-economic interventions, such as changing social norms, or peer pressure. Such strategies as treating water downstream of agricultural areas, or educating other stakeholders about the importance of agriculture for an area and the potential tradeoffs between agricultural production and water quality goals have also been used.

This paper shows that on a watershed scale, producers' risk perceptions and their price and production expectations influence the

BMP adoption rate, and that this factor should be accounted for in watershed management decisions. The analysis of risks and risk perceptions would allow better estimates of the BMP adoption rate for different incentive payment levels, where the payments can be government cost-share payments or market-based payments (such as water quality credit sales or transactions related to payments for ecosystem services). Comprehensive economic analysis will also assist in designing new water quality policies. For example, risk analysis can be used to design an insurance strategy to compensate producers for yield losses attributed to fertilizer BMP adoption given specific production and market conditions (Huang, 2002).

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Appendix.

Table A1

Table A1
Potato Production Expenses for 0.4 ha (1 acre equivalent).

Cost of goods sold	Unit	Quantity	Price	Total cost
Materials				
Seed/transplants	Units	26.00	11.87	308.62
Fertilizer, mixed and lime	Units	1.00	426.24	426.24
Nitrogen	kg N/ha	232.00	GRKS(1.21, 1.32,1.43)	124.67
Crop insurance	Units	1.00	35.00	35.00
Cover crop seed	Units	1.00	20.00	20.00
Herbicide	Units	1.00	22.48	22.48
Insecticide and nematicide	Units	1.00	146.92	146.92
Fungicide	Units	1.00	131.55	131.55
Tractors and equipment	Units	1.00	413.98	413.98
Farm trucks (driver cost included in overhead expense)	Units	88.67	0.51	45.22
Aerial spray	Units	1.00	19.50	19.50
Total				$1694.48
Labor				
General farm labor	Hrs	15.92	7.79	124.00
Tractor driver labor	Hrs	20.54	7.79	160.00
Total				$284.00
Sales, general & administrative				
General & administrative				
Analytical services& repairs	Units	1.00	100.12	100.12
Land Rent	Units	1.00	150.00	150.00
Overhead and management	Units	1.00	445.69	445.69
Taxes & insurance[a]	%	185.00	1.37%	2.53
Total				$698.34
Sales & marketing				
Dig and Haul	Box	268.53	0.70	187.97
Grading	Box	268.53	0.30	80.56
Total				$268.53
Total annual production costs				$2945.36

Source: Enterprise budget information for potato production is constructed by authors by using experimental plot data and Florida Partnership for Water, Agriculture, & Community Sustainability at Hastings and UF/FRED published data (Smith and VanSickle, 2009).
[a] The taxes and insurance are taken as 1.37% of the total durable cost.

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