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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).