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What motivates farmers to apply phosphorus at the "right" time? Survey evidence from the Western Lake Erie Basin

Wendong Zhang [a,*], Robyn S. Wilson [b], Elizabeth Burnett [b], Elena G. Irwin [c], Jay F. Martin [d]

[a] Department of Economics, Iowa State University, Ames, IA, USA
[b] School of Environment and Natural Resources, The Ohio State University, Columbus, OH, USA
[c] Department of Agricultural, Environmental and Development Economics, The Ohio State University, Columbus, OH, USA
[d] Department of Food, Agricultural and Biological Engineering, The Ohio State University, Columbus, OH, USA

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ABSTRACT

Phosphorus loadings from the Maumee River watershed have significantly compromised the Lake Erie ecosystem, as evidenced by the most severe harmful algal bloom in Lake Erie in 2015 and the shut-down of Toledo drinking water supply in 2014. Despite government payments for adoption of voluntary conservation practices, excess nutrient runoff from agricultural production remains a substantial challenge. The right timing of nutrient application is a critical best management practice (BMP). Using a unique survey of 2540 farmer respondents in the Maumee River watershed, this paper analyzes how socio-psychological, socio-demographic, and field-based spatial characteristics impact farmers' adoption of timing-related best practices for nutrient management, including delaying broadcast application before a storm event, avoiding winter application of nutrients, and avoiding fall application of nutrients. Results reveal three unique classes of farmers for each of the timing-related management decisions. While the significance of most farmer and field characteristics varies across the three BMP adoption decisions, perceived efficacy—the belief that the particular practice will actually reduce dissolved phosphorus runoff from farm fields—is positively correlated with a higher likelihood of adopting each of the BMPs across almost all classes of farmers. For example, results from the ordered logit model suggest that a 20% increase in perceived efficacy would result in the likelihood of actual adoption of delaying broadcast from 35% to 48%. An implication is that policies and outreach efforts aimed at increasing farmers' perceived efficacy of practices could lead to higher adoption levels, but the effectiveness may vary across different classes of farmers.

Introduction

Nutrient runoff from agricultural production contributes to freshwater eutrophication and coastal hypoxia across the United States and globally, posing great risks to freshwater and marine ecosystems (Diaz and Rosenberg, 2008; Hudnell, 2010). A recent rise in the amount of dissolved reactive phosphorus (DRP) entering the western Lake Erie basin has increased the frequency and extent of harmful algal blooms (HABs) (Michalak et al., 2013), as evidenced by the record-breaking blooms in 2011 and 2015, and the two-day shutdown of the City of Toledo's public water system in summer 2014 due to algal toxins. These toxic blooms pose significant risks to many ecosystem services, including recreational opportunities, water clarity, public health and potable water (International Joint Commission, 2014). Experts believe that the increase in DRP is in part due to poor nutrient management planning (i.e., poor timing and over-application) as well as the broadcast application of fertilizer without incorporation (Ohio Lake Erie Phosphorus Task Force, 2013; Scavia et al., 2014). These factors, in combination with warmer than average temperatures in Lake Erie during the summer and an increase in heavy rain events, have amplified the spread of toxic algal blooms (Meehl et al., 2007; Michalak et al., 2013; Ohio Lake Erie Phosphorus Task Force, 2013; Thomson et al., 2005; van de Vijver et al., 2008). Additional regulations and strategies to improve farmers' management practices are needed to achieve recommended nutrient loading reductions.

In reaction to the Toledo incident, the Ohio House and Senate passed a new bill effective in June 2015 that bans nutrient application on frozen or saturated ground, and when there is a forecast of heavy rain (Ohio Senate Bill 1, 2015). At the same time, prior recommendations to avoid winter and fall application of nutrients are now being reconsidered due to the likelihood that applying under the appropriate conditions in the fall and winter could be more effective than applying in the spring when storm-based runoff will most likely contribute to harmful blooms (Stumpf et al., 2012). However, by delaying broadcast application of nutrients in the spring when a storm is forecasted, farmers could further reduce DRP loads flowing into western Lake Erie (Ohio Lake Erie Phosphorus Task Force, 2013). Recent studies of climate

* Corresponding author.
E-mail address: wdzhang@iastate.edu (W. Zhang).

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change impacts show that the Lake Erie region will see more frequent and more intense rainfall as well as greater spring precipitation (Diaz and Rosenberg, 2008), which suggests that farmers' adaptations in altering phosphorus timing could be even more significant in the future.

Nutrient runoff from agricultural fields varies with seasons and increases during periods of heavy precipitation events. For instance, less nutrients are lost if the nutrients are applied in the spring rather than the fall, but this difference is offset by a heavy (e.g., 25% or more) increase in mean annual precipitation during the spring season (Nangia et al., 2010). Even when nutrients are applied during the growing season, the amount of precipitation can have a significant impact on runoff. For example, an intense rain event 30 days after manure application can cause more runoff than a light rain event the day after application (Vadas et al., 2011). Increasingly the literature on agricultural pollution control and conservation practices recognizes that solving the “phosphorus pollution puzzle” depends critically on understanding the complex interplay between agricultural production processes such as farmers' land management decisions and biophysical processes of nutrient flows (Garnache et al., in press), and altered nutrient application timing is being recognized as one key component of the solutions (Rabotyagov et al., 2014).

The purpose of this paper is to investigate the factors that motivate farmers to apply phosphorus at the “right” times. We do this by evaluating the impact of select socio-psychological, socio-economic, and field-based spatial characteristics on farmers' adoption of three timing-related best practices for nutrient management: 1) delaying broadcast application before a storm event, 2) avoiding winter application of nutrients, and 3) avoiding fall application of nutrients. An ordered logit model is used to assess likelihood of adoption for each of these three timing related practices, and latent class models are then used to identify unique subgroups of farmers who may vary in their likelihood of adoption given a range of both shared and unique explanatory factors.

The main results reveal that for each of the timing-related practices, three unique classes of farmers exist who vary in the way they think and act as it relates to the particular practice. While the level of adoption for each class does not necessarily vary across the classes, the characteristics of individuals in each class and the factors motivating their choices differ, suggesting that policies and outreach efforts aimed at increasing adoption will vary in their effectiveness across different groups of farmers. The only variable that is consistent across all three practices and across almost all classes is perceived efficacy—i.e., the belief that the particular practice will actually reduce dissolved phosphorus runoff from farm fields. This individual-level characteristic is positively correlated with a higher likelihood of adopting all of the timing-related BMPs for the majority of farmers.

This paper makes at least three contributions to the literature on modeling the adoption of best management practices. First, our paper offers one of the first analyses of the relative effect of socio-psychological, socio-economic and field-based spatial characteristics impacting farmers' decisions to apply phosphorus at the right time, both in terms of seasonal timing and timing applications in light of storm forecasts. Second, our analyses reveal that often-neglected socio-psychological characteristics, such as the perceived efficacy of a practice in reducing phosphorus runoff, are significant in driving the adoption decisions of these timing-related BMPs. This highlights the potential of improved education and extension to promote environmental stewardship and the importance of considering the efficacy of a practice in addition to other socio-psychological characteristics that are more commonly used to explain adoption decisions (e.g., environmental values and attitudes). Finally, while our models reveal substantial heterogeneity among farmers in their BMP adoption decisions, we are able to nonetheless identify classes of farmers who are most likely to have the practice in place and may be more amenable to changing their practices, e.g., as a result of more targeted education and extension efforts that provide farmers with the right tools and information to adapt their land management decisions.

Role of farmer and spatial heterogeneity in land management decisions

Some management decisions by farmers have been extensively studied individually or as part of a suite of practices including conservation tillage (e.g., Konar et al., 2014; Kurkalova et al., 2006), soil testing (Khanna, 2001), phosphorus application (Zhang, 2015), and crop rotation (Wu and Babcock, 1998). However, these studies typically focus on the profit motives of farmers, and ignore other behavioral considerations. In addition, very limited research exists about farmers' decision-making regarding the timing of their nutrient applications. The small set of studies that have examined farmers' application timing decisions only investigate seasonal timing in nitrogen applications (e.g. Huang et al., 1994, 2000; Johnson et al., 1991) while neglecting socio-psychological characteristics such as the role of perceived efficacy of the practice in reducing nutrient runoff. Furthermore, even studies of non-timing related adoption that do address socio-psychological characteristics do not typically focus on perceived efficacy, but instead focus more on farmer identity as a conservationist or some measure of general environmental concern or values (e.g., Prokopy et al., 2008).

Most previous studies of phosphorus reductions in the Lake Erie agroecosystem (e.g., Bosch et al., 2013) assume a given amount and location of BMP adoption and ignore the factors influencing individual farmers' responses to policies and adoption decisions. With seasonality, weather forecasts, and other biophysical and farm-level characteristics to consider (e.g., soil moisture and nutrients, tillage practices, and crop schedules), the motivations behind timing decisions are complex and may encompass other concerns in addition to profit maximization. It is likely that the suite of factors contributing to the adoption of each best management practice is unique, and that both socio-psychological and socio-cultural influences play important roles (Burnett et al., 2015; Zhang, 2015). In addition, previous research has examined the significance of the field or farm-specific characteristics in affecting farmers' nutrient application decisions, including: farmers' opportunity cost of time, machinery and equipment level, and different level of weather risks (Sheriff, 2005); adoption costs of the conservation practices (Kurkalova et al., 2006); as well as other farm enterprise characteristics that might impact nutrient applications. However, most existing studies of application timing decisions just focused on an individual farmer's tolerance for risk (e.g., Huang et al., 1994), and structural aspects like insurance programs designed to mitigate risk (Huang et al., 2000).

Spatially heterogeneous land characteristics have long been shown to influence the economic aspects of decision making related to tillage (Kurkalova et al., 2006; Wu et al., 2004), crop rotation (Wu and Babcock, 1998), crop choice (Hendricks et al., 2014), land allocation (Laukkanen and Nauges, 2014), and a variety of conservation practices (Rabotyagov et al., 2014). Because these spatial characteristics may interact with socio-psychological characteristics (e.g., farmers may put different weights on crop yield goals and soil erosion for high quality land vs. low quality land), these interactions add an important layer of contextual complexity in driving farmers' timing-related land management decisions. Specific to phosphorus timing, for example, the dominant soil texture of the field could affect the farmers' seasonal timing decisions, e.g. farmers may be more likely to avoid fall application if their fields are sandier because most of the fertilizer applied would wash through the soil while more nutrients could be retained until the spring for plant use in the case of clay soils (McDowell et al., 2001). Spatial heterogeneity also plays an important role in understanding the environmental impacts of agricultural land management decisions, implying the potential for “hot spots” with high runoff levels and potential gains from spatial targeting of conservation practices (e.g., Bosch et al., 2013; Babcock et al., 1997).

In summary, existing studies of farmer land management decisions highlight the importance of heterogeneity both in terms of individual behaviors and land characteristics. On this basis, we hypothesize that

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