Journal of Applied Farm Economics

Volume 3 | Issue 2 Article 6

2020

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Recommended Citation

Griffin, Terry Wayne and Traywick, LaVona (2020) "The Role of Variable Rate Technology in Fertilizer Usage," *Journal of Applied Farm Economics*: Vol. 3 : Iss. 2, Article 6.
DOI: 10.7771/2331-9151.1049
Available at: https://docs.lib.purdue.edu/jafe/vol3/iss2/6

The Role of Variable Rate Technology in Fertilizer Usage

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ABSTRACT

Precision technologies such as variable rate fertilizer applications have been touted as solving production agricultural issues, increasing yields, and improving environmental stewardship. Variable rate technologies have been widely available on farms especially via custom service providers; however, utilization rates of these technologies remain relatively low. Low adoption rates indicate barriers to adoption and an opportunity for market expansion. The degree to which such technologies may reduce the demand for fertilizers will depend on VRT adoption rates.

KEYWORDS

precision agriculture, agricultural technology, variable rate, fertilizer, millennial

INTRODUCTION

Fertilizer usage has been the topic of considerable conversation among farmers, land grant university extension professionals, environmentalists, and agricultural industry leaders for many decades. Discussion and debate regarding synthetic fertilizers go back to post–World War II when munitions factories were converted to fertilizer plants. For nearly a century the supply of synthetic fertilizers has kept pace with farm-level demand such that per acre soil amendment costs were readily budgeted by farmers (Bekkerman et al., 2020). Technologies such as variable rate applications are hypothesized to increase overall fertilizer productivity at the field, farm, and regional scales (Khanna, 2001). The demand for applied fertilizer may also be impacted by these agricultural technologies by providing better information to the farm operator. Here, the role of variable rate technology (VRT) with respect to fertilizer applications and demand is presented.

The United States has the capacity to manufacture fertilizer required to produce crops at current fertility recommendations; however, whether capacities must increase (or decrease) will partially hinge on the use of upcoming agricultural technology, including variable rate application. Fertilizer demand expectations continue to be relatively stable; however, a common misconception is that variable rate technology is already ubiquitous across the American heartland such that fertilizer usage has already been minimized. The fact is variable rate technology is ubiquitous only in that nearly all growers have access—Erickson et al. (2017) report 88% of service providers offer VRT—but less than half of growers have adopted the technology (Hellerstein et al., 2019; Ofori et al., 2020).

Initial Promises of Variable Rate Fall Short of Industry Expectations

In the 1990s, many fertilizer distributors and retailers were excited to provide variable rate applications of fertilizer. Excitement was quickly replaced with frustration once the fertilizer industry realized that farmers were not purchasing more fertilizer but rather redistributing similar total amounts of product across fields (Babcock & Pautsch, 1998). These lessons could have been learned by investing in grid soil sampling rather than machinery capable of applying variable rate fertilizer. As Schimmelpfennig and Ebel (2016) point out with evidence from USDA ARMS, farmers utilize precision agricultural technologies in an effort to reduce input usage rather than increase purchases of fertilizer. Schimmelpfennig and Ebel (2016) examined technology adoption with expectations of reduced input costs. They reported

differences in acreage, education of operator, and type of farm were significant indicators of adoption. They also reported that use of variable rate in combination with other precision technologies led to additional cost savings. Schimmelpfennig (2018) later reported that variable rate technology was associated with a 4% reduction in fertilizer costs if yield mapping had already been adopted. Ofori et al. (2020) report that automated variable rate controllers became commercially available in 1996, although beta test versions were likely available before global navigation satellite systems (GNSS, formally known as GPS) and as early as 1987 (Lowenberg-DeBoer & Erickson, 2019).

Actual Adoption Rates of Variable Rate Technology

One of the most detailed farm-level data sets on adoption of precision agricultural technologies focuses on midwestern farms in Kansas. The Kansas Farm Management Association (KFMA) has collected data from thousands of farms on their production and financial history. The KFMA database is comprised of financial and production data going back many decades. In 2015, KFMA economists began collecting and updating technology adoption records (Ofori et al., 2020). By January 2019, 656 commercial crop-producing farms reported having either "used" or "never used" variable rate fertilizer or lime (Ofori et al., 2020).

Hellerstein et al. (2019) and Schimmelpfennig (2016) used USDA ARMS survey results to report national technology adoption for individual crops; their results indicate that no single crop was associated with variable rate application for more than 45% of planted acres (Hellerstein et al., 2019; Schimmelpfennig, 2016). National adoption rates were consistent in this respect with adoption statistics in Kansas. Currently, less than one-fourth of Kansas farmers have variable rate fertilizer capabilities (Figure 1), much less utilization than GNSS-equipped yield monitors or the more widely adopted automated guidance technologies (Ofori et al., 2020). A factor worth noting in the discussion of technology adoption is the amount of human capital required (Khanna, 2001). Data technologies assigned to the information-intensive category tend to require more human capital and have slower adoption rates than embodied-knowledge technologies (Griffin et al., 2004). Variable rate has been categorized as an information-intensive technology, although some on-the-go automated variable rate applications (Raun et al., 2005) could be considered embodied knowledge; however, at least one study discussed variable rate as an actionable manifestation of data collected rather than an information-intensive technology itself (Miller et al., 2019). This idea can be seen specifically in the discussion on variable rate fertility in Kansas.

The most notable technologies evaluated in the KFMA study were GNSS-equipped yield monitors and grid soil sampling. Nearly 40% of Kansas farms have technologies to make yield maps or soil nutrient maps suitable for developing site-specific fertilizer prescriptions (Figure 1). Some debate exists regarding best practices for fertilizer prescriptions, although the consensus is to not rely solely on yield monitor data for the long run. Fertilizer prescriptions based on yield maps are typically a short-term replacement strategy based on nutrient removal factor rates of harvested grain. Soil nutrient analyses tend to be long-term strategies that allow farmers to monitor changes in fertility levels, then choose their preferred recommendation system, typically some version of a build and maintenance philosophy to develop prescriptions. Once fertility prescriptions are available, farmers and their advisers can evaluate the payback potential for applying fertilizer at variable or uniform rates, or not applying fertilizer at all (Babcock & Pautsch, 1998; Schnitkey et al., 1996). The stark difference in the proportion of farmers either mapping yields or collecting grid soil samples (40%) and applying fertilizer at variable rates (25%) speaks to the number of interested farmers who opt to apply fertilizer at uniform rates (Figure 1). Alternatively, as Schnitkey et al. (1996) point out, optimal uniform rates of fertilizer may be applied based on "information rates" such that a penalty-minimizing rate is chosen. This supports anecdotal observations that fertilizer retailers made in the 1990s prior to exiting the service provider industry, and the more recent circumstantial evidence that while most agricultural service providers across the Midwestern U.S. corn belt offer variable rate applications of fertilizer (88%) and lime (70%) (Erickson et al., 2017), relative few farmers utilize the technology in their farm management practices.

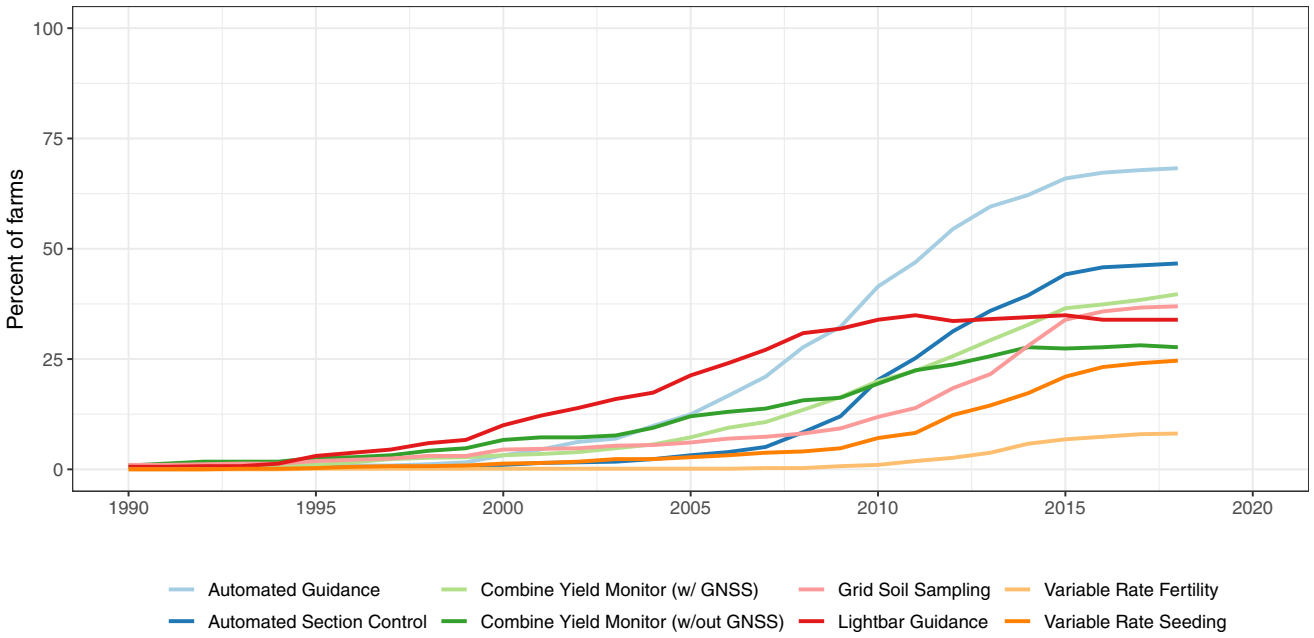

Figure 1. Percent of Kansas KFMA farms adopting technology over time (Griffin & Yeager, 2019).

Although VRT has been available for many years before other technology were introduced, adoption rates lag behind automated technologies—even those introduced much later. Evidence suggests that farmers take specific paths in acquiring technology through some sort of sequential adoption strategy (Lambert et al., 2015; Miller et al., 2019; Schimmelpfennig & Ebel, 2016). Variable rate technology is usually the final technology in the complete bundle acquisition.

The concept of optimality differs by the assumed objective function (Bullock et al., 2009). Some agriculturalists may set their goal to maximize yields (agronomic optimal) or profitability (economic optimal). Whole-field and site-specific economically optimal nitrogen rates have been extensively studied in corn (Bullock et al., 2009) and wheat (Biermacher et al., 2009). The distinction between yield maximization and profit maximization is price ratio between output and input, for example, yield and price of fertilizer. At the farm level, optimal decisions are likely to be more complex. Farm operators may choose to maximize profitability within their own constraints; however, binding constraints may include mechanical limitations of automated controllers on variable rate applicators such that nonoptimal site-specific rates may be applied for overall optimal application for the entire field. In most on-farm scenarios, farmers are incentivized to avoid overapplication of inputs including fertilizer; and variable rate technology and automated guidance empower farmers to control their input application rates and costs. However, barriers exist preventing variable rate technology from being ubiquitously adopted, at least in the short term.

Barriers to Adoption of Farm-Level Variable Rate Technology

Relatively low adoption of variable rate technologies may in fact be the intermediate equilibrium of profit-maximizing farmers accurately assessing their benefit-cost ratio. In many cases, farmers and their advisers endowed with site-specific information from yield monitors and grid soil samples may decide a uniform rate of fertilizer is most profitable or at least less risky than varying application rates across the field (Schnitkey et al., 1996). In the decision-making process, farmers tend to focus on tangible costs of technology adoption more than perceived benefits such as increased yields, profitability, or knowledge creation.

Three costs of variable rate fertilizer application usually considered include per acre upcharge, human capital, and potential of making incorrect application rates. Upcharge costs are per acre

fees for variable rate in addition to standard uniform rate applications. Even though the per acre upcharge for variable rate has become very low (McClure, 2018), farmers may be hesitant to intentionally pay any fee that increases their chances of making wrong decisions. In Nebraska, fees for uniform and variable rate custom applications of dry fertilizer were $5.00 and $6.50 per acre, respectively (McClure, 2018). The $1.50 per acre upcharge for variable rate is a 30% increase above the uniform rate; however, this is relatively inexpensive, at less than the value of a single bushel of corn (even at the currently below trendline commodity prices).

Human capital—the second of the three costs of variable rate fertilizer application—can be evaluated as an intangible asset to the farm operation. At present, the leading barrier of increased farm-level adoption of variable rate fertilizer seems to be farmers' unwillingness to devote necessary amounts of human capital. Human capital includes education, ability to learn, and capacity to devote effort to a project. A substantial portion of current farm operators may not have adequate human capital to devote to fine-tuning fertilizer applications. Many farm operators may perceive the opportunity costs of devoting efforts to farm data issues as too high relative to other information-intensive alternatives. During the infancy of precision agricultural technology, Popp et al. (2002) reported farmers responding that complication and uncertainty of outcome were the second largest barriers to adoption. As the cost of technology has decreased, requirements on human capital and unknown outcomes have not improved as much. Even for trained researchers the benefit-cost analysis of precision technology is not always clear. Of 234 variable rate studies included in a quantitative review of the literature, 68% reported benefits; however, only a fraction of studies reporting benefits of the technology were coauthored by an economist (Griffin et al., 2004).

Although most precision technologies have evolved to become more automated over time, variable rate still places substantial requirements on human capital without consistent outcomes. Sensor-based on-the-go variable rate fertilizer applicators exist that require virtually no human interaction, for example, nitrogen applied to wheat (Raun et al., 2005); however, most variable rate fertilizer applications are map-based and require substantial human capital to be effective. Farmers with access to site-specific yield and soil nutrient analysis data often attempt to develop variable rate fertilizer prescriptions but become frustrated with the complexity and uncertainty of the process, even after consulting with crop advisers and professional agronomists. The farmer, crop adviser, sales agronomist, and remaining team members may not be willing or able to collectively devote the human capital necessary to make the most of variable rate technology.

The potential of making incorrect application rates and/or the risks associated with making wrong decisions may be overwhelming given the sheer volume of individual site-specific locations that may receive a "wrong" rate of fertilizer. This third cost of variable rate fertilizer application is a prime example of how farmers tend to focus on tangible costs more than perceived benefits. Incorrect rates may be higher or lower than that location requires, potentially leading to reduced crop yields relative to status quo uniform rates. Many risk-averse farmers are likely to feel somewhat comfortable with uniform rates of a product since the correct rate is likely to be applied in at least several locations as opposed to variable rate prescriptions where some probability of making incorrect application rates exists at every subfield location.

Future Expectations of Technology, Farm Consolidation, and the Future Farmer

Forecasting adoption rates requires the analyst to consider characteristics of the next generation of farmers. Griffin et al. (2019) considered the age and experience levels of Kansas farm operators and reported proportions in respective generations of Silent, Baby Boomer, Generation X, and Millennials (Figure 2). Baby Boomers (born between 1946 and 1964) remain the largest proportion of Kansas farm operators (over 50% of all farm operators since at least 2012) and are likely to have the final decision on machinery investment; however, Generation X (born between 1964 and 1980) and Millennials (born between 1981 and 1996) are the only generations currently increasing as a proportion of farm decision makers. The proportion of Kansas farms operated by the Silent generation

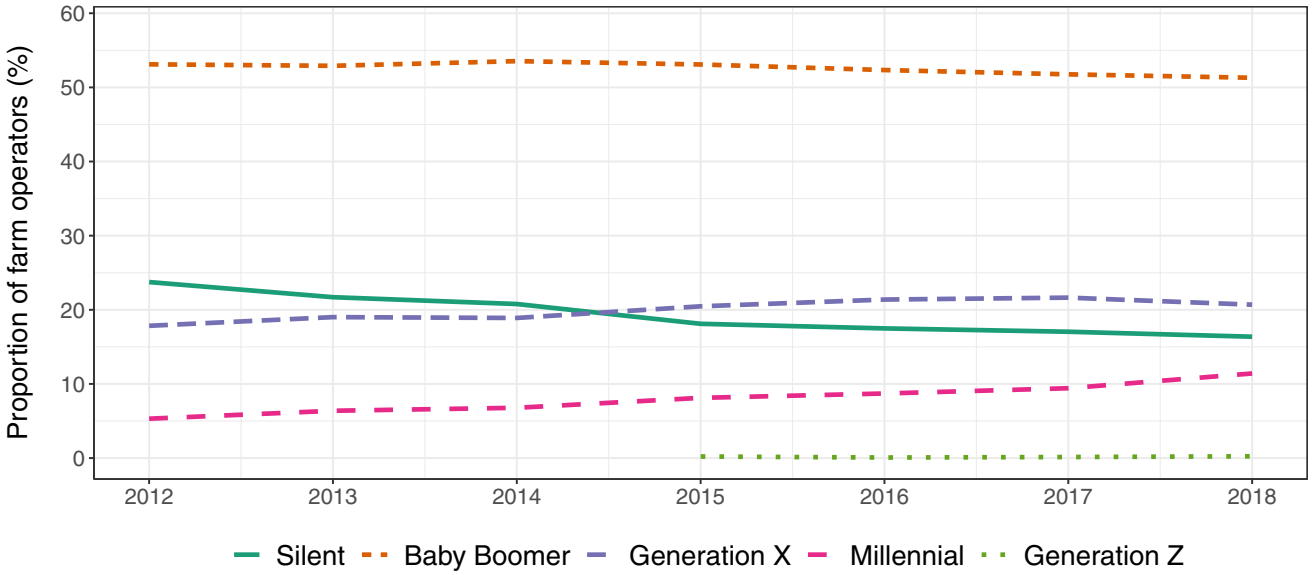

Figure 2. Proportion of Kansas farm operators by generation over time (Griffin et al., 2019).

(born before 1946) is steadily decreasing. Sometime in the future, Generation Z (born after 1996) will be attempting to influence Generation X and Millennial operators to invest in technology that has yet to become commercially available.

If current trendlines presented in Figure 2 continue, no operators born during the Silent generation are expected to remain by 2029 when the youngest member will be 84 years old. By 2041, one-third of farm operators are expected to be of the Millennial generation when they will be 45 to 60 years old. Eventually, the agricultural industry will need to market their services to Millennials and Generation Z rather than Baby Boomers and Generation X. Some variable rate service providers have attempted to create local monopolies by insinuating their proprietary processes are the only method that works and that the technology is not understandable by the competition; these tactics are not likely to be accepted by the younger generation.

It has been argued that not all farmers who are farming in 2020 are likely candidates to adopt variable rate technology. Baby Boomers' technology use lags behind that of younger generations; they are less comfortable with current technology than younger generations, and keeping up with new technological products is often challenging so they tend to be late adopters of technological innovation (Kamin et al., 2017; Shen, 2020; Van Volkom et al., 2013). Older generations have little motivation to change and need a compelling rationale for how technology can form a part of their daily activities or benefit their needs (Marston et al., 2016; Pitt-Catsouphes et al., 2012). These characteristics align with the technology acceptance model or TAM, which simply predicts older adults will adopt technology based on its perceived usefulness and its perceived ease of use (Davis, 1989). In considering perceived ease of use for adoption of technology, a more recent article by Shen (2020) states that physiological and cognitive decline more than age itself determined adoption of technology. Using that viewpoint, the physiological decline associated with aging lends itself to the argument that older farmers would adopt labor-saving technologies such as automated guidance to enhance their ability (Feder et al., 1985; Griffin et al., 2005); but for data-insensitive technology such as VRT this does not hold. Variable rate technology is a manifestation of information-intensive technology (data) as opposed to automated guidance that is embodied knowledge tech. A cognitive decline may negatively affect the perceived ease of use over the perceived usefulness of the fertilizer technology, thus hindering the adoption of VRT.

One subset of farmers who are likely to adopt include those fitting the traditional younger, more experienced, more educated, greater farm acreage demographic. A subset of farmers who may not be

likely to adopt are those who are unable to devote necessary human capital or unwilling to accept associated risks of unproven technology. In time, shifts in farm operators are likely to favor those who continue to operate farms albeit with larger acreage. At that time, farm operators making management decisions may be born of the Millennial or even Generation Z generations.

As a generation, Millennials are tech savvy and readily look for the newest technology advances, value their family time as important, or more important, than hours spent at work, lack job loyalty, and are environmentally conscious (Barroso et al., 2020; Howe & Strauss, 2000; Suh & Hargis, 2016). With these characteristics, Millennials may see VRT as nonthreatening due to their acceptance with new technology and a way to protect the environment by prevention of fertilizer overuse and possible runoff. As part of a technology bundle, technologies can be seen as a way to save time farming, which will allow more time for family activities. With the consolidation of farms, the additional acreage will require farmers to either spend more man-hours, that is, human capital, working the land or adopt technologies to decrease the workload. As Millennials are prone to job hopping, always looking for something new or better, it makes logical sense to predict that Millennial farmers who embrace technology and industry change may be more likely to be the farmers who stay the course in the future compared to those farmers who avoid adoption of farming technology.

Generation Z, as a whole, are also technologically savvy as they have grown up with smartphones and other gaming devices. At the same time, they seek financial value in their choices and are interested in finding practical ways to do a job. As Generation Z desires individualizing experiences for themselves (Johnson & Sveen, 2020), it is an easy jump that they will accept VRT as it is a form of technology, has potential for financial value, is a practical way to fertilize, and can bring individualization to areas of the field.

Looking forward, manufacturers of farm machinery and synthetic fertilizer must consider how Millennials and Generation Z behave with respect to technology adoption rather than expecting adoption paths similar to those chosen by Baby Boomers. One key expectation of future technology is that the agricultural industry must reduce or eliminate the high human capital requirements to make technology work. This is especially true for Generation Z who value new and cutting-edge products over industry standards. If the product does not perform, they move on to the next technology (Johnson & Sveen, 2020). Another insight that the agricultural industry must anticipate is how future generations may express loyalty differently than previous generations. As seen with Millennials already in the workforce, they tend to change jobs every few years and do not hold the same brand loyalty as the Silent generation and Baby Boomers do (Suh & Hargis, 2016).

Decades or even centuries of evidence suggest nearly constant acreage of farmlands are being managed by fewer operators each year (MacDonald et al., 2018). The total number of farm operations in the United States fell from nearly 7 million in 1940 to 2 million in 1980. Although it is unlikely that the majority of current farm operators, that is, Baby Boomers, will adopt a complete bundle of technologies without the influence of younger operators on the farm, nearly all arable acreage is expected to be under some sort of precision management once sufficient farm consolidation occurs. At that point in the future, technologies such as variable rate fertilizer application are likely to be ubiquitous.

Hart reported that average acreage on Midwestern corn belt farms were relatively stable until the 1950s when consolidation began to occur, presumably in conjunction with mechanization of row crop agriculture (Hart, 2003). Hart emphasized that precision agricultural technology may not only favor current larger acreage farms due to the fixed costs of adoption but may be most beneficial for farm operators who are prepared to add new fields to their existing acreage. MacDonald et al. (2018) reported that farm consolidation has been consistently documented with each USDA Census of Agriculture since 1982. Lin et al. (1980) forecast that consolidation of farms and acreage being controlled by fewer farm operators would continue for the foreseeable future.

Discerning farmers who value loyalty less than previous generations, that is, Millennials (Gurau, 2012), are less likely to readily trust prescription fertility recommendations from retailers profiting from increased fertilizer sales. Generation Z has very different media preferences than Millennials and they are known for actively blocking

advertisements. Separation of fertilizer sales from custom applications and fertility prescription recommendations may be necessary before variable rate application technology adoption rates increase. In part, separating fertilizer prescription recommendation from sales alleviates some of the perceived risks; however, separation of fertilizer sales from recommendations may necessitate structural change in the custom hire of fertilizer application.

SUMMARY

Variable rate technology has not met the agricultural industry's expectations after two decades; however, considerable market potential remains, especially for farmers who understand how to apply the required human capital. The agricultural industry will have to market to Millennials and Generation Z rather than continue practices aimed at Baby Boomers. This next generation of farm decision makers are expected to invest in the necessary financial and human capital that will result in near ubiquitous adoption of variable rate technologies, provided that marginal benefits actually exceed marginal costs (including risks) of the technology. Historical evidence suggests that as variable rate fertilizer technologies are adopted, less product will be purchased and applied. As farm consolidation occurs and Millennial and Generation Z operators control the majority of farms in the future, variable rate fertilizer adoption will asymptotically approach its long-term adoption level and fertilizer sales will likely decrease on properly managed acreage.

The demand for applied fertilizer may also be impacted by other agricultural technologies such as transgenics, for example, CRSPR, reducing nutrient requirements by the plant. The question remains that if a critical mass of growers adopts variable rate fertilizer technology to the extent that the industry anticipates, will domestic demand for synthetic fertilizer actually decrease? In the short run (perhaps the next 5–10 years if adoption rates continue at trendlines), analyses suggest that the American agricultural industry is still going to rely on large amounts of synthetic fertilizer due to lack of variable rate technology utilization at the farm level. Eventually in the long run, variable rate technology is expected to become ubiquitous due to favorable cost ratios of crops, fertilizer, and application costs plus differences in human capital capacity and risk preferences of the next generation of farm operators.

ACKNOWLEDGMENTS

The authors appreciate insights and discussions with Gary Brester and Anton Bekkerman, Montana State University, Dorivar Ruiz Diaz, Kansas State University, Joshua McGrath, University of Kentucky, Brian Arnall, Oklahoma State University, Jason Ward, North Carolina State University, Brian Luck, University of Wisconsin, participants of the Montana fertilizer meeting, and two anonymous reviewers for their thorough review and constructive comments.

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