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FEATURE

Moving toward sustainable farming systems: Insights from private and public sector dialogues on nitrogen management

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Agricultural systems face the challenge of increasing production to meet growing global demand for food while protecting the natural resource base in a changing climate. Major environmental challenges include rebuilding soil health after centuries of heavily extractive production systems, improving water and air quality, and contributing to climate change mitigation (Robertson 2015). These resource problems are diffuse and pervasive, resulting from the decisions of individual farmers who are struggling to balance production with environmental protection. Moreover, public policies in the United States promote large-scale monoculture production and heavy reliance on industrial inputs through direct subsidies and insurance options that limit farmer choices (Iles and Marsh 2012; Stuart and Gillon 2013). Meeting these challenges requires a multipronged and multilayered approach: actions by thousands of individual farmers supported by research into new approaches, education about emerging practices and technologies, and policies that promote sustainability.

These types of challenges have been described as wicked problems (Batie 2008) because they are dynamic, complex, and occur in both technical and social dimensions as compared to problems with straightforward causes and effects that are largely solvable through technical solutions. In the agri-environmental context, wicked problems arise because farming is both an ecological and a socioeconomic process. One of the most challenging aspects of wicked problems is that, as a result of dynamic social processes, different stakeholders engaging with these problems often hold different views, definitions, or understandings of the problem itself (Batie 2008). Solving wicked problems requires cooperation and collaboration between multiple stakeholders, which involves engaging in social and political processes to bridge gaps in understanding. To this end, we offer here ideas and insights on how to begin this bridging process and start to identify solutions to a pressing challenge facing agriculture and the environment, namely agricultural nutrient pollution.

Excess nitrogen (N) in the environment serves as a prime example of the type of wicked problem facing agriculture. Nitrogen is a key input in modern crop production systems. Gains in production of important crops, including wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.), have been driven in large part by increased inputs of N, especially in the form of synthetic fertilizers (Robertson and Vitousek 2009). But crop production suffers from leakiness, with only about 40% of applied N being utilized directly by the crop (Cassman et al. 2002). This loss of N from cropping systems contributes to pollution of groundwater and eutrophication of surface waters; pollution of coastal zones leading to hypoxia; and climate change through the emission of nitrous oxide (N_2O), a potent greenhouse gas (Davidson et al. 2012).

Gains in N use efficiency at the field and landscape scale can be made in a number of ways. For field crops of the Midwest this is primarily through crop selection, crop rotations, use of cover crops, and modification of fertilizer practices including adjusting the formulation, timing, rate, and placement of N fertilizer (Robertson and Vitousek 2009). In the US context, these modifications require voluntary adoption by farmers. New improvements in precision agriculture technologies and practices are also allowing for more efficient management of N at field and farm scales. These technologies have developed rapidly in recent years, increasing pressure on farm advisors to make timely and practical recommendations. This is particularly acute for N management, where decisions can carry significant risk in terms of both yields and environmental impacts.

Researchers and Cooperative Extension services have traditionally played an important role in developing and transferring new practices and technologies to farms, but this model has changed in recent decades. This is particularly evident in the N management context, where most farmers indicate that they receive information about N mainly from private consultants and agricultural retailers (Stuart et al. 2012; Arbuckle and Rosman 2014). Prokopy et al. (2015) found that these retailers and advisors rely on university extension for information on a variety of topics, including climate change. As extension services in many states continue to face decreases in funding and declines in staffing, new models of information transfer and on-farm knowledge generation are needed. This new system will require innovative networks, a richer understanding of direct and indirect communication channels, and greater collaboration between private and public agricultural advisors.

A NITROGEN ROUNDTABLE

How best to develop these new networks and foster greater collaboration? We know that identifying stakeholders and initiating dialogue among them is an important step. To that end, in early June of 2016 we hosted a workshop on N management at the W.K. Kellogg Biological Station in southwest Michigan. Entitled The N Roundtable: Finding Solutions for Sustainable N Use in the Midwest (Doll

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and Reimer, in review), this event was part of a larger interdisciplinary research project exploring variation in on-farm use of N within the upper US Midwest and the socioeconomic dimensions of N management (Stuart et al. 2012). Early findings from the social science work of this project had established that private sector advisors provide valued advice to farmers about fertilizer management. In this two-day workshop we brought together key advisors involved in N management—including researchers from appropriate disciplines, extension educators, and private retailers and consultants—to discuss new research findings and identify critical research, education, and outreach needs for making N management in the Midwest more economically and environmentally sustainable. As the name implies, this roundtable focused primarily on encouraging discussion among participants—on valuing and hearing all voices in the room—rather than simply transferring information to participants.

Our workshop was attended by a diverse audience from four midwestern states (Iowa, Indiana, Illinois, and Michigan), and included extension educators, Certified Crop Advisors, other farm advisors, fertilizer dealers, and farmers. One full time farmer and several advisors who also participated in farming operations attended the event. Participants enthusiastically engaged in panel discussions and breakout sessions where we facilitated conversations targeted at identifying the primarily challenges and opportunities for improving N management.

SHARED CHALLENGES

Participants from all stakeholder groups expressed a high degree of agreement about the challenges associated with improving N management, both for farmers and the consultants who advise them. Most strikingly, private advisors and extension educators face many of the same challenges, especially regarding information dissemination. In their common expression of these challenges, we can begin to identify the most critical constraints on improving on-farm and system-wide environmental performance and the potential for solving these challenges through enhanced collaboration between important stakeholders.

Some of the challenges identified are inherent to the complexities of the systems involved. Managing N in cropping systems includes the critical linkage of human behavior (e.g., selecting crops and crop rotations and annual or multiannual additions of N) with biophysical systems (soil, climate, and weather events). The incredible complexities of the biophysical systems alone are still not well understood by researchers, advisors, or farmers. There are a myriad of variables involved in a decision about how much N to apply in given growing season, including crop genetics, precipitation, heat, and soil microbiology to name a few, and these variables interact differently over time. One advisor noted that "nitrogen is now," explaining that recommendations are based on environmental conditions that can change in a given field by the day. This makes providing reliable recommendations inherently difficult, both for researchers trying to distill complex science into useable information and for advisors trying to craft recommendations for individual farms and fields.

Advisors, both extension and private, indicated that their work with farmers is also complicated by the numerous management decisions that impact N use in cropping systems, including tillage, rotation, and fertilizer placement and timing. These decisions are in turn affected by variations and extremes in the weather. There is no "one size fits all" solution for N management, and advisors noted the diversity of their audience with respect to farm size, farm goals and interest in N conservation, and farmer skills. This requires advisors to carefully craft recommendations to meet the needs of a diverse audience, necessitating long-term relationships with farmers to fully understand their goals and management systems and to build trust. These types of relationships are increasingly difficult to maintain, especially for extension educators hampered by decreased capacity but also for private advisors operating in a competitive market. The role of trust in advisory relationships was a common theme expressed by consultants and extension educators.

Offering fertilizer recommendations requires not only technical expertise but also the ability to "speak farmer," in the words of one participant. This includes understanding what an individual farmer is trying to accomplish and how they perceive the recommendations they are receiving. Advisors, including private sector advisors, noted that as educators their role is simply to provide technical recommendations. This extends to educating farmers about both the profitability aspects of N management as well as the sustainability dimension. Advisors indicated that while farmers are concerned with the environmental impacts of N management, they are constrained in their thinking and decision making by the need to maintain farm profits through aggressive use of inputs. Advisors also noted that crop yields can represent an image of the farmer to their community, making it difficult for some farmers to shift their focus from yield to profitability.

In addition to the inherent complexities of managing N, the rapid pace of technological change is another challenge faced by both farmers and advisors. Participating advisors indicated that farmers are largely overwhelmed by the dramatic increase in data collection technologies and how data can be utilized effectively on their farms. Participants noted that farmers experience a great deal of social pressure to implement new technologies; they buy the technology often with little follow-on support. Rapid technological improvements also make it difficult for advisors to stay familiar with the most cutting-edge technologies. The increasing availability of private sector data management systems increases the complexity of management, but also offers exciting opportunities for improving resource use in farming systems.

ADDRESSING WICKED PROBLEMS AS A SOCIAL PROCESS

While the challenges to improving N management across farming systems are significant, workshop participants noted a number of opportunities for moving forward. These ideas are applicable beyond the case of N management. While excess nutrient flows into the environment are a significant global problem, many of the

other types of environmental harm share key challenges and characteristics. In particular, the change in traditional institutional arrangements and increased pace of technology development strain the ability of farmers and those who advise them to keep pace with new information and practices. Below we detail five opportunities identified by workshop participants to improve the delivery of critical information in increasingly interconnected agri-environmental systems: (1) taking advantage of data technology developments to increase information sharing and speed development of new practices; (2) facilitating the use of new tools and models by farmers to address complex problems; (3) developing new and strengthened collaborative relationships between important stakeholders, especially public and private sector advisors and researchers; (4) greater integration of social and biophysical data to move toward more farm- and field-relevant, applied research; and (5) broadening focus beyond individual aspects of N management, particularly N rate, and addressing multiple aspects of more integrated agricultural systems (e.g., soil quality or crop diversity).

Data Technology Developments. Some of these opportunities are inherently linked to the challenges such as the rapid increase in technology, especially for data management, which is seen as simultaneously a benefit and a challenge. Although participants saw this as a challenge, they also noted that improvements in data collection and data management offer the potential for increased efficiency in N management. This increase in technological capacity, coupled with available information and the ability to more finely tune management strategies to the conditions in the field applies beyond the N context. The immense complexity of agroecological systems and wide variety of farming approaches have made many aspects of farm management difficult, but improvements in data technologies allow farmers and their advisors to develop a clearer picture of what is occurring in the field and develop strategies for improving agronomic and environmental performance.

Harnessing data technologies offers significant challenges for all involved. The wide variety of stakeholders with an interest in improving on-farm performance offers a solution to this challenge. The ability to not only collect field data but also to easily share those data with a wide range of stakeholders and advisors, from university researchers to independent consultants and agricultural retailers, allows for an immense amount of expertise to address the problem. For example, a national database could collect de-identified data from farm fields across the country, allowing for comparison of agronomic and environmental performance across a wide range of variables. Data sharing brings with it another set of concerns about privacy and ownership that must be built into any scaling of this approach. Setting aside those privacy issues for the moment, data sharing offers real potential for innovation in management. Rather than having isolated expertise, data sharing can allow for more collaboration among the various stakeholders. By themselves, data availability and sharing are insufficient for improving N management practices. Combined with quantitative models and effective decision support tools (DST), however, they hold tremendous potential to generate useful information for advisors and farmers.

Facilitating Use of New Tools and Models. New DSTs, data collection and management technologies, and models to help farmers manage N and other nutrients have proliferated widely in recent years, especially as farmers have become more connected to the internet. Agricultural retailers and product companies have also become increasingly active in this space. One high profile example is Monsanto's acquisition of the Climate Corporation in 2013 and their development of integrated farm management tools. These private sector efforts are mirrored in the public sphere by university and extension services online tools. A notable example is the Corn N Rate Calculator (Sawyer et al. 2006). This online tool provides recommendations on N application rate based on the Maximum Return to N (MRTN) approach. While this tool is based on a large database of in-field production data and has been calibrated for most corn-growing states in the Midwest, the tool has not been widely utilized by farmers.

Roundtable participants identified a variety of reasons for limited use and adoption of online N management tools, including a lack of farmer trust, recommendations that are too broad, and lack of consideration of agronomic or environmental consequences. Advisors largely recognize that tools and models face a difficult tradeoff between simplicity and accuracy. For example, an oversimplified model may be more user-friendly but farmers may not trust it if it seems to make too many assumptions. Farmers want tools that are complex enough to be believable but are still usable, that provide good value but are also readily available, and that are both widely applicable and can fit the unique complexities of their own farm setting. The online tools also vary with regard to inclusion of social, economic, and/or biophysical data, thus providing farmers with outcomes based on different sets of information inputs across the agri-environmental dimensions noted at the outset. These are difficult criteria to meet, such that efforts to develop and promote new tools for farmers and advisors must be coordinated between a wide range of stakeholders and institutions and tailored to different audiences. Recent efforts (e.g., the MRTN) have proven effective at creating a regional tool but have been subject to the difficulties of maintaining a research network and sustaining funding for each state. Private sector resources, access to customer data, and existing relationships with farmers can be powerful assets for tool development.

Strengthening Collaborative Relationships among Stakeholders. Participants had insightful recommendations for moving beyond conversation about sustainable N management in order to make real change. They stressed improved collaboration as one of the most important changes needed to improve N stewardship system wide. Improved collaboration is needed among public and private entities, as well as among the advisors who work directly with farmers (extension, private agronomists/consultants) and those working on developing new technologies and practices (university and private sector researchers). Data sharing structures are one avenue for improving collaboration and have been proposed in other resource

management contexts (Braden et al. 2015). Another would be improved collaboration between university and retailers on regional N rate recommendations.

While the participants represented a number of important stakeholders, they acknowledged that there were still others not in attendance whose voice should be represented in order to better reflect the wide array of actors involved in the complex farm N management picture. Seed and equipment dealers, banks and other financial stakeholders, environmental groups (including non-governmental groups and local soil and water management agencies), and major agricultural retailers all play a role either directly or indirectly in sustainable N management across the landscape. Moving forward effectively will require strategic conversations with these groups.

Integration of Social and Biophysical Sciences. Increased collaboration between extension and the wide variety of private sector advisors would ideally not be isolated to the technical development of tools but extend to developing a better understanding of the social and psychological dimensions of innovation transfer. Many of our workshop participants emphasized the importance of the skills and expertise needed to work with farmers, who have a wide range of abilities, financial and technical capacities, goals, and attitudes that influence how they perceive and utilize tools. For example, many advisors emphasized the importance of building trust with farmers, a process that can take years to establish. Wicked problems in agriculture are both biophysical (environmental and agronomic) and social in nature. Nearly all of the roundtable participants acknowledged this explicitly and emphasized the need for improved understanding of how social, political, and economic systems operate to incentivize or constrain farmer behavior.

Broader Focus. Beyond improvements in collaborations between stakeholders, broader perspectives and focus are needed to tackle environmental challenges that include N management. Traditionally N management has been very focused on limited-scale microconsiderations, such as determining the appropriate N rate. While N rate is important, N management is too complex to be simplified to a "magic ratio" of pounds of N to desired crop yield. Researchers, advisors, and farmers should also keep macroscale, system-wide considerations in mind. Participants called for a return to "basic or applied agronomy" to really understand the cropping system and management options. To this end, many participants emphasized the need to move beyond a narrow focus on N rate and develop recommendations that are more holistic—for example, recommendations that are more tailored, focused on precision application and splitting application based on in-field conditions, and that are more complex but account more completely for year to year and field to field variations. The fertilizer industry has recently acknowledged this holistic approach through their development of the 4Rs nutrient stewardship approach (IFA 2009).

Taking such an integrated approach would help represent the complex and interrelated reality of agri-environmental challenges and the complexity of farming systems themselves. Nitrogen management is connected with other challenges, including managing soil health, building resiliency in the face of climate change, and socioeconomic changes in the farming sector. Treating these challenges separately fails to account for their interrelatedness and undermines the need for systemic changes in farming approaches. Indeed, advisors challenged the researchers in the room to "push the envelope," to be innovative with new ideas and technologies to overcome these challenges.

Agriculture is not only a complex agronomic or ecological system, but a complex social system as well. While many participants in our workshop had technical training in natural science fields or agronomy, they all emphasized the need for a better integration of social science methods and approaches. As with development of DSTs, working with farmers requires a basic understanding of the social dimensions of farming. For example, participants brought forward the following questions:

- What does success look like on the farm?
- We talk a lot about efficient use of N, but do farmers have a shared recognition of this notion?
- What exactly are they working toward?
- When achieved, how can farmers communicate their successes?

Other participants noted the need for better understanding how farmers use N management tools and the importance of helping to facilitate education on their use. Social science offers a role to help to define, describe, and explain such aspects of the complex sustainable N management reality.

CONCLUSION

The take-home message of our N roundtable outlines experiences and perspectives from diverse stakeholders interested in increasing N use efficiency and addressing environmental, economic, and social problems associated with N use. The N roundtable event illustrated that, rather than being at odds, a diverse group of advisors from the private and public sectors and working for profit and nonprofit goals had similar ideas about areas of disconnect that if connected could serve to benefit farmers, society, and the environment. We recommend five steps to develop and disseminate information and new practices to farmers that address N sustainability in agri-environmental systems that can be applied more generally to other wicked problems:

1. Use data technology developments to increase information and data sharing between farmers and advisors, speeding development of new practices.
2. Facilitate the use of new management and DSTs and models by farmers to address complex problems.
3. Develop linkages and strengthened collaborative relationships between important stakeholders, especially public and private advisors and researchers.
4. Increase the integration of social and biophysical data to move toward more farm- and field-relevant, applied research.
5. Broaden the focus of applied research beyond N rate to move toward more integrated agricultural systems.

New lines of communication between diverse stakeholders and the identification of similar goals are key steps in a direction to address a range of agri-environmental issues, including N pollution. Addressing these complex, multiscale challenges remains a goal that must be addressed with a synthetic approach.

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