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FEATURE

Edge-of-field research to quantify the impacts of agricultural practices on water quality in Ohio

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When settlers first reached central and northwestern Ohio, they encountered sprawling forested wetlands. Many viewed these swamps as a barrier to prosperity and began to drain them by straightening and dredging stream channels and by installing subsurface drainage to remove excess water (Blann et al. 2009). Draining of these landscapes was a celebrated accomplishment since centuries of decaying vegetation that accumulated in these swamps had created organic-rich soils that are some of the most productive in the world. Without drainage, it would not be feasible to sustain agricultural production to meet the demands of a growing global population (Tilman et al. 2011). Drainage reduces the risk of crop loss from excess water stress, provides more uniform crop production amidst climate variability, gives farmers more control over field operations, and reduces crop susceptibility to pests and disease (King et al. 2015). Drainage, however, also increases the hydrologic connectivity between streams and agricultural fields through subsurface pathways (King et al. 2014). As a result, agricultural pollutants, such as nitrogen (N) and phosphorus (P), flow through subsurface tile drains to receiving water bodies where these loadings have been linked to deleterious impacts on water quality (Smith et al. 2015).

Today, approximately 150 years after the installation of drainage began, the state of Ohio is facing the tremendous challenge of maintaining agricultural production while protecting the environment and critical ecosystem services. Agricultural production and environmental quality are both vital to local and regional economies. The agricultural industry in Ohio represents US$93 billion (17.5%) of the State's economic output (USDA 2010), while tourism associated with Lake Erie generates more than US$11 billion annually in direct sales (Ohio Phosphorus Task Force 2013). In addition to tourism, water bodies across the state serve as a primary source of drinking water. The importance and fragility of this ecosystem service is best illustrated by the 2014 outage of potable water to approximately 500,000 citizens of Toledo, Ohio, due to harmful algal blooms. To achieve a balance between two of Ohio's most important resources, there is a need to better understand the effect of agricultural practices on water quality in these artificially drained landscapes.

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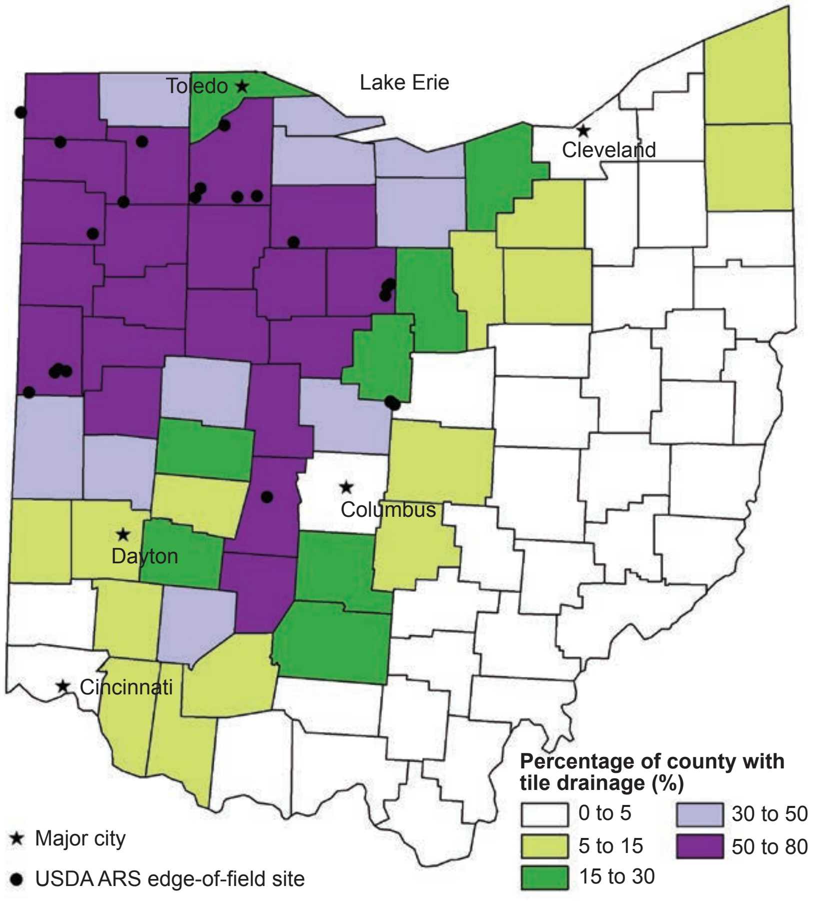
NETWORK DESCRIPTION

The USDA Agricultural Research Service located in Columbus, Ohio, has established a monitoring network dedicated to quantifying the impacts of agricultural practices on edge-of-field water quality. The current network is comprised of 40 monitored fields on 20 separate farms across the intensively drained region of Ohio (figure 1). The first edge-of-field monitoring sites were installed in 2003, with additional sites instrumented over the past twelve years. Since its inception, the edge-of-

Figure 1

The USDA Agricultural Research Service (ARS) edge-of-field monitoring network in central and northwestern Ohio.



field monitoring network has facilitated multidisciplinary research efforts aimed at developing solutions for the complex water quality problems found in tile-drained landscapes. The edge-of-field monitoring network has been an integral component of several regional and national initiatives including the Conservation Effects Assessment Project, the Mississippi River Basin Initiative, and multiple Conservation Innovation Grants with university partners and nongovernmental organizations. Recently, the edge-of-field monitoring network has also become part of the Eastern Corn Belt Long-Term Agroecosystem Research Network, The Ohio State University Field to Faucet Initiative, and the 4R Research Project.

Site Selection. Within the edge-of-field monitoring network there are several site characteristics that all fields share. In general, silt loam, silty clay, and clay soil types that are classified as poorly to very poorly drained are found across all fields. Each field is also artificially drained with tile lines positioned between 0.7 and 1.0 m (2.3 and 3.3 ft) below the soil surface. The monitored fields are relatively flat (<0.5% to 3% slope), with the size of the field ranging from 4 to 32 ha (10 to 80 ac). All fields are cultivated in two- to three-year rotations of corn (*Zea mays* L.), soybean (*Glycine max* L.), and wheat (*Triticum aestivum* L.). To be selected for inclusion in the edge-of-field monitoring network, all fields had to meet several initial criteria: (1) they had to be representative of prevailing agricultural practices in the tile-drained region of the midwestern United States; (2) they had to be hydrologically separated from neighboring fields; (3) they had to be paired with another field in close proximity with the same management practices (see experimental approach); and (4) farmers had to be willing and active participants.

Management practices in individual fields are often unique due to differences in site characteristics (e.g., slope and soil type) and farmer preferences (e.g., timing and method of nutrient application). The majority of monitored fields are either no-tilled or rotational tilled. Most fields receive either commercial fertilizer, animal manure, or a mixture of fertilizer and manure as a source of nutrients, with applications generally occurring in spring or fall, with some side-dressing during summer months. Soil test P levels across all fields range from 20 to >400 ppm Mehlich-3 P in the top 20 cm (8 in) of the soil profile and decrease rapidly below the plow layer.

Instrumentation and Laboratory Analysis. Precipitation and discharge are continuously monitored at all of the edge-of-field sites within the monitoring network (figure 2). Precipitation is measured using both a tipping bucket rain gauge and a standard rain gauge. These rain gauges provide data on rainfall duration, intensity, and depth. Edge-of-field monitoring stations capture both surface and subsurface hydrologic pathways. Tile discharge is measured using compound weir inserts and Isco 4230 Bubbler Flow Meters (Teledyne Isco, Lincoln, Nebraska) that are installed at the tile outlet (figure 2). An Isco 2150 Area Velocity Sensor is also installed in each tile outlet to measure discharge under submerged conditions. Surface runoff is measured with a 61 cm (2 ft) H-flume, with a bubbler flow meter measuring the depth of water flowing through the flume (figure 2). Discharge measurements for both tile drainage and surface runoff are recorded every 10 minutes.

Water samples are collected from each surface flume and tile outlet using an Isco 6712 Portable Sampler. Water samples from tile outlets are collected every six hours and four samples are composited into one bottle to comprise a daily sample. More intensive sampling (one to two hours) is also conducted during storm events at several sites. A flow proportional sampling strategy is employed for the collection of surface runoff water samples, where samples are collected after a preset volume of water passes through the flume. The volume of water required for sample collection is different for each field depending on the drainage area and site characteristics. All instrumentation is powered by solar panels and housed inside an insulated box (figure 2) that is equipped with a hot water tank. The tank serves as a source of heat during the winter; thus, water samples can be collected year round, which has traditionally been difficult for edge-of-field applications in temperate climates. All water samples are analyzed for concentrations of ammonium (NH_4-N), nitrate (NO_3-N), total N, dissolved reactive P, and total P.

EXPERIMENTAL APPROACH

To quantify the effects of prevailing agricultural practices as well as the implementation of innovative conservation practices on edge-of-field water quality, a before-after control-impact (BACI) experimental design is being employed at all edge-of-field monitoring sites. Baseline data (e.g., discharge and nutrient concentrations) are collected from paired fields for an entire crop rotation, with the farmer managing the fields as they typically would (i.e., prevailing practice). After this baseline period, one field is designated as the control field and the other as the treatment field. For a second crop rotation, the management practices in the control field remain the same as during the baseline period, whereas a change in management (e.g., banding fertilizer rather than broadcast fertilizer or drainage water management) is implemented on the treatment field. The strength of the BACI approach is that any changes over time (e.g., weather, crop, management, etc.) in the treatment fields, unrelated to the treatment, are controlled for by these same changes over time in the control field.

TOWARD SUSTAINABLE AGRICULTURAL MANAGEMENT

Recent increases in the extent and severity of Harmful and Nuisance Algal Blooms (HNABs) in Lake Erie have prompted a call for action across Ohio. In a report by the Ohio Phosphorus Task Force (2013), it is suggested that a 40% reduction in annual total P load (~1,000 t [1,102 tn]) is required to reduce the potential for HNABs in Lake Erie. As a result, the agricultural industry has been firmly placed in the public's spotlight. The edge-of-field monitoring network described herein will be essential as we move toward improved water quality and try to balance agricultural production and environmental quality. Edge-of-field datasets will allow us to understand the mechanisms and processes for nutrient transport in artificially drained landscapes and to gain insight into which conservation practices may be better suited to reduce nutrient loads in surface runoff and tile drainage. Once in the treatment phase, the monitoring network will aid in the evaluation of conservation practices, such as 4R nutrient stewardship (right rate, source, method, and timing of nutrient application), cover crops, drainage water management, gypsum, tillage type, controlled traffic, and bioreactors, on water quality and crop yields. Not only will the edge-of-field network be useful for understanding single or multiple practices on a single field, but also for understanding tradeoffs associated with agricultural practices. A practice that may be well suited to decrease N loads in tile drainage, for example, may inadvertently increase P loads and vice versa. Ultimately, results from edge-of-field studies will help facilitate increased adoption of conservation practices and lead to downstream improvements in water quality.

Beyond monitoring data, the network will provide vital information for identifying gaps in numerical models and to supply essential validation datasets for scenario simulations. Numerical modeling will help quantify the impacts of current and future climate scenarios, elucidate the effect of using conservation practices at larger spatial scales, provide a better understanding of the underlying processes governing nutrient transport, and help guide future edge-of-field monitoring. Numerical models are increasingly used to guide decisions regarding water resource policy, management, and regulation (Ford et al. 2015); therefore, advancing and applying these models in tile-drained landscapes will be important for improving water quality in Ohio and across the midwestern United States. The integrated monitoring and modeling approach, in

Figure 2

Instrumentation at the edge-of-field monitoring sites: (a) typical edge-of-field monitoring site, with surface runoff and tile discharge instrumentation; (b) H-flume for surface runoff monitoring; and (c) compound weir for tile discharge monitoring.

turn, will help inform widely used tools such as P indices (Williams et al. 2015), the Nutrient Tracking Tool (Saleh et al. 2011), the Nitrogen Index (Delgado et al. 2008), and Adapt-N (Melkonian et al. 2008). These user-friendly tools will assist farmers with managing crop nutrient needs while minimizing nutrient losses and the associated environmental impacts.

Developing integrated water, land, and crop management systems and conservation practices that support profitable agriculture and environmental protection is an immense challenge. An important step in this process is the improved understanding of how agricultural management practices affect water quality. While the monitoring network described in this article is focused on edge-of-field quantification of water quality in Ohio, the fields, issues, and conservation practices described are representative of many tile-drained regions throughout the Midwest and across the world. Management of water and nutrient resources supported by scientifically based monitoring of conservation practices will propel agriculture in tile-drained regions into a more productive, environmentally sustainable future.

REFERENCES

Blann, K.L., J.L. Anderson, G.R. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: A review. Critical Reviews in Environmental Science and Technology 39:909-1001.

Delgado, J.A., M. Shaffer, C. Hu, R.S. Lavado, J. Cueto-Wong, P. Joosse, D. Sotomayor, W. Colon, R. Follett, S. DelGrosso, X. Li, and H. Rimski-Korsakov. 2008. An index approach to assess nitrogen losses to the environment. Ecological Engineering 32:108-120.

Ford, W., K.W. King, M.R. Williams, J. Williams, and N.R. Fausey. 2015. Sensitivity analysis of the Agricultural Policy/Environmental eXtender (APEX) for phosphorus loads in tile-drained landscapes. Journal of Environmental Quality 44:1099-1110, doi:10.2134/jeq2014.12.0527.

King, K.W., M.R. Williams, M.L. Macrae, N.R. Fausey, J. Frankenberger, D.R. Smith, P.J.A. Kleinman, and L.C. Brown. 2015. Phosphorus transport in agricultural subsurface drainage: A review. Journal of Environmental Quality 44:467-485.

King, K.W., N.R. Fausey, and M.R. Williams. 2014. Effect of subsurface drainage on streamflow in an agricultural headwater watershed. Journal of Hydrology 519:438-445.

Melkonian, J.J., H.M. van Es, A.T. DeGaetano, and L. Joseph. 2008. ADAPT-N: Adaptive nitrogen management for maize using high-resolution climate data and model simulations. *In* Proceedings of the 9th International Conference on Precision Agriculture, ed. R. Kosla, 20-23 July 2008, Denver, CO (CD-ROM).

Ohio Phosphorus Task Force. 2013. Ohio Lake Erie Phosphorus Task Force II final report. Columbus, OH: Ohio Department of Agriculture.

Saleh, A., O. Gallego, E. Osei, H. Lal, C. Gross, S. McKinney, and H. Cover. 2011. Nutrient Tracking Tool: A user-friendly tool for calculating nutrient reductions for water quality trading. Journal of Soil Water Conservation 66(6):400-410, doi:10.2489/jswc.66.6.400.

Smith, D.R., K.W. King, and M.R. Williams. 2015. What is causing the harmful algal blooms in Lake Erie? Journal of Soil Water Conservation 70(2):27A-29A, doi:10.2489/jswc.70.2.27A.

Tilman, D., C. Balzer, J. Hill, and B.L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences, USA 108:20260-20264.

USDA. 2010. A look at Ohio agriculture. http://www.agclassroom.org/kids/stats/ohio.pdf.

Williams, M.R., K.W. King, E. Dayton, and G. Labarge. 2015. Sensitivity analysis of the Ohio phosphorus risk index. Transactions of the American Society of Agricultural and Biological Engineers 58:93-102.