Fulton County Nutrient Loss Reduction Research and Demonstration Program

Research and Outreach Highlights (2015-2019)

1. BACKGROUND

In 2008 the United States Environmental Protection Agency released the Gulf of Mexico Hypoxia Action Plan. The plan established the goal to achieve at least a reduction by 45% in total nitrate-nitrogen (N) and total phosphorus (P) discharged into rivers, measured against the average load over the 1980-1996 time period:

1). Significantly reduce the size of the Gulf of Mexico hypoxic zone to less than 5,000 km^2,

2). Restore and protect local and regional water quality in the Mississippi river basin, and

3). Improve communities and economic conditions through improved land management and a cooperative, incentive-based approach.

In 2011, U.S. EPA provided a recommended framework for states in the Mississippi River Basin to develop plans to reduce the amount of nutrients discharged into rivers. Based on this framework, in 2015, Illinois released a statewide Nutrient Loss Reduction Strategy (IL NLRS). The NLRS was developed by the Illinois Environmental Protection Agency (IEPA), Illinois Department of Agriculture and a multi-stakeholder group. The NLRS establish a goal to reduce total P load by 25% and N load by 15% by 2025 with the eventual target of a 45% reduction in the loss of these nutrients to the Mississippi River.

While reducing N and P concentrations in effluent at its water reclamation plants through a series of wastewater nutrient removal technologies, Metropolitan Water Reclamation District of Greater Chicago (MWRD) believes 45 percent nutrient loss reduction goal established in the Illinois Nutrient Loss Reduction Strategy could be achieved most quickly and economically through the collaborative effort of the point and non-point sources of nutrients. Thus, in 2014, MWRD initiated a research and demonstration program at the Fulton County site (13,000 acres) with 4,000 acres of strip-mined (reclaimed) and nonmined land to develop and test best management practices to reduce non-point source (agriculture) nutrient loss in a partnership with organizations of agriculture research and extension addressing nutrient loss. This program focuses on 1). Developing and demonstrating the effectiveness of in-field and edge-of-field best management practices (BMPs) in reducing nutrient loss from agricultural fields; 2). Disseminating BMPs to farmers via field days and various media; 3) Establishing the Fulton County site as a model to foster collaboration between the point source and the agricultural sectors in addressing nutrient loss reduction.

Since 2015, research and demonstration projects *(Figure 1)* have been established at the site in collaboration with the University of Illinois at Urbana-Champaign's (UIUC) Crop Science Department, UIUC Department of Agricultural and Biological Engineering, Illinois Sustainable Technology Center, Illinois Central College, Ecosystem Exchange, Illinois Farm Bureau (IFB), and Fulton County Farm Bureau (CFB). The projects established include inter-seeded cover cropping, riparian grass buffer, runoff irrigation, sub-irrigation, drainage water managements, designer biochar, and watershed-scale nutrient reduction demonstration. Findings from these projects are reaching local and regional agricultural communities, through field days and annual meetings, and publications (e.g. project reports and peer-reviewed journal articles).

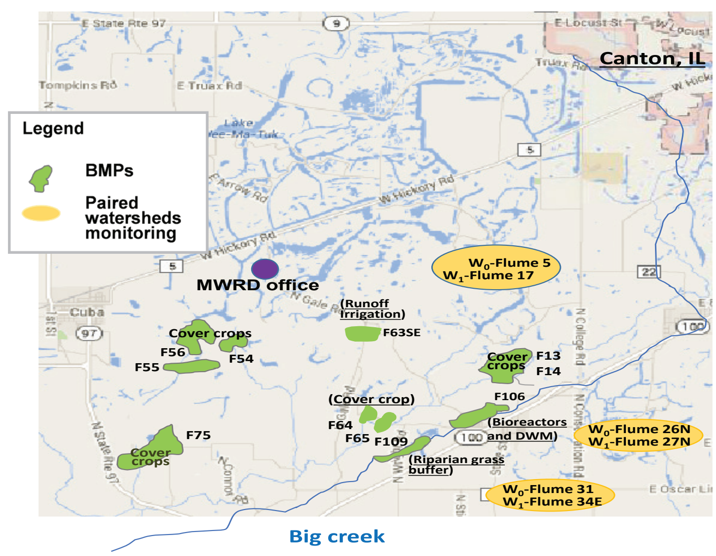

Figure 1. The *layout of best management practices (BMPs) research and demonstration experiments at MWRD's Fulton County site located between Canton and Cuba, Illinois*

2. DEVELOPMENT AND TESTING OF BEST MANAGEMENT PRACTICES

2.1 Cover crops:

To improve the efficiency of the winter cover crop system in reducing nitrogen leaching during the off-season (no crop), a modified approach to the traditional cover crop systems is evaluated. In this approach the cover crop is planted three months earlier than that in the traditional system by inter-seeding. This enables the cover crops to have adequate time to develop a root system ahead of the winter *(Picture 1)*. The growth of cover crop is slow during the summer, but accelerates after corn harvest in fall to take up residual soil N, thus preventing it from being lost through leaching. The cover crop also provides groundcover for reducing soil erosion and runoff.

Since 2015, cover crops have been planted (mainly annual ryegrass and cereal rye) every year in rotation in six fields between corn rows using an inter-seeder at three to four weeks after corn planting. The inter-seeded cover crops generally established well in soils of moderate fertility, but poorly in soils with high compaction and poor nutrient availability. Both ryegrass and cereal rye grew well under the corn canopy, but it seems that cereal rye had better survival over the summer dormancy period than ryegrass.

Picture 1. *Cover crop inter-seeding (upper left), growth of cereal rye under corn (upper right), and cover crop groundcover in early spring (lower left)*

Biomass and soil sampling and nutrient analyses were conducted in April 2018 in fields with cover crops inter-seeded in June 2017. The aboveground dry matter of cover crops was 0.17 and 0.95 Mg/ha for ryegrass and cereal rye, respectively. The biomass production for the mixture of ryegrass/cereal rye/clover (0.86 Mg/ha) was nearly the same as the cereal rye only plot. Ryegrass did not recover well after a slow-growing period during summer, leading to lower aboveground biomass. However, the root biomass of ryegrass (0.50 Mg/ha) and cereal rye (0.56 Mg/ha) was similar, suggesting the root development of the cover crops was largely dependent on the summer/fall growth period, which is not available for traditional cover crops seeded in fall/winter. The total nutrient uptake by cereal rye cover crop was 30.5 kg/ha for N and 3.9 kg/ha for P, thus the harvest of the cover crop aboveground biomass could lead to substantial N removal from the agricultural field.

The data for observation in 2018 spring also showed a large reduction in NO_3^- mass (28.9%) at 60 - 100 cm depth of the field inter-seeded with cereal rye or cereal rye/rye grass/clover mixture *(Figure 2)*. Since this soil depth is just above the drainage tile, such reduction in soil NO_3^- mass would reduce the NO_3^- in tile drain, which is the main route of N loss in Illinois row crops fields. Reduction in NO_3^- mass in other depths of subsoils by cover crops was also observed, particularly for cereal rye only. The reduction in subsoil N was not observed after ryegrass cover crop, due to poor survival of the plant during the slow-growing period in summer. In 2020, cover crops will be planted in tiled fields, and drainage will be collected for analysis to quantify the impact of cover crops on nitrate concentration in water leaving the tile drains..

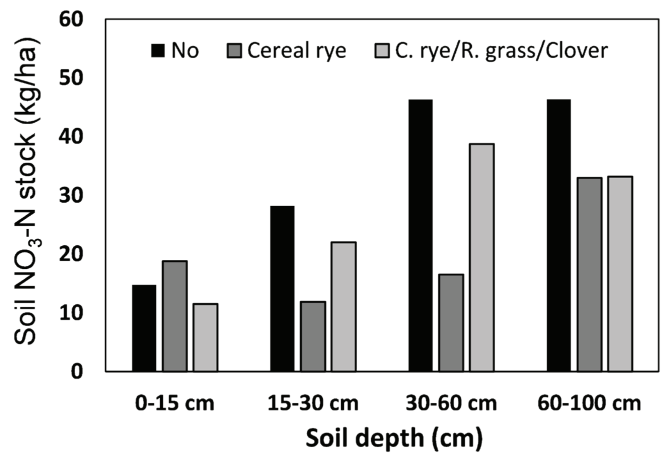

Figure 2. *Soil nitrate stock in various soil depths in early spring of 2018 as affected by the cover crops inter-seeded in the previous corn*

The inter-seeded cereal rye slightly decreased soil nitrate concentrations for companion corn at corn tasseling during the cover crop establishment, but there was not reduction in corn yield.

The planting of cover crops was also conducted in other fields following corn or soybean by aerial seeding at the crop maturity. The cover crop by aerial seeding could establish well in the fields with high soil moisture. The cover crops by inter-seeding and aereial seeding with the same plant type (ryegrass, cereal rye, and ryegrass/ cereal rye/clover mixture) are being established in the same field, and data collection for the comparison of rooting depth and nutrient uptake of cover crops and soil nutrient profile between summer inter-seeded and fall aerially-seeded cover crop systems will be conducted during 2020-2021 seasons.

2.2 Riparian Grass Buffer

A collaboration with researchers at the UIUC under the program, starting in 2016, and has focused on design and establishment of multifunctional grass buffer at riparian zones based on forage and bioenergy-based grasses that can potentially generate income for farmers through producing hay, thus making the BMP more economically appealing to farmers. The forage-based riparian grass buffer is composed of Alfalfa, tall forage fescue, orchardgrass, perennial ryegrass, timothy, and meadow fescue, and bioenergy grass with switchgrass, big bluestem, indiangrass, and prairie cordgrass.

The on-farm 60-foot wide multifunctional buffer strips with a 1,200 feet length for research and 800 feet length for demonstration were established in 2016 at the edge of a 25-acre row crop field along Big Creek which runs through the Fulton County site. At end of 2017, the riparian buffer strips were well established *(Picture 2)*.

Picture 2. *Forage grass (upper) and bioenergy grass (lower) riparian buffer strip established*

MacroRhizons **samplers** were installed in 2018 to collect leachate water for the analysis of nutrients. On the creek side, both forage and bioenergy plots were found to have lower concentrations of nitrate-N as compared to corn plots. During spring (April and May), when soil water nitrate was prevalently high, riparian grass buffer was very effective in reducing NO_3^- concentration of subsurface water to the creek: 21.4% by bioenergy grass and 66.8% by forage grass (Figure 3). Both bioenergy and forage grass has shown an insignificant effect on P concentration of subsurface water to the creek. The DNA analysis showed a greater abundance of total soil N cycling bacteria and denitrification function groups, particularly under forage grass, compared to no buffer.

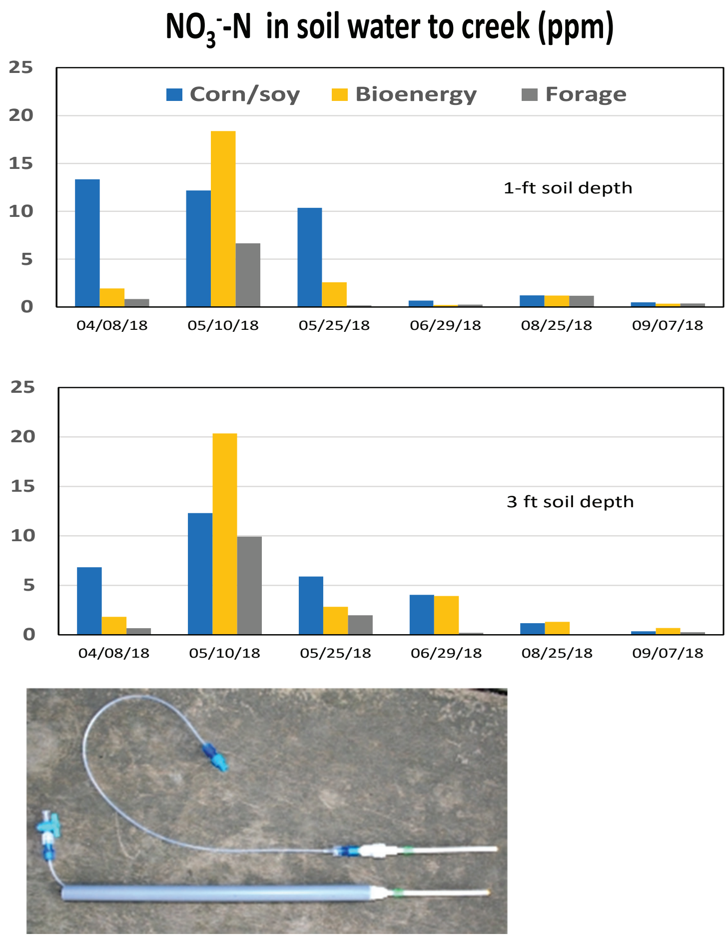

Figure 3. *The concentration of nitrate of soil water in an agricultural field next to a creek as influenced by forage and bioenergy grass riparian buffer strip*

2.3 Runoff Irrigation

Runoff water from agricultural fields flowing into a retention basin can be pumped back onto production areas for irrigation *(Figure 4)*. Not only nutrients in the water can be directly reused by crops, but the improvement in soil moisture by runoff water during the drought periods can also help to improve the crop's use of nutrients in the soil. Although there is an increase in cost for pumping the water, it might be offset by the decrease in the use of fertilizer due to the recycling of nutrients in the runoff water and increase in crop yield.

This work, done in collaboration with UIUC, focused on measuring fertilizer replacement value of irrigation with field runoff. Irrigation of corn using runoff in an adjacent pond to reuse the nutrient lost along with field runoff was conducted in a field from 2016-2018.

Figure 4: *Layout of the field study to assess how irrigation with runoff water affects crop yields.*

The total amount of nutrients added back to the field with irrigation water was low (3.8 - 9.3 kg N/ha and 0.7 - 1.5 kg P/ha annually), but, irrigation with runoff largely increased N and P uptake by corn. The fertilizer replacement value (FRV) of the runoff irrigation, estimated based on increase in crop N and P uptakes, were 122 kg N/ha and 49 kg P/ha in 2017, and 73 kg N/ha and 6 kg P/ha in 2018 *(Table 1)*. It appears, therefore, that reduced fertilizer application (up to 50% reduction in agronomic N and P rate) coupled with runoff irrigation may be a suitable management practice to be further explored as part of the Illinois nutrient loss reduction strategy.

Table 1: *Fertilizer replacement value of irrigation water applied in 2017 and 2018 based on crop N and P uptake1*

	Nitrogen		Phosphorus	
Year	kg/ha	% of N applied	kg/ha	% of P applied
2017	122 ± 66	50	49 ± 26	72
2018	73 ± 36	30	6 ± 5	8

1Based on the requirement of 244 kg N/ha and 67 kg P/ha for corn crop

2.4 Denitrifying Bioreactor

Woodchip bioreactor as an edge of field practice is a technology to reduce the level of N in subsurface drainage and researchers at UIUC have led the development of this practice. Subsurface tile-drainage can also transport P from fields to streams in Illinois. So, if the woodchip bioreactor can be modified to remove the P in drainage as well, it can increase the benefits and likelihood of adoption of this technology. Thus, the denitrifying bioreactor project at Fulton County aims at looking into the effectiveness of woodchip bioreactors for the simultaneous removal of P in addition to N.

With the collaboration with UIUC, Ecosystems Exchange Services, and Illinois Farm Bureau, an 80-acre field was tiled and nine bioreactors were established in 2018 to accommodate the research and demonstration of a series treatment of carbon sources for microbial activity, including woodchips, corn stover, woodchips/corn stover mix, and P- sorption materials including iron filling and designer biochar *(Figure 5)*.

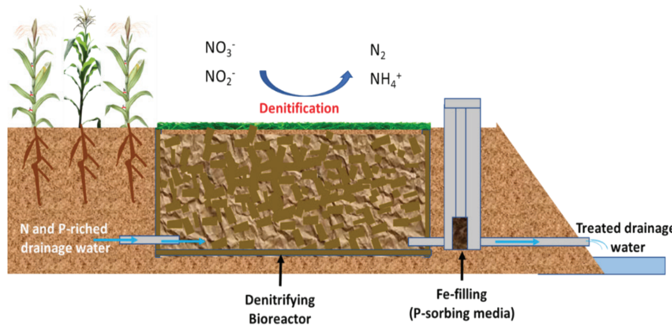

Figure 5: *Layout of a denitrifying bioreactor including a P-media to remove both nitrate N and P from tile-drained water*

Based on the data collected so far, drainage water samples at the inlets and outlets of each bioreactor and the outlet of P-sorbing media showed an estimated NO_3^-N reduction of 69, 75, and 67% by bioreactors made with corn stover, woodchips/corn stover mix, and woodchips as media, respectively *(Figure 6)*.

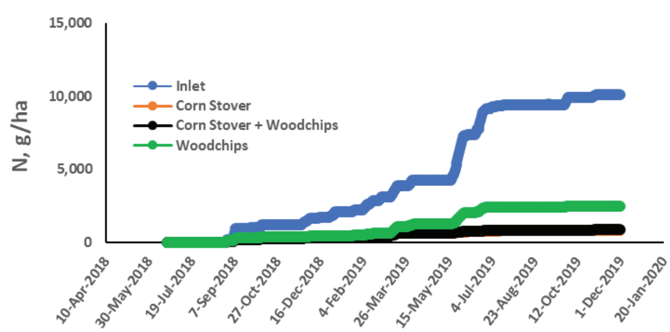

Figure 6. *Cumulative N load in drainage water before and after passing through bioreactors with various carbon sources.*

For the three bioreactors, P loads in the drainage water at the outlet was lower than that at the inlet of the P-sorbing media and reduction by the iron filling (P-sorbing) media averaged 49%. Preliminary results indicate that complementing woodchip-based denitrifying bioreactors with P-sorbing media can remove both the N and P of agricultural drainage water by 67 and 49%, respectively. In 2020, the different bioreactor media and P-sorbent will be characterized to optimize the effectiveness of nutrient removals.

2.5 Drainage Water Management and Sub-Irrigation

Controlled drainage and subsurface irrigation can increase water use efficiency on farm fields and minimize net nutrient loss from the field year-round. This UIUC-MWRD-Illinois/Fulton County Farm Bureau joint project is funded by Illinois Nutrient Research and Education Council (NREC). The project is designed to demonstrate and evaluate drainage water recycling through sub-irrigation as a BMP to reuse nutrients from agricultural drainage and to optimize crop yield at reduced fertilizer use. The 20-acre tiled field is divided into four subfields and each is randomly assigned with one of four treatment combinations: full or half agronomic fertilizer rate both with and without irrigation.

Crop irrigation is done by controlling the drainage through field drainage tile line head (sub-irrigation) *(Figure 7)*. Sub-irrigation water seeps out of the perforated tile and is re-delivered to the crop root zone upwards from below the soil surface through capillary action. The outlet of tiles is equipped with a controlled structure that is operated using a remotely controled Smart Drainage Systems designed by Agridrain Inc. When the draining is not necessary during the dry period and at the time there is no crop in the field, the DWM can reduce drainage outflow, leading to the reduction in nutrient loss from the fields.

The data collected between 2018 and 2019 (without treatments) are used to calibrate the field. Starting in 2020, the fertilizer and sub-irrigation treatments will be applied, and the outlet elevations of the sub-irrigation treatments will be adjusted based on seasonal needs as follows:

- raise outlet elevations after harvest to limit drainage outflow and reduce nutrient export
- put the system into conventional drainage mode before planting.
- lower outlet elevations to allows the soil to drain freely for planting & other field operations
- raise the outlet elevations after spring field operations to reduce drainage outflow
- add supplemental water as needed to maintain the water table at fixed levels

Each control structure is equipped with a satellite-controlled system, accessed via a computer with internet connectivity, to remotely monitor flow, water table level, and rainfall. Water samples are being collected weekly and within 24 hours of a rain event equaling or exceeding 0.5 inches. In addition to monitoring the flux and nutrient concentrations in the drainage and irrigation water, crop yield and other growth-index data are being collected throughout the growing season. Data collected during the calibration period (2018 and 2019) showed a good correlation between flow amount, N loads, and P loads across the four subfields *(Table 2)* and highly sensitive to detect differences when treatments are applied in 2020.

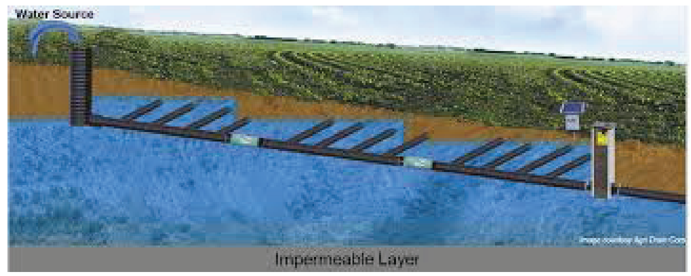

***Figure 7:** A sub-irrigation system (Ecosystem Exchange Services, Adair, Iowa)*

Field	Field A	Field B	Field C	Field A	Field B	Field C	Field A	Field B	Field C
	------------Flow---------			------------Nitrate---------			------------P---------		
Field B	0.99***			0.99***			0.91***		
Field C	0.99***	1.00***		0.98***	0.96***		0.92***	0.97***	
Field D	0.82**	0.79**	0.81**	0.45*	0.51*	0.32*	0.47*	0.59**	0.53**

***Table 2:** Field calibration in 2018 - Correlation coefficient of flow amount, and nitrate and P loads in drainage water*

2.6 Watershed-Scale BMP Effectiveness Quantification and Upscaling

To quantify the overall nutrient reductions in watersheds where multiple BMPs are implemented, six fields in three pairs for use in watershed verification of BMPs effectiveness have been established using the U.S. EPA's paired watershed research approach. One field in each pair serves as a reference and a BMP is implemented in the other. In each field, a collection flume is equipped with flow meters and automatic runoff samplers to quantify the nutrient loss via runoff after every rain. Nitrogen and P loss via leaching is quantified using the sampling of soil depths to 1-m before the winter and in early spring.

The data of effectiveness for these BMPs together with soil properties, hydrological condition, regional climate, landscape characteristics will be integrated into models to generate output on the percentage of lands in a watershed needs to be implemented with BMPs to achieve the nutrient reduction target. Such information will also be used to prepare BMP package for dissimilating it to farmers through a joint effort with agricultural extension services. This study will also generate data relevant to a potential nutrient trading market in Illinois, which can increase the rate of adoption of BMPs.

3. FIELD DAYS, INFORMATION DISSEMINATION, OUTREACH, AND EXTENSION TO FARMERS

Since 2015, the annual field day has been organized with partners to demonstrate the application and benefits of BMPs to farmers, regulatory agencies, and other stakeholders. Most of the research and demonstrations established so far have been showcased to the farming community through annual field days conducted as collaborations between MWRD, the IFB, Fulton CFB, Illinois Central College, UIUC, and Prairie Research Institute. At each of the annual Field Days, agricultural professionals teamed up with water experts and soil scientists from the MWRD to offer different techniques that can increase crop yields while reducing nutrient loss. Crowds toured several demonstrations that included cover crop inter-seeding, improved denitrifying bioreactor to remove both N & P, drainage water management, and multipurpose riparian grass buffers *(Picture 3 and 4)*.

Picture 3 *Fulton County field days Activities (1)*

Picture 4 *Fulton County field days Activities (2)*

Outreach activities also included the preparation and dissemination of BMP fact sheets. So far two Fact sheets have been produced, one on the Fulton County Research and Demonstration Program and Other on Gasses Buffer *(see Appendix)*.

4. FUTURE WORK (NEXT 5 YEARS)

In the next phase of Fulton County Nutrient Loss Reduction Research and Demonstration Program, the focus will be on:

- Combining different BMPs, for instance woodchip bioreactor with designer biochar at the tile drain outlet to capture phosphorus within the biochar. The biochar can be spread over the field as a form of slow-release phosphorus fertilizer to reuse the P in drainage.
- Test effectiveness of BMPs or combined BMPs in watershed level or field-based watershed using paired watersheds/fields approach to generate information that facilitates nutrient trading and accelerates joined effect of point and nonpoint sources in achieving the state nutrient loss reduction goal.
- Search for forage plants that adapt well to wet areas, and develop a forage plant-based nutrient uptake system to capture the nutrients from tile drainage and generate income for farmers.
- Look into residue management on N release from the cover crop residues so that N accumulation in cover crop biomass could be translated into high yields of the succeeding crops, promoting the farm profitability with the nutrient loss reduction effort.
- Progressively implement BMPs in many fields at the Fulton County site to establish the site as a nonpoint source nutrient loss reduction model.
- Continue to build partnerships and broader capacities to capitalize on all the effort for utilizing the Fulton County site to facilitate the collaboration of point source and agricultural communities for nutrient loss reduction.

5. LIST OF MANUSCRIPTS UNDER PREPARATION:

1. Reduction of spring soil nitrogen load by inter-seeding cereal rye cover crop, manuscript in preparation for Journal of Soil and Water Conservation.
2. The use of multifunctional perennial riparian buffer strips in reducing the nutrient loss from agricultural fields, manuscript in preparation for Plant and Soil.
3. Assessment of runoff irrigation impacts on corn nutrient uptake in western Illinois: implications for nutrient loss reduction, manuscript in preparation for Agronomy Journal.
4. Effectiveness of denitrification bioreactors with phosphate sorbing media for removal of subsurface drainage N and P in corn-soybean system, manuscript in preparation for Journal of Environmental Quality.

6. PARTNERSHIP

MWRD Participants

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APPENDIX

Brochure: ***MWRD Fulton County Nutrient Research and Demonstration Program – Nutrient Loss Reduction from Agricultural Fields.***

UIUC Extension guide: ***Multifunctional Perennial Filter Strips: An effective way to reduce nutrient loss.***