2018 Annual Report for NREC Project 2015-5-360350-374

Evaluating Nutrient Loss Reduction Strategies: Longer rotation with cover crops and bioreactor

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Synopsis:

This project will provide an on-farm evaluation of best management practices, both in-field and edge of field, to demonstrate how low we can go in regard to tile nutrient losses. The University of Illinois Science Assessment which served to guide the Nutrient Loss Reduction Strategy evaluated combinations of nutrient remediation techniques to create BMP scenarios that when adopted regionally would make a significant reduction in the N and P export from agricultural runoff (overland and tile flow). Two remediation techniques that were often included in the various scenarios were 1) growing winter cover crops and 2) constructing woodchip bioreactors on drainage tiles. This proactive research is demonstrating the potential of maintaining high-yielding systems with minimal nutrient losses and is directly testing scenarios used in the University of Illinois Science Assessment. Considering the challenge the agricultural sector faces in regard to reducing nutrient losses to surface waters, this experiment will demonstrate the potential to reduce tile nutrient loss (especially nitrate) on a field scale. In direct response to the Illinois Nutrient Loss Reduction Strategy, this type of research will show that voluntary actions can work to improve water quality and that regulation is not warranted at this time.

Objectives

The overall goal of this study is to test the effectiveness of a longer rotation with cover crops in combination with a bioreactor to decrease tile nitrate loss and directly examine this potential nutrient loss reduction scenario on a field-scale production system.

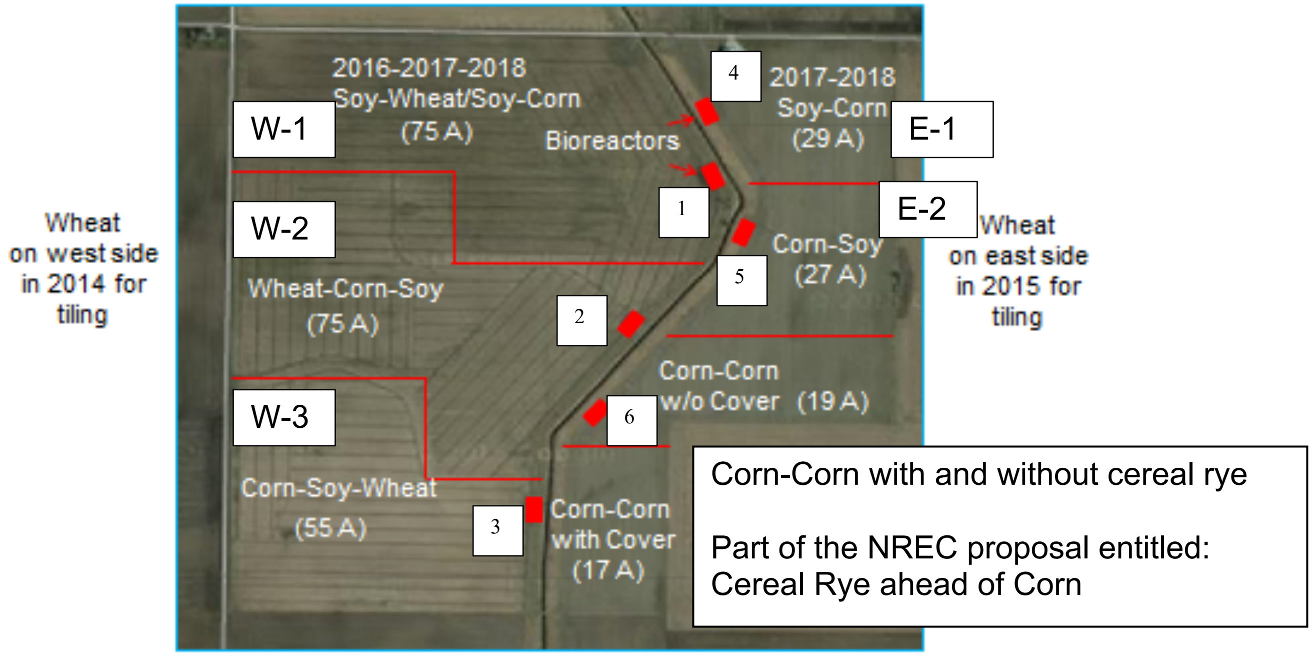
Specific objectives are to:

1. Determine the effect of a C-S-W rotation with cover crops on crop yields, nutrient cycling, field hydrology, and nitrate leaching on field scale plots.
2. Examine the role of cover crops in N cycling and nitrogen availability.
3. Perform economic evaluation of the four cropping systems on this farm.
4. Evaluate bioreactor performance.

Length of Project

This project has completed the 4th year of funding. Following the setup year of 2015 when we measured baseline conditions, we now have completed tile monitoring for three complete drainage seasons (2016, 2017, and 2018).

Field Design, Crop Rotation, and Bioreactor Locations (field sizes in acres included)



Project Update:

Field work has been timely at this Piatt County site. This site compares and contrasts four cropping systems (C-S-W vs. C-S vs. C-C with cereal rye vs. C-C without cereal rye).

Field operations for **Corn-Soybean-Wheat** (with cover crops and double cropped soybean after wheat):

- Oct. 2, 2017: Fertilizer applied (220 lbs/A of 1240-D and 200 lbs/A of 0-0-60) to winter wheat
- Oct. 21, 2017: Winter wheat planted (AgriMAXX 444 and 473) (1,550,000 seeds/A)
- Oct. 31, 2017: Cereal rye drill planted (50 lbs/A) following corn
- Nov. 1, 2017: Fertilizer applied (0-46-0 VRT for 83 lbs/A and 200 lbs/A of 0-0-60) following corn
- Nov. 13, 2017: Fertilizer applied (200 lbs/A of 0-46-0 and 0-0-60) following double cropped soybean
- Dec. 3, 2017: Strips made for next year's corn
- Mar. 15, 2018: Top-dress N applied to winter wheat (50 lb of N/A as 32%)
- April 24, 2018: Collected cereal rye biomass
- April 26, 2018: Termination of cereal rye ahead of soybean with glyphosate

- April 30, 2018: Corn planted (DeKalb 64-34) at 38,000 seeds/A with 20 lbs of N/A starter (combination 2x2 and popup)
- May 2, 2018: Soybean planted (Pioneer 31A22) at 140,000 seeds/A
- May 2, 2018: Top-dress N applied to winter wheat (50 lb of N/A as 32%)
- May 29, 2018: Corn side-dress N applied (160 lbs of N/A of 32%)
- May 29, 2018: Corn N rate trial established
- June 29, 2018: Wheat harvested (88 bu/A)
- June 30, 2018: Double cropped soybean planted (Asgrow 39X7 at 225,000 seeds/A)
- Sept. 11, 2018: Stalk nitrate test in N rate trial
- Sept. 17, 2018: Soybean harvested (97 bu/A)
- Sept. 30, 2018: Corn harvested (265 bu/A), N rate trial harvested
- Oct. 1, 2018: Fertilizer applied (200 lbs. of 1240-D and 200 lbs. of 0-0-60) to soybean stubble
- Oct. 2, 2018: Cereal rye planted (40 lbs/A)
- Oct. 9, 2018: Winter wheat (AgriMAXX 444) planted at 1,750,000 seeds/A
- Oct. 30, 2018: Double crop soybean harvested (52 bu/A)
- Oct. 30, 2018: Fertilizer applied (220 lbs. 0-46-0, 200 lbs. 0-0-60) to corn stubble
- Oct. 30, 2018: Fertilizer applied (90 lbs. 0-46-0, 200 lbs. 0-0-60) to double crop soybean stubble

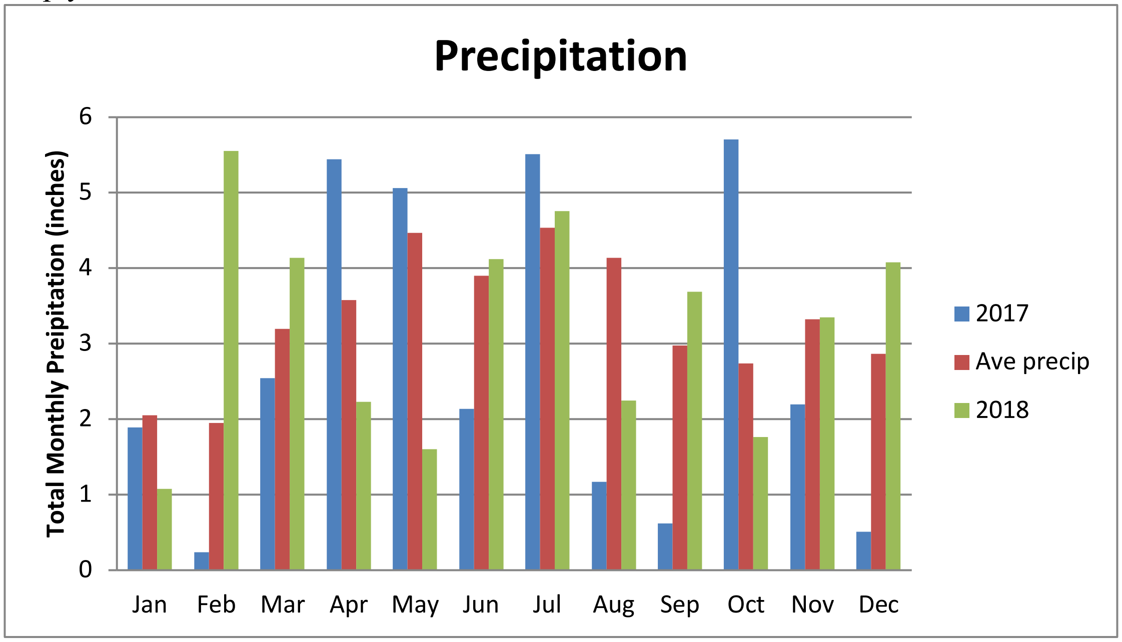
Field operations for **Corn-Soybean** (with conventional tillage and fall N application):

- Oct. 20, 2017: Fertilizer applied (100 lbs/A of 11-52-0 and 200 lbs/A of 0-0-60) to corn and soybean stubble
- Nov. 24, 2017: Applied anhydrous ammonia at 105 lbs of N/A
- Nov. 24, 2017: Corn N rate trial boundaries delineated with 0 lbs/A of fall N
- April 29, 2018: Field cultivated ahead of corn
- April 29, 2018: Corn planted (DeKalb 6434) at 38,0000 seeds/A with 20 lb of N/A as a combination of 2x2 and pop-up)
- May 2, 2018: Soybean planted (Credenz 3548) at 135,000 seeds/A
- May 29, 2018: Applied side-dress N (32% at 50 lbs of N/A); completed application of corn N rate trial
- Sept. 11, 2018: Stalk nitrate test in N rate trial
- Sept. 21, 2018: Corn harvested (271 bu/A), N rate trial harvested
- Sept. 23, 2018: Soybean harvested (86 bu/A)
- Oct. 24, 2018: Applied anhydrous ammonia at 125 lbs. N/acre (95 lbs. N/acre averaged over 25 acres); Set up N rate trial w/no N
- Oct. 30, 2018: Fertilizer applied (220 lbs. 0-46-0 and 200 lbs. 0-0-60) to corn stubble
- Oct. 30, 2018: Fertilizer applied (150 lbs. 0-46-0 and 200 lbs. 0-0-60) to soybean stubble

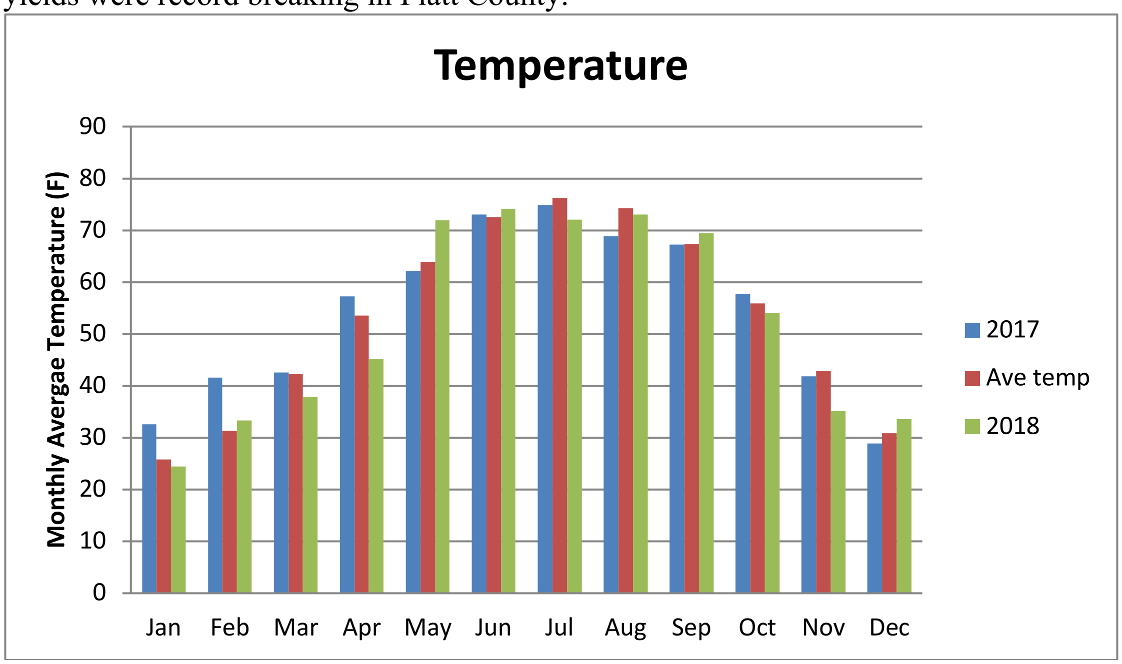
Field operations for Corn-Corn with and without cereal rye are listed in the NREC funded project entitled: Cereal rye ahead of corn (NREC #086302).

Results:

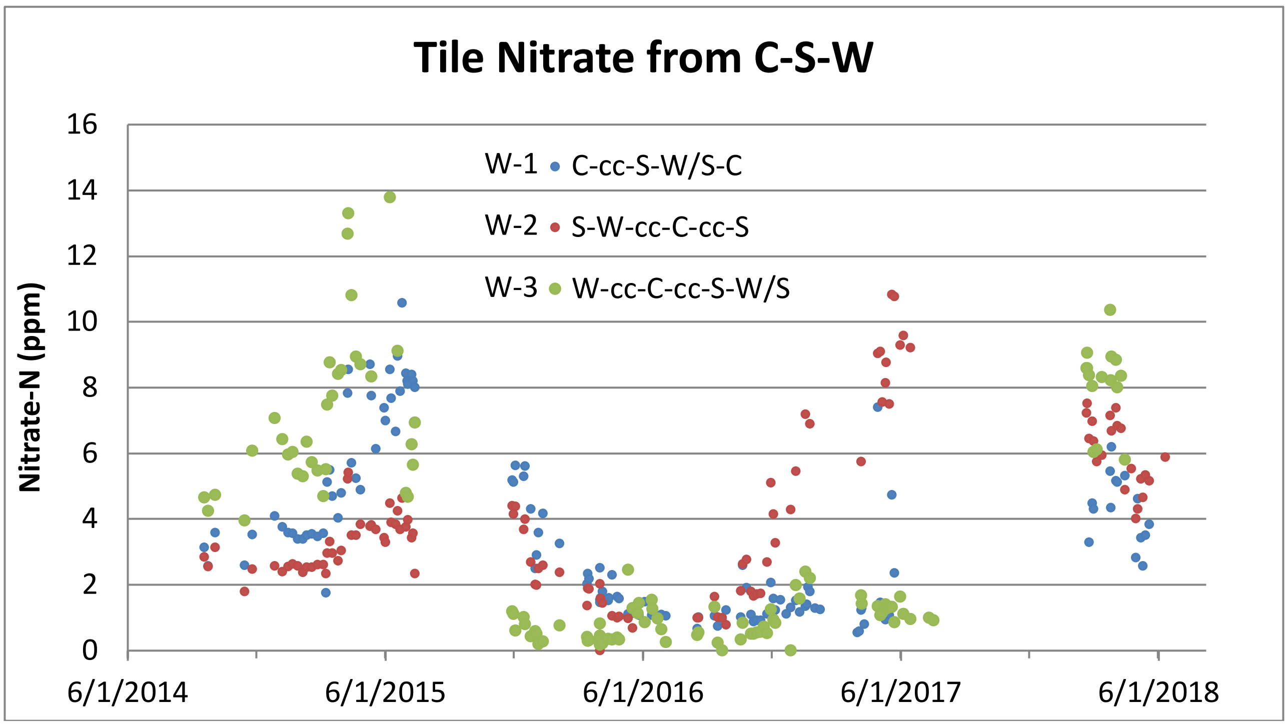
After a 15% shortfall in annual precipitation in 2017 at this site, total precipitation was nearly equal to the 30 yr average in 2018 with 38.6 inches. Although below average precipitation occurred in April and May of 2018, sufficient timely rains in June and July produced excellent crop yields.



The year of 2018 could be characterized as having a nearly opposite start to the crop growing season compared with 2017 (2017 was warm in the winter and early spring, but became cool after corn planting; whereas 2018 had the 2nd coldest April followed by the warmest May on record). Thus cover crop growth and biomass was lower in 2018 than in 2017, yet 2018 row crop yields were record breaking in Piatt County.



In the C-S-W rotation, crop yields were 265 bu/A for corn, 97 bu/A for soybean, 88 bu/A for wheat, and 52 bu/A for double cropped soybean. In the C-S rotation, corn yield was 271 bu/A and soybean yield was 86 bu/A. The corn and soybean yields were the highest ever attained in these fields and were the finest yields that I have ever witnessed from research fields of this size. There appears to be a yield advantage for soybean in the 3 yr rotation compared to the 2 yr rotation in 2018 (Table 1). Wheat yield was good, but high temperatures may have limited growth and overall production. However, high temperatures allowed the wheat grain to dry quickly and harvest to be completed by July 1. Eric Miller (landowner and farm operator) has decided that if he can harvest wheat and plant soybean before July 1, then he will plant double crop soybean; otherwise, he would have planted annual ryegrass and radish mixture after wheat and ahead of corn.



Tile nitrate concentrations varied across the 3 fields/cropping systems due to when fertilizer N was applied or when cover crops were grown in C-S-W. Fertilizer N was applied to corn and wheat phases of the rotation sequences (corn with 20 lbs/A starter and 160 lbs/A side-dress; wheat with 24 lbs/A in the fall and 100 lbs/A top-dress in March). When March was cold (2015 and 2018), we found more tile nitrate coming from wheat than when March was warm. This suggests that an actively growing wheat crop can reduce the potential for nitrate leaching after the spring top-dress.

Radish/turnip following wheat in 2015 reduced tile nitrate concentrations to <1 ppm for 4 months. Cereal rye after corn in 2015 reduced tile nitrate concentrations to<2 ppm. Red clover frost seeded into wheat in 2016 increased tile nitrate loss during the following winter. Growth of cereal rye following corn in 2017 was limited by cold spring temperatures, which led to a small reduction in tile nitrate load. Winter and spring temperatures were critical factors in cover crop growth, N uptake, and impact on tile nitrate.

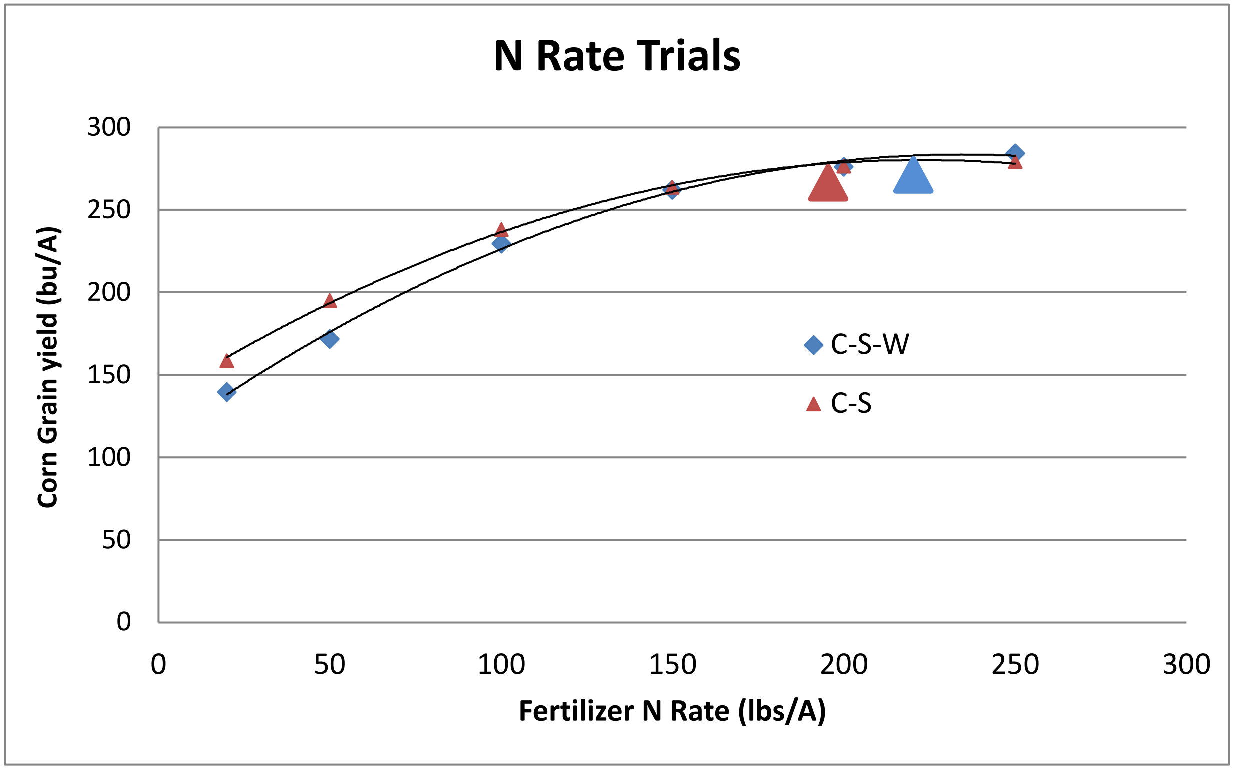
Table 1. Crop yield (bu/A) and tile nitrate (Flow-weighted mean nitrate-N concentration in ppm) for Corn-Soy-Wheat with cover crops vs. conventional Corn-Soy. Note: in 2017 and 2018, wheat was followed by double crop soybean in C-S-W. Cover crop code: CR=cereal rye, R/T = radish and turnip, and RC/CR = red clover followed by cereal rye.

Fields	2015	Cover	2016	Cover	2017	Cover	2018	Cover
W-1	**Corn**	**CR**	**Soy**	**-**	**Wheat/Soy**	**-**	**Corn**	**CR**
Yield	253		75		98/55		265	
Tile N	7.68		2.16		2.19		4.67	
W-2	**Soy**	**-**	**Wheat**	**RC/CR**	**Corn**	**CR**	**Soy**	**-**
Yield	83		101		259		97	
Tile N	3.76		2.27		7.48		6.71	
W-3	**Wheat**	**R/T**	**Corn**	**CR**	**Soy**	**-**	**Wheat/Soy**	**-**
Yield	77		206		80		88/52	
Tile N	7.33		0.76		1.17		8.63	
E-1			**Corn**	**-**	**Soy**	**-**	**Corn**	-
Yield			219		79		271	
Tile N			-		4.96		9.36	
E-2			**Soy**	**-**	**Corn**	**-**	**Soy**	
Yield			86		242		86	
Tile N			-		7.30		5.83	

The radish/turnip cover crop may have produced too much biomass with a wide C:N ratio, which tied up soil inorganic N and reduced the subsequent corn yield in 2016; however, the annual flow weighted nitrate-N concentration was as little as 0.76 ppm and remained low in 2017 (1.17 ppm) following cereal rye after corn (ahead of soybean). Soybean yield in C-S-W in 2017 was not reduced compared to conventionally grown soybean in C-S. Red clover after wheat coupled with fertilizer N on corn increased the flow weighted mean nitrate N concentration to 7.5 in 2017.

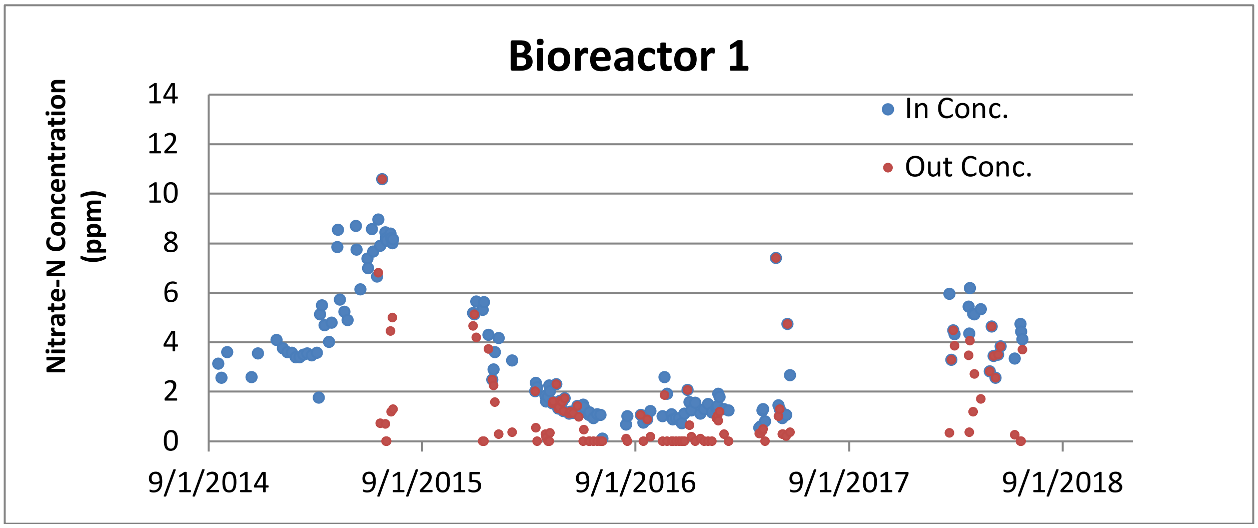
The system that has performed the best is located in Field W-1. During the setup year of 2015, the annual mean tile nitrate concentration was 7.7 ppm coming from corn in this field. Cereal rye reduced the nitrate concentration to 2.2 ppm in 2016 and the subsequent wheat crop did not add to the concentration, where it remained at 2.2 ppm for another year (2017). The 3 year flow weighted mean nitrate concentration for this system following the setup year was 2.6 ppm (3.7 ppm including the setup year). Compared to the recently proposed numeric criteria for total N (4 ppm) for IL, this farm demonstrates on a real world production field (75 A) a system that is in compliance today and could help us reach our goal of 45% reduction in N loss from the state. The conventionally grown C-S rotation did not meet the proposed nutrient criteria in 2017 or 2018 (Table 1).

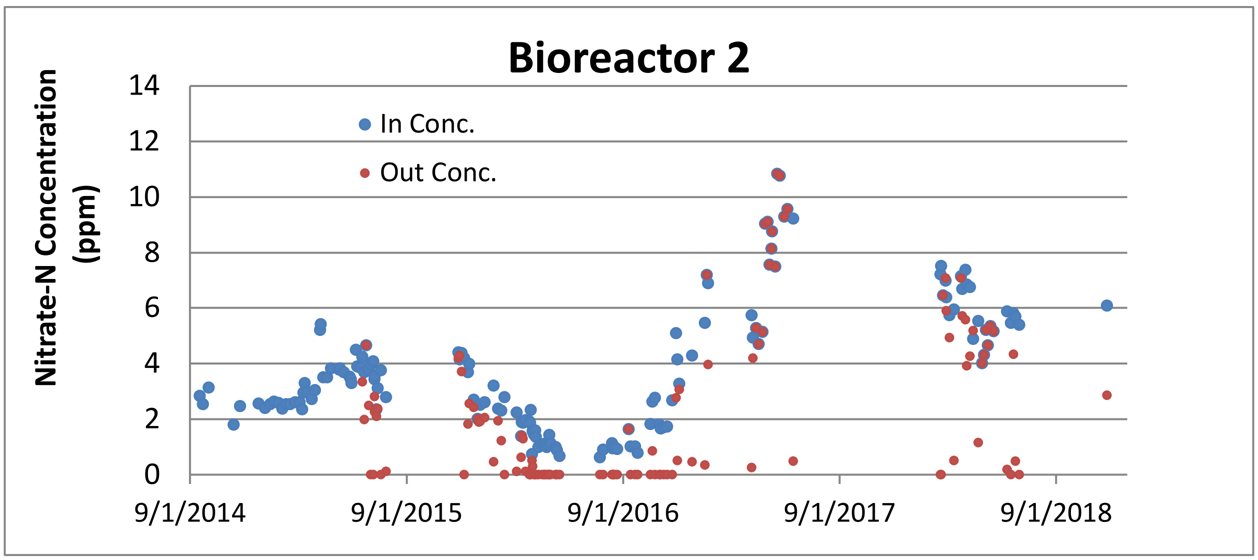
There have been two times when the conventionally managed crop in the 2 year rotation (Fields E-1 and E-2) has produced greater yield than the same crop in the 3 year rotation (corn in 2016 and soybean in 2016). More recently, on two occasions the crop in the 3 year rotation has produced greater yield than the 2 year rotation (corn in 2017; soybean in 2018). The wheat/double cropped soybean phase of the 3 year rotation has been more profitable than either corn or soybean alone. Eric Miller has met with Dr. Gary Schnitkey and a cost benefit analysis will be forthcoming. Also, Eric Miller has scored his fields using the S.T.A.R. survey and has entered his information into the Precision Conservation Management program led by Illinois Corn Growers Association for this evaluation as well.

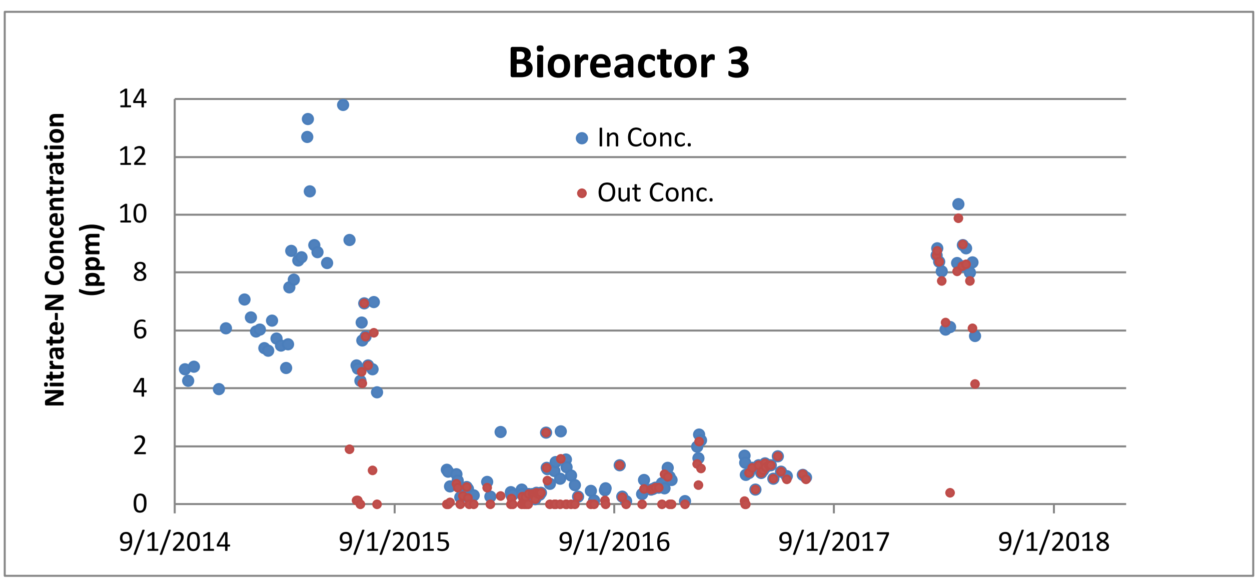


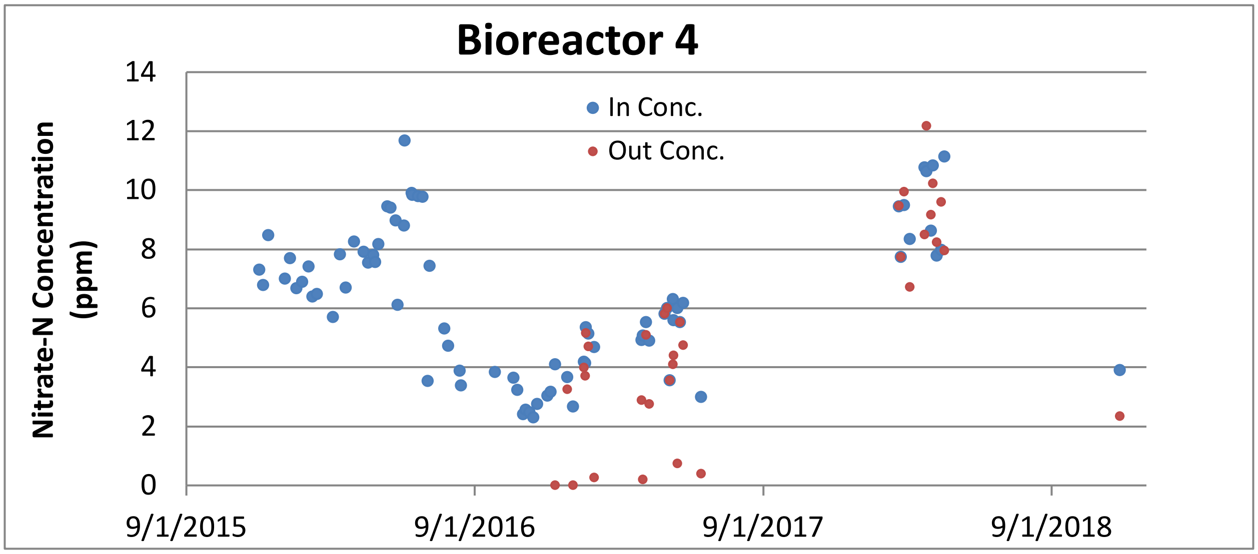
Corn N rate trials in the two rotational systems reached similar maximum yields (approx. 280 bu/A); however, the optimum N rate was 216 lbs/A for corn in C-S-W; whereas the optimum N rate for corn in C-S was 198 lbs/A. It is interesting to note that lower N rates produced less corn grain yields in C-S-W compared with C-S. Stalk nitrate test values showed that sufficient N was achieved at the 200 lbs/A N rate in C-S and at the 250 lbs/A N rate in C-S-W. Overall, these data indicate there was less plant available N in the 3 year rotation than in the 2 year rotation and may suggest that microbial immobilization is limiting nitrate leaching; reducing annual tile flow weighted mean nitrate concentrations (4.7 ppm C-S-W vs. 9.4 ppm for C-S) (Table 1). Field grain yield averages were similar between the two rotational systems (265 bu/A in C-S-W and 271 in C-S) and similar to the maximum yield in the N rate trials.

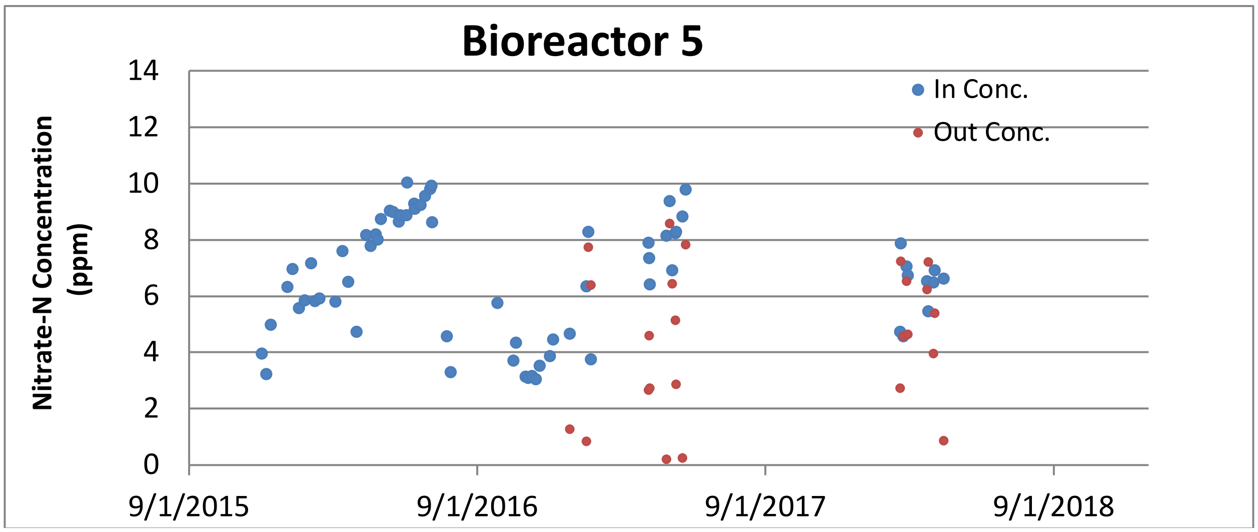
There are 6 woodchip bioreactors being evaluated on this farm. We measured flow rate in and out of the bioreactors as well as bypass flow (high flow events create bypass flow that exits the Agridrain structure untreated). Our full suite of water quality measurements (in and out) include: nitrate, ammonium, total N, dissolved phosphorus, total phosphorus, dissolved organic carbon, chloride, and sulfate. For bioreactors 1, 2, and 3, start time was June 19, 2015 and for bioreactors 4, 5, and 6, start time was Dec. 12, 2016. We have accumulated a sizable amount of bioreactor data (a total of 18 bioreactor/water years).

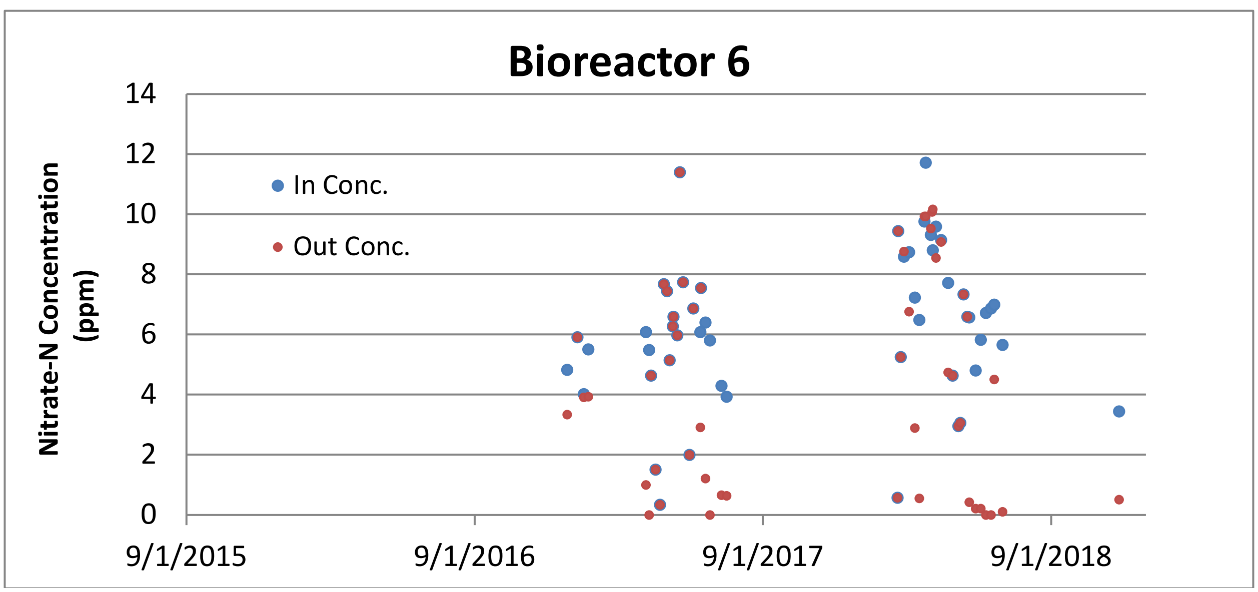

Bioreactor 1
Nitrate-N Concentration (ppm)
14
12
10
8
6
4
2
0
9/1/2014
9/1/2015
9/1/2016
9/1/2017
9/1/2018
In Conc.
Out Conc.


Bioreactor 2
Nitrate-N Concentration (ppm)
14
12
10
8
6
4
2
0
9/1/2014
9/1/2015
9/1/2016
9/1/2017
9/1/2018
In Conc.
Out Conc.


Bioreactor 3
Nitrate-N Concentration (ppm)
14
12
10
8
6
4
2
0
9/1/2014
9/1/2015
9/1/2016
9/1/2017
9/1/2018
In Conc.
Out Conc.


Bioreactor 4
Nitrate-N Concentration (ppm)
In Conc.
Out Conc.
0
2
4
6
8
10
12
14
9/1/2015
9/1/2016
9/1/2017
9/1/2018


Bioreactor 5
Nitrate-N Concentration (ppm)
In Conc.
Out Conc.
0
2
4
6
8
10
12
14
9/1/2015
9/1/2016
9/1/2017
9/1/2018


Bioreactor 6
Nitrate-N Concentration (ppm)
In Conc.
Out Conc.
0
2
4
6
8
10
12
14
9/1/2015
9/1/2016
9/1/2017
9/1/2018

The graphs on the two previous pages of this report are the nitrate-N concentrations that entered (In Conc.) and exited (Out Conc.) the Agridrain structure at each of the 6 woodchip bioreactors. The greater the spread between the blue and red dots on a given day suggests greater nitrate removal. However, there are numerous days when nitrate entering the structure was similar to nitrate exiting the structure; indicating high flow events with bypass flow, especially in the winter when tile water is cold. In addition, there are periods of time in the spring and fall when stoplogs are removed to allow field work and all tile flow bypasses the woodchips. In general, low tile-water temperatures limit nitrate removal rates in the winter and spring; therefore, there is a tradeoff between residence time (which can improve removal rates) and bypass flow.

During the past four years, a total of 566 lbs of nitrate was removed (2845 lb in and 2278 lbs out) by bioreactors 1, 2, and 3 from 205 acres. On a per area basis, nitrate removal ranged from 0.2 to 1.4 lbs/A/yr with an average removal of 0.70 lbs/A/yr. Bioreactors receiving tile water from the C-S-W rotation may have been nitrate limited in some years by low tile nitrate concentrations as tile nitrate loads were greatly reduced by adding wheat and cover crops into the rotation. Overall, bioreactors 1, 2, and 3 removed 20% of the tile nitrate.

During the past two years, a total of 74 lbs of nitrate was removed (834 lbs in and 760 lbs out) by bioreactors 4, 5, and 6 from 56 acres. On a per area basis, nitrate removal ranged from 0.1 to 2.0 lbs/A/yr with an average removal of 0.66 lbs/A/yr. Overall, bioreactors 4, 5, and 6 removed 9% of the tile nitrate load. The percent nitrate removal is lower for bioreactors on the east side of the ditch as those tiles originating in C-S and C-C production systems transport greater nitrate concentrations and loads than tiles in C-S-W.

In the first year of operation, bioreactors were net producers of dissolved organic carbon (DOC) and dissolved P (data not shown). The export of DOC from the woodchips suggests that there was greater available C for the microbes in the first year and might explain why removal rates were best in year 1. In addition, we observed sulfate reduction in the first year after nitrate concentrations dropped below detection limits of 0.1 ppm in July of 2015. When bacteria do not have sufficient oxygen, they switch to another electron acceptor, such as nitrate; and when nitrate is used up they switch to sulfate, and then finally carbon dioxide. Bioreactors are not designed to run out of nitrate and the reduction of sulfate indicates that tile nitrate concentrations were too low. Again, tile nitrate was low due to the tightening of the N cycle under the C-S-W system with cove crops.

This type of bioreactor with only one Agridrain structure (unlike a flow through bioreactor with two Agridrain structures) was designed to combine a bioreactor with drainage water management; increasing the height of the water table in the field. During the fallow period of a given field, stoplog settings maintain approximately 2 feet of water in the woodchips and this back pressure on the tile retains a portion of the tile flow in the field. The upstream diversion stoplogs can hold back another foot of water (for a total of 3 feet of back pressure) before bypass flow occurs and untreated tile water is shunted to the ditch. Our preliminary estimate is that annual tile flow is decreased by approximately 30% due to drainage water management. We are investigating the fate of this retained water by measuring ground water heights and nitrate concentrations in wells in the fields and around the bioreactors. We continue to work with the NRCS state agricultural engineer (Ruth Book) and follow NRCS guidelines for stoplog management during the fallow season as well as during the cropping season. We will meet with her soon to discuss all of our bioreactor data and future direction. It is possible that our woodchips consist of too many hard wood species and is therefore too recalcitrant; restricting metabolic activity of the bacteria. We may want to try a new media such as a combination of woodchips and corn cobs.

Summary

First, I would like to state that working with Eric Miller (owner and operator) and Dan Schaefer (IFCA) on this study is a pleasure. Eric and Dan keep this experiment on track with field work conducted in a timely manner. I greatly value their insights and enjoy regularly meeting with them to discuss immediate and longer term plans.

Overall, tile nitrate losses are very low coming from C-S-W with cover crops. It is clear that the longer rotation and the presence of cover crops limit nitrate losses as compared with the control treatment (corn-soybean). Wheat in the rotation has a dramatic effect on reducing tile nitrate loss as well as it takes up mineralized N following soybean.

Finally, we are pleased to show that tile nitrate from the C-S-W rotation with cereal rye after corn and double cropped soybean can achieve the proposed nutrient criteria for nitrate of 4 ppm over the past 4 years. It is also worth noting that we didn't have to resort to growing only perennials (i.e. prairie plants or miscanthus) to accomplish this level of reduction in N loss. **Our current research documents the dramatic reduction in tile nitrate concentration and load that is possible under row crop agricultural production.**

Bioreactor performance is below our expectations and less than what has been reported in popular press and journal articles. However, the combination of bioreactor and DWM at this site has reduced tile flow by approximately 30% and therefore reduced tile nutrient load by the same percentage. It is possible that DWM has provided greater nutrient reduction than the bioreactors. It is also possible that DWM has limited tile flow during the warmer months and thus deprived the bioreactor of nitrate that would have been removed via denitrification in the woodchips; decreasing bioreactor performance. I look forward to sharing and discussing this data with experts from NRCS, ABE, and Crop Science in the coming months and then will submit a recommendation and plan of action to the NREC board members for their consideration.

Outreach

In 2018, Mr. Gentry was invited to present results from this study (and the Douglas County Study) at 16 events including: Illinois Fertilizer and Chemical Association Conference on January 16; Illinois Farm Bureau Winter Conservation Workshop on January 17; Illinois Association of Drainage Districts Conference on January 18; Conservation Cropping Seminar Series on January 23, 24, and 25; Central Illinois Professional Wastewater Operators Winter Meeting on January 31; Central States Water Environment Association 2018 Government Affairs Seminar held jointly with AWA Mini Conference on February 28; Illinois Chapter of the Soil and Water Conservation Society on March 16; Risk Management Conference hosted by the

Illinois Sustainable Ag Partnership on June 19; webinar (Partnership for Ag Resource Management) on August 9; webinar (Illinois Soybean Association) on August 21; IL 4R Field Day on October 23; American Society of Agronomy annual meeting on November 6; poster at IL NLRS workshop on November 13; and IL Certified Crop Advisor conference on December 12.

2018 Project Budget (Jan.1 through Dec. 31)

B8487: 1-508744-875000-191100 (NREC agreement 2015-02539):

Personnel:	**Salary**	**Fringe benefits**
Administrative/professional	$70,398.56	$26,693.12
Total personnel	$70,398.56	
Total fringe benefits	26,693.12	
Travel (domestic)	11,233.00	
Supplies	6,838.86	
Contractual services	(7,545.39)	
Facilities and administration	11,945.59	
Tuition		
Total expenditures	$119,563.74	

We believe this study demonstrates the potential to greatly decrease nitrate loss from production agriculture and that long lag times do not exist for improving water quality (at least not for nitrate). The combination of a longer rotation with cover crops and a bioreactor can nearly eliminate nitrate loss via tile drainage, hower, we must carefully document any agronomic and economic disadvantages these systems impart to the producer before making recommendations at this time. With the assistance of Dr. Gary Schnitkey, we will conduct a thorough economic evaluation of both the 3 year rotation vs. the two year rotation. We thank NREC for their continued support of this research.