4Rs of nitrogen management and cover crops for reducing nitrate-N losses

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Introduction

Much of the U.S. Corn Belt is characterized by relative flat, poorly-drained areas which with extensive subsurface drainage, have become some of the most valuable and productive agricultural land in the world. However, this is not without consequences. Nitrate-N loss from these systems is of particular concern due to its potential adverse impacts on both public health and ecosystem function. In addition to the potential local impacts on receiving waters in the Corn Belt, nitrogen loads from the region are suspected as a primary contributor to hypoxia in the Gulf of Mexico. For nearly 30 years Iowa State University has been studying the impacts of nitrogen and land management practices on drainage water quality at a variety of sites throughout the state (Figure 1).

Currently, there is a concerted effort from industry, universities, and state and federal action agencies to promote the 4R nutrient management approach on-farm– considering the Right source, Right rate, Right time, and Right place– for managing nutrient additions from commercial fertilizer and organic materials (http://www.nutrientstewardship.com/). The drainage water quality information collected at various sites throughout Iowa have provided important information on the impacts of 4R Nitrogen Management on drainage water quality. A short description of the sites and main findings to date from these sites are provided below. In addition, more complete discussion of recent results from NWRF where various nitrogen management practices are being studied are included.

Drainage water quality research Sites

Gilmore City Research Facility/Ag Drainage Well (ADW) - Research focused on the effects of nitrogen (N) management on crop production and tile drainage water quality has been conducted in north-central Iowa near Gilmore City since 1989. The research farm (ADW) includes 72 individually drained plots that are 50 ft. wide and 125 ft. long. Tile lines were installed with 3.5 ft depth and 25 ft spacing. The center tile line from each plot is pump monitored continuously for drainage volume with a flow meter and a flow-proportional sample is passively collected for nitrate-nitrogen (nitrate-N) and dissolved-phosphorus (P) analysis. Drainage flow is recorded and water samples are collected for analysis weekly. Soil types at ADW include Nicollet, Webster and Canisteo, all of which are clay loams. The 30-year average annual rainfall for ADW is 33.5 inches. At ADW, multiple management practices including cover crops, tillage, land use, and N-fertilizer source/rate/timing have been examined for their impact on N and P loss and crop yield.

Drainage Water Quality Impacts of Various In-field Nutrient Management Practices: Northeast Research and Demonstration Farm (NERF) - NERF has 36 1-acre research plots equipped with a drainage water monitoring system installed in 1988. Plots have 1 to 4% slope with Kenyon, Floyd, and Readlyn soils. Tile lines are installed at a depth of four ft. spaced 95 ft. apart. Management practices are evaluated for their impact on nitrate-N and dissolved phosphorus (P) loss and crop yield. To quantify the impact of these practices, researchers are monitoring subsurface drainage volume and collecting flow-proportional water samples for nitrate-N and dissolved P analysis. The 30-year average annual rainfall for NERF is 29.7 inches. At NERF, multiple management practices have been examined for their impact on N and P loss and crop yield. The cropping systems studied include continuous corn, corn-soybean rotations, and extended corn-oats-alfalfa rotation (1993-1998). Management practices studied include rye cover crop, tillage/no-till, swine manure/urea ammonium nitrate (UAN), varied N application rates and timing, stover removal, and nitrification inhibitor. Current treatments are examining perennial ground cover and early seeding of cover crops.

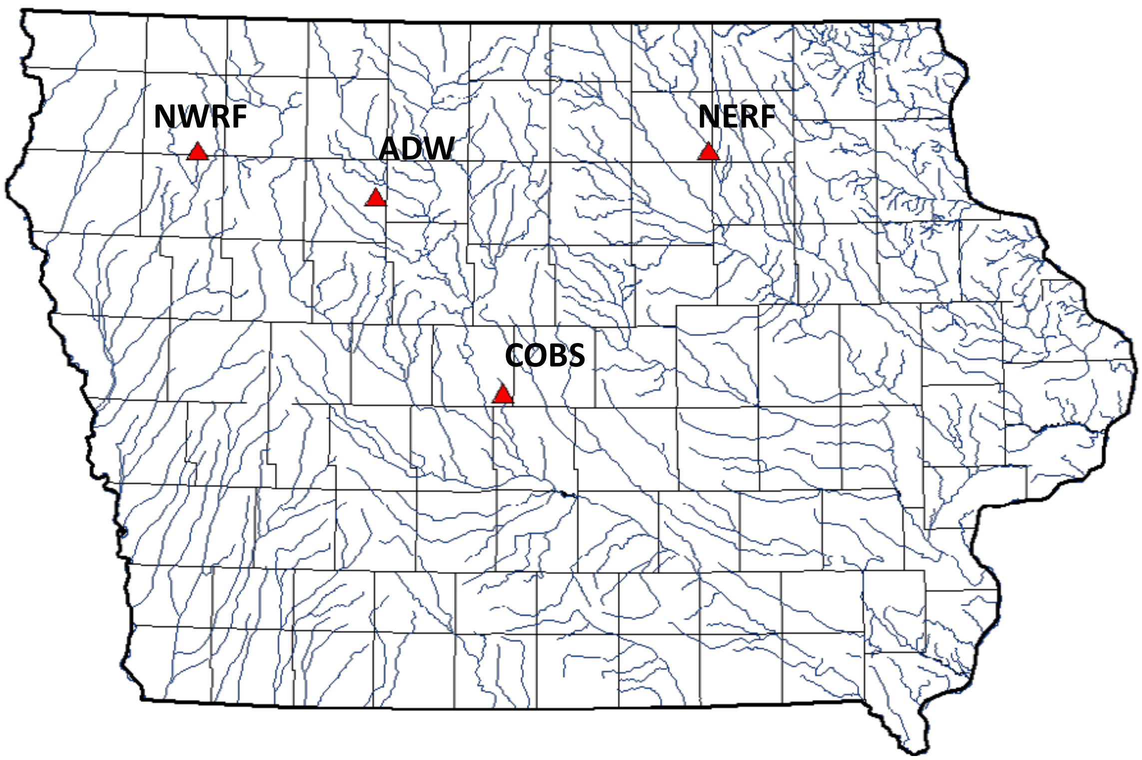

Figure 1. Location of Drainage Water Quality Research Facilities

Drainage Water Quality Impacts of Various In-field Nutrient Management Practices: Comparison of Biofuel Systems (COBS) site - The COBS site has 24 0.4-acre research plots equipped with a drainage water monitoring system installed in 2008. Plots have <1% slope with Nicollet and Webster soils. Tile lines are installed at a depth of 3.5 ft. spaced 45 ft. apart. Management practices are evaluated for their impact on nitrate-N and dissolved phosphorus (P) loss and crop yield. To quantify the impact of these practices, researchers are monitoring subsurface drainage volume and collecting flow-proportional water samples for nitrate-N and dissolved P analysis. The 30-year average annual rainfall at COBS is 35.8 inches. At COBS, multiple management practices including continuous corn, corn-soybean rotations, and perennial prairie have been examined for their impact on N and P loss and crop yield:

Drainage Water Quality Impacts of Various In-field Nutrient Management Practices: Northwest Iowa Research Farm (NWRF) - NWRF is located near Sutherland, Iowa. Drainage research on the impacts of 4R N-management on crop production and nitrate-nitrogen (nitrate-N) loss began in 2015. The site includes 32 individually subsurface drained plots. Tiles were installed in 2013 with 3.5 ft depth and 80 ft spacing. The center tile line from each plot is pumped and monitored continuously for drainage volume with a flow meter. A flow-proportional sample is passively collected and subsamples are taken for nitrate-N, total-phosphorus (P) and total-reactive-phosphorus analysis. Soils are predominantly Marcus, Primghar and Galva, all silty clay loams. The 30-yr average annual precipitation at NWRF is 30.7 inches. At NWRF, 4R N-management practices including fall N-application with inhibitor, spring application, split N-application and no N-fertilizer application are examined for their impact on drainage N and P loss and crop yield.

Main findings

ADW

- When N-fertilizer is applied at economic N-rates, the average concentration of nitrate-N in tile drainage ranged from 12 to 16 mg/L (drinking water standard is 10 mg/L).
- When similar N-application rates to corn are used in 1) a corn-soybean rotation and 2) a continuous corn rotation, similar nitrate-N concentrations are observed in the tile drainage. When an additional 50 lbs-N/acre are applied to continuous corn, however, nitrate-N concentrations are about 25% greater than the corn-soybean system.
- Over the long-term, approximately 10 in. of the annual (30 in.) precipitation exited through the tile drains. This resulted in an average nitrate-N loss of approximately 36 lb/acre through the drainage system with a 150-160 lb/acre N-fertilization rate to corn in a corn-soybean rotation. Due to weather conditions, the annual N-loss at this application rate varied from 0.9 lb/acre to 94 lb/acre over the period from 1990-2016.
- For a corn–soybean rotation with no N-fertilizer applied there was still 15–20 lb-N/acre lost through tile drains at nitrate-N concentrations of 6–8 mg/L.
- In general, concentration of nitrate in the tile drainage was similar for the corn and soybean phases of the corn-soybean rotation.
- During the sixteen years that timing of fertilizer application was studied, there was little difference in the concentration or loss of nitrate between spring- and fall-applied N fertilizers.
- Use of a cover crop has the potential to reduce nitrate-N concentration in drainage water.
- Perennial land use has the potential to dramatically reduce nitrate-N concentrations in drainage water.
- The use of poly-coated urea as a source of nitrogen fertilizer showed some potential to reduce nitrate concentrations in subsurface drainage.

NERF

- Corn-soybean-oat strip crop and alfalfa forage systems resulted in the lowest nitrate-N concentrations (<10 mg/L) in subsurface drainage water in comparison to other practices evaluated at this site from 1993-1998.
- Continuous corn systems required higher input of N fertilizers and resulted in significantly higher nitrate-N leaching losses compared to corn-soybean rotations fertilized with manure or urea ammonium nitrate (UAN).
- Over a 15 year period, fall manure applied to both corn and soybeans resulted in significantly higher nitrate-N concentrations than fall manure on corn only in a corn-soybean rotation (31 vs 19 mg/L).
- A cereal rye cover crop significantly reduced nitrate-N concentrations in drainage water compared to a similar treatment without a cover crop (10 mg/L with cover crop vs 14 mg/L without cover crop).
- An 8-year study found minimal difference in dissolved P concentrations in drainage water from six different management systems, with total losses less than 0.03 lb/acre·yr from all systems.
- Stover removal in a continuous corn system had no significant impact on nitate-N or dissolved P levels in drainage water.
- Chisel plowed and no-till plots had similar overall nitrate-N concentrations and total N losses via subsurface drainage water.

COBS

- Flow-weighted nitrate-N concentrations were 0.1, 0.6, 9.3, 10.4, 13.1, and 13.2 mg/L for prairie, fertilized prairie, continuous corn with cover crop, corn, soybeans, and continuous corn, respectively.
- Annual nitrate-N loads averaged over seven years were 0.6, 0.8, 12.1, 15.7, 18.3, and 22.3 lb/acre for prairie, fertilized prairie, continuous corn with cover crop, continuous corn, soybeans, and corn, respectively.
- Despite higher nitrogen application in the continuous corn with cover crop treatment (176 lb N/acre 7-year average), the nitrate-N loss was less than under the continuous corn with no cover crop (162 lb N/acre 7-year average).

Recent results from NWRF

Except for the early fall 2014 freezing conditions, which prevented fall anhydrous ammonia application (completed early spring 2015), agronomic operations were completed in a timely manner each year (Table 1). The 2015 year was characterized by greater than normal precipitation in late summer and fall, as well as a greater yearly precipitation than the 30-yr average (Cherokee, IA weather station about 10 miles south of the project site) (Table 2). The 2016 crop year also had more than the 30-yr average precipitation, with noticeably greater precipitation in April and September which resulted in >10 inches of average annual drainage. The April precipitation delayed planting in 2016. The 2017 crop year had near normal precipitation in April and May, but much less than normal precipitation the rest of the year which resulted in <4 inches of drainage on average. Precipitation in 2018 was above normal in May, June, and September with the total being 5 inches above normal for the year. The wettest year of the study was 2019 with 10 inches above normal precipitation and most came from May to September. Precipitation in 2020 was well below normal after May.

In 2015, there was a 40 bushels/acre corn yield increase with N application in Treatments 1–3 as compared with Treatment 4 where no N was applied (Table 3). In 2016, the corn yield increase with N application was greater than 50 bushels/acre. During both 2015 and 2016, no statistically significant corn yield differences were observed between the treatments where N was applied. In 2017, corn yield increase with Treatments 1 and 2 compared with no N application was more than 75 bushels/acre. Also, in 2017, there was a lower corn yield with the split N application compared with fall and spring ammonia timing. This was likely due to the limited precipitation after the sidedress N application and dry summer conditions (dry surface soil), which limited N movement into the soil and active corn root zone. In 2018, the split N application was timely with over an inch of precipitation a day after application. There was no statistically significant difference between the N application treatments in 2018, but all were significantly different compared with no N applied. In 2019 and 2020, there were no differences among N treatments, and they were all >50 bushels/acre greater than the no N treatment. There were no statistical differences among the soybean yields in 2015, which would be expected based on the uniform previous site history, no treatments applied to soybean, and no prior-year N applications to corn. Soybean yields in 2016 were greater than 70 bushels/acre for all treatments and greater than 60 bushels/acre in 2017. In 2018, soybean yield had very little variability in treatments and were 70–72 bushels/acre. Soybean yield for 2019 was not different among treatments, but all were between 58 and 63 bushels/acre. In 2020, soybean yield was significantly lower in the no N treatment.

Annual flow-weighted nitrate concentration was statistically similar whether N fertilizer was applied in the fall with inhibitor or in the spring in all years (Table 4). The split N treatment had statistically lower nitrate-N concentrations on average than either the fall N or spring N treatment. The six year average nitrate-N concentration from the no N treatment was only about 30% lower than the fall N or spring N treatment. Annual nitrate load was lowest in 2017 from all plots due to low drainage in the dry year

(Table 4). There were not many differences among treatments in nitrate-N load due to high plot to plot flow variability.

Table 1. Dates of field operations for corn.

Crop year	2015	2016	2017	2018	2019	2020
Fall NH_3 + N-Serve application	4/1/2015	11/10/2015	11/16/2016	11/6/2017	11/16/2018	11/1/2019
Spring NH_3 application	4/4/2015	4/12/2016	4/12/2017	4/26/2018	4/22/2019	4/1/2020
Planting date	5/4/2015	5/19/2016	5/6/2017	5/9/2018	5/2/2019	5/7/2020
Urea starter banded at planting	5/4/2015	5/19/2016	5/6/2017	5/9/2018	5/2/2019	5/7/2020
Agrotain treated urea sidedress	7/9/2015	7/14/2016	7/6/2017	7/3/2018	7/15/2019	7/8/2020
Harvest	10/13/2015	10/29/2016	10/24/2017	10/4/2018	10/16/2019	10/7/2020
Sulfur application		11/3/2016				
Planting population (seeds/acre)	34,000	34,000	35,077	35,077	35,077	35,077
Corn hybrid	Pioneer P0453	AgriGold 6267VT2RIB	Pioneer P0157AMX	Legend 9701	Wyfells W2506RIB	Wyfells W2506RIB

Table 2. Monthly precipitation from 2015 to 2020.

	Precipitation (in)						30-yr Avg. Precip. at Cherokee, IA (in)
Month	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
Jan	0.1	0.2	1.0	0.7	0.1	0.0	0.6
Feb	0.0	0.4	0.8	0.8	2.0	0.0	0.6
Mar	0.6	2.1	1.4	2.0	3.2	2.5	1.9
Apr	3.1	5.2	3.2	1.5	3.5	0.7	3.1
May	3.5	3.5	3.0	4.4	6.7	4.1	3.9
Jun	2.6	1.8	1.9	6.3	4.2	3.6	5.0
Jul	6.8	3.9	1.3	3.1	6.6	1.4	3.9
Aug	6.1	3.2	4.3	4.2	3.2	1.3	3.7
Sep	2.8	7.5	2.3	8.2	4.7	1.0	3.5
Oct	1.9	3.5	3.3	2.1	4.0	1.2	2.1
Nov	4.9	1.8	0.2	1.2	1.6	1.4	1.5
Dec	1.8	1.0	0.2	1.5	1.3	0.0	0.9
Total	**34.1**	**34.0**	**22.9**	**36.0**	**41.0**	**17.1**	**30.7**

Table 3. Corn and soybean yields for 2015 - 2020 (bu/acre).

Nitrogen Management for Corn	Corn					
	2015[a]	2016	2017	2018	2019	2020
Fall NH_3 (with inhibitor)	221a[b]	198a	203a	200a	214a	229a
Spring NH_3 (no inhibitor)	223a	200a	203a	195a	216a	231a
Split N	224a	196a	181b	205a	207a	220a
None	183b	141b	125c	107b	137b	171b

Nitrogen Management for Corn	Soybean					
	2015	2016	2017	2018	2019	2020
Fall NH_3 (with inhibitor)	62	74	62	70	58	69a
Spring NH_3 (no inhibitor)	64	75	67	71	62	67a
Split N	64	72	66	70	59	66ab
None	61	74	64	72	63	59b

[a] Early fall 2014 freezing conditions prevented fall anhydrous ammonia application (completed early spring 2015).

[b] Means with the same letter in the same column are not significantly different, P=0.05. There were no significant differences among soybean yields.

Yields are reported at 15.5% moisture for corn and 13% moisture for soybean.

Table 4. Annual Nitrate-N concentration and load (lb/acre) from 2015 to 2020.

		Flow-weighted NO_3-N concentration ($mg\ L^{-1}$)				Nitrate-N Loss ($lb\ ac^{-1}$)			
		Fall	Spring	Split	None	Fall	Spring	Split	None
Corn[a]	2015	16.1a[b]	15.5ab	11.9bc	9.2c	21.8a	17.4a	16.2a	11.6a
	2016	12.9a	12.8a	10.4b	10.0b	15.8a	20.5a	22.0a	22.0a
	2017	13.0a	13.5a	9.6b	11.6ab	6.0a	2.6a	4.3a	3.8a
	2018	11.4a	9.6b	9.7b	7.0c	13.7a	16.3a	8.3a	13.9a
	2019	10.5a	10.2a	8.1b	8.9ab	14.5a	10.4a	12.9a	3.9a
	2020	8.4a	9.1a	9.7a	7.4a	1.1a	1.4a	0.9a	1.1a
	All[c]	12.0a	11.7a	9.9b	9.0b	11.2a	10.2a	9.3a	8.2a
Soybeans[d]	2015	12.7a	13.4a	12.2a	12.4a	9.5b	13.8ab	13.2ab	16.2a
	2016	13.8a	13.9a	11.1b	9.2c	34.4a	28.7a	29.0a	16.4a
	2017	8.4ab	12.1a	8.5ab	5.6b	1.8a	2.9a	1.9a	1.7a
	2018	11.4a	11.2a	8.6b	6.5c	26.6a	19.0a	20.4a	10.4a
	2019	10.4a	9.0a	10.4a	5.7b	7.2a	8.7a	6.3a	6.3a
	2020	11.5a	10.9a	10.1ab	7.9b	2.7a	1.2a	2.6a	1.3a
	All	11.3ab	11.7a	10.1b	7.7c	10.8a	10.2a	10.1a	7.3a
Corn and soybeans	2015	14.3a	14.5a	12.0ab	10.7b	7.0a	7.3a	6.7a	6.2a
	2016	13.4a	13.4a	10.8b	9.6b	24.2a	24.5a	23.8a	19.1a
	2017	10.6ab	12.8a	9.1b	8.3b	1.4a	0.9a	1.1a	0.9a
	2018	11.5a	10.4ab	9.2b	6.7c	19.6a	17.6a	13.7a	12.1a
	2019	10.4a	9.5ab	9.2ab	7.2b	5.9a	5.2a	5.0a	2.6a
	2020	9.9a	10.0a	9.9a	7.6a	1.8a	1.3a	1.6a	1.2a
	All	11.7a	11.7a	10.0b	8.3c	11.1a	10.3ab	9.7ab	7.8b

[a] Corn year is the calendar year when corn is planted and harvested. Fall N fertilizer is applied the November before.

[b] Response variables within the same year (row) and crop with the same letter are not statistically different at the 0.05 probability level.

[c] Average loading and FWANC over 6 years

[d] Soybean year is the calendar year when soybean is planted and harvested. No fertilizer is applied to soybeans, but in November of the soybean year, Fall-N is applied for the following corn crop.

Additional resources

Additional information about the studies described above are available for download through the Iowa State University Extension and Outreach Extension Store. The titles and publication numbers are listed below.

- Agricultural Drainage Research and Demonstration Site – Gilmore City – AE 3614
- Comparison of Biofuel Systems Site – AE 3615
- Northeast Research and Demonstration Farm – AE 3616
- Northwest Research and Demonstration Farm – AE 3617