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Annual Report for Crop Year 2005 and 2006

Water and Nutrient Research: In-field and Offsite Strategies

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Annual Report

Water and Nutrient Research: In-field Strategies

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NUTRIENT AND WATER MANAGEMENT PROJECT 2005-2009

Much of Iowa is characterized by relatively flat, poorly-drained soils which, with extensive artificial subsurface drainage, have became some of the most valuable, productive lands in the state. In 2002, the average land value for the 22-county area making up most of the Des Moines Lobe was $2,436 an acre, and 80.5% of that area was in row-crops (42.9% in corn and 37.6% soybeans). However, this drained land has also become a source of significant NO_3 loss because of the changes in land-use and hydrology brought about by tile drainage. While surface runoff is decreased with subsurface drainage (resulting in decreased losses of sediment, ammonium-nitrogen, phosphorus, pesticides and micro-organisms), subsurface flow and leaching losses of NO_3 are increased. This is due mostly to an increase in volume and the “short-circuiting” of subsurface flow, but also in part to the increased aeration of organic-rich soils with potentially increased mineralization and formation of NO_3 (and less denitrification) in the soil profile.

The problem of excess nutrient loads can probably be ameliorated by a combination of in field and off site practices, but the limitations and appropriateness of alternative practices must be understood and outcomes must be measurable. Promising in field practices include nutrient management, drainage management, and alternative cropping systems. Nitrate-removal wetlands are a proven edge-of-field practice for reducing nitrate loads to downstream water bodies and are a particularly promising approach in tile drained landscapes. Strategies are needed that can achieve measurable and predictable reductions in the export of nutrients from tile drained landscapes. The principal objectives of this project are (1) to evaluate the performance of nutrient management, drainage management, and alternative cropping systems with respect to profitability and export of water and nutrients (nitrate-nitrogen and total phosphorus) from tile drained systems and (2) to evaluate the performance of nitrate-removal wetlands in reducing nitrate export from tile drained systems.

This annual report describes activities related to objectives 1 and 2 along with outreach activities that were directly related to this project. For objective 1, both crop year 2005 and 2006 are presented.

Gilmore City Project Site

Treatments
The specific treatments investigated at the Gilmore City Research Facility (GCRF) are listed in Table 1. All treatments except the harvestable perennials consist of eight plots with four in soybeans and four in corn each year. The harvestable perennials each have four plots. The harvestable perennials were investigated during the winter of 2004 and planted in spring 2005 after discussion with the investigators and Iowa Department of Agriculture and Land Stewardship (IDALS) personnel.

Table 1. Treatments at the Gilmore City Research Facility for Crop Years 2005-2009.

Treatment Number*	Treatment	Nitrogen Application Time	Nitrogen Application Rate (lb/acre)
1,2	Conventional tillage	Fall	75
3,4	Conventional tillage	Fall	125
5,6	Conventional tillage	Spring (early season sidedress)	75
7,8	Conventional tillage	Spring (early season sidedress)	125
9,10	Conventional tillage	Spring (early season sidedress)	150
11,12	Strip tillage	Spring (early season sidedress)	125
13,14	Cover crops after harvest	Spring (early season sidedress)	125
15,16	LCD every other row application	Spring (early season sidedress)	125
17	Kura clover	-	no fertilizer
18	Orchardgrass + Red/Ladino clover	-	no fertilizer

* within the corn and soybean rotation treatments, even numbers are soybean and receive no nitrogen.

The treatments included allow for varied comparisons as follows:

- Timing of nitrogen application (treatments 1,2 and 3,4 vs. 5,6 and 7,8)
- Rate of nitrogen application (treatments 1,2 vs. 3,4 and 5,6 vs. 7,8 vs. 9,10)
- Method of nitrogen application (treatments 7,8 vs. 15,16)
- Potential impacts of tillage (treatments 7,8 vs. 11,12)
- Cropping practices through the use of a winter cover crop (treatments 7,8 vs. 13,14)
- Impacts of complete conversion to perennial vegetation (treatments 17 and 18 vs. other treatments)

These treatments allow for comparison of existing questions related to lower rates of nitrogen application and the potential impacts of fall nitrogen fertilizer application. Additionally, the LCD method of application is being investigated to determine if this application method can reduce nitrate leaching. Inclusion of the strip tillage system will investigate and demonstrate a minimal tillage system and assess its impacts on crop yield and nitrate leaching. Inclusion of cover crops and harvestable perennials allows for evaluating alternative cropping practices and the impact on nutrient movement and drainage. Evaluation of these alternatives is important for considering progressive methods for minimizing nutrient transport from tile-drained landscapes. The concentration and loading of nutrients exiting the various treatments will be monitored and evaluated on an annual basis and for the five year study period, 2005-2009. In addition, crop yield will be documented each year to evaluate treatment effects on yield, specifically whether there are declines in annual yield at the lower nitrogen rate applications. The evaluation of the treatment effects will be for the study period but each year will be analyzed to evaluate treatment effects on a yearly basis and after the completion of this phase of the research study. It is understood that climatic variability plays a significant role in the leaching of nutrients in the tile drained landscape.

From this, it is important to have numerous years of leaching data to evaluate the treatment effects both from a production (crop yield) perspective and a nutrient leaching perspective. The multiple years of data allows for evaluating how the treatments respond under varying climatic conditions and after subsequent years with similar cropping practices. Also, these multiple years of data allow for additional characterization of tile flow under varied precipitation conditions and allow for further understanding of the hydrology of the site.

Agronomic Activities in 2005 and 2006

Agronomic field activities were completed in a timely manner prior to and during the crop season. Rye for 2005 was seeded on October 15, 2004. Fall chisel plowing was performed on November 2-3, 2004. Fall fertilization was completed on November 15, 2004. Tillage for seedbed preparation was completed in the spring just prior to planting of perennial crops on April 18th and followed by 0.72" of precipitation. RoundUp herbicide was applied on April 14, 2005 in the rye/corn system and in rye/soybean plots on May 24. Seedbed preparation for corn and soybean was also completed just prior to May 3 and 4 seeding dates. Fertilizer was applied just after corn crop emergence on May 12-13, 2005. Rye for 2006 was planted on October 11, 2005. Fall chisel plowing of corn residue was performed on November 14, 2005. Fall fertilization for 2006 was completed on November 21, 2005. Field activities in 2006 were completed in a timely manner prior to and during the crop season. Seedbed preparation for corn and soybean was completed just prior to May 4 corn seeding date. Soybean was seeded on May 10. Fertilizer was applied just after corn crop emergence on May 17-18th. Rye cover crop in corn plots was sprayed to eliminate on April 24. Soybean rye cover crop plots were sprayed to eliminate rye on May 16. Rye for 2007 was planted on October 12, 2006. Fall fertilization for 2007 was completed on November 21, 2006. Fall tillage (chisel plow of corn residue) was performed on November 22, 2006.

Weed Control 2005 and 2006

RoundUp ready crops were used at the site in 2005. Dual II was used for pre-plant weed control and was broadcast on May 10, 2005. First application of RoundUp was on May 21, 2005. Second application was on June 17, 2005.Weed control was acceptable in most soybean plots; poor control of lambsquarter was noted in 6 of 32 plots, likely due to sprayer malfunction or poor herbicide application timing. Corn weed control was superior; no specific weed control problems were observed. Cultivation for weed control was not incorporated in the weed management system.

As in 2005, RoundUp ready crops were used at the site in 2006. Dual II was used for pre-plant weed control and was broadcast on May 22, 2006. First application of Round-Up for weed control was on May 22 for strip till plots; all other plots had first application on June 2, 2006. Second application was on June 19, 2006 in corn plots only. Soybeans had second application on June 22, 2006. Weed control was acceptable in most soybean plots; poor control of lambsquarter was noted in the strip till plots, for both corn and soybean due to poor herbicide application timing. Corn weed control in all other treatments was superior except as mentioned in strip till plots; no specific weed control problems were observed. Cultivation for weed control was not incorporated in the weed management system.

Precipitation 2005

Precipitation was recorded at the site in 2005 from April through November; freezing weather (Jan-March and December) precipitation was obtained from NOAA weather stations in Pocahontas and Humboldt (Table 2). January through March precipitation in 2005 was slightly below normal at the site. April, May and June were each above normal (0.4” to 1.15” higher). July precipitation was nearly 2”, August nearly 3” and September 1.4” below normal. March through November total was 6.47” below normal. Highest individual storm event precipitation was on June 25-26 when 2.65” were recorded.

Table 2. Precipitation in 2005 at the Gilmore City Research Facility (GCRF) and comparisons to norms and amounts at local NOAA weather stations.

Precipitation at the GCRF in 2005				NOAA weather stations in 2005		
			normal*	Pocahontas	Humboldt	average
	mm	inches	inches		inches	
Jan	-	-	0.91	0.62	0.60	0.61
Feb	-	-	0.70	1.77	1.60	1.69
Mar	-	-	2.20	1.33	1.07	1.20
Apr	89	3.49	3.09	3.32	3.61	3.47
May	129	5.09	3.94	5.85	4.15	5.00
Jun	134	5.27	4.37	7.46	8.89	8.18
Jul	63	2.47	4.37	3.82	4.42	4.12
Aug	45	1.76	4.60	1.41	3.20	2.31
Sep	39	1.53	3.16	3.38	4.54	3.96
Oct	20	0.79	2.17	1.00	0.59	0.80
Nov	43	1.69	1.86	1.50	2.18	1.84
Dec	-	-	1.37	1.54	1.23	1.39
total			32.74	33.00	36.08	34.54

* From: Climatological Data for Iowa, National Climate Data Center for Pocahontas Iowa 1971-00.

Precipitation 2006

Precipitation was recorded at the site in 2006 from March through November; freezing weather (Jan-Feb and December) precipitation was obtained from NOAA weather stations in Pocahontas and Humboldt (Table 3). January and February precipitation was slightly below normal. March and April were each above normal (0.51 and 0.57” higher). May, June and July were all well below normal, with August and September slightly above normal. March through November total was 8.59” below normal. Highest individual storm event precipitation was on August 9 when 2.32” was recorded.

Table 3. Precipitation in 2006 at the research site and comparisons to norms and amounts at local NOAA weather stations.

Precipitation at the GCRF in 2006				NOAA weather stations in 2006		
			normal*	Pocahontas	Humboldt	average
	mm	inches	inches		inches	
Jan	-	-	0.91	0.46	0.45	0.46
Feb	-	-	0.70	0.43	0.54	0.49
Mar	69	2.71	2.20	3.74	2.87	3.31
Apr	93	3.66	3.09	4.22	3.54	3.88
May	14	0.87	3.94	0.92	2.08	1.50
Jun	56	2.39	4.37	1.58	1.96	1.77
Jul	26	1.10	4.37	2.64	1.79	2.22
Aug	46	5.30	4.60	5.01	4.39	4.70
Sep	56	3.60	3.16	3.18	4.50	3.84
Oct	19	0.76	2.17	0.70	1.46	1.08
Nov	20	0.78	1.86	NA	NA	NA
Dec	-	-	1.37	NA	NA	NA
total			32.74			

* From: Climatological Data for Iowa, National Climate Data Center for Pocahontas Iowa 1971-00

Drainage 2005

Average soil temperature at a 4" depth rose above freezing on March 22 and continued to rise. Treatment plot sampling pumps were installed during the last week of March. Drainage started during this period and the first samples were collected on April 1st. Eighteen of the seventy-two plots had enough drainage to provide a sample on this date. By April 7th, fourteen additional plots were sampled. Samples were collected on at least a weekly basis, and for most plots, drainage was sufficient for sampling through the month of June. Only ten plots had drainage in July; the last samples were gathered on July 26th. Table 4 lists drainage volumes by treatment in 2005 with statistical differences at p=0.05. Five of the eighteen treatments had one of four replications removed due to excessive drainage volume values. Statistical differences among treatments were noted for four of eighteen treatments (LSD=7.22 inches). Average drainage for all treatments was 8.45 inches. When the treatments were grouped by crop (C vs. S) it was noted that there was a significant difference between crops, with soybean having a lower value (C=10.17", S=7.19") possibly related to tillage operations performed prior to the drainage season. With 23.29" of precipitation between March 1 and November 30 and using an overall drainage volume of 8.45", approximately 36% of the precipitation became subsurface drainage. Nearly half of the precipitation amount that occurred between March and the end of July, when drainage ceased, became subsurface drainage (see Table 5). The site was winterized on December 5. Average soil temperature at 4" depth did not drop below freezing in December 2005 in the region.

Drainage 2006

Average soil temperature at a 4"depth rose above freezing on March 11 and remained steady and began to rise after the 17th of March. Treatment plot sampling pumps were installed on March

28th. After installation, 0.92” of rainfall was recorded on March 30-31st, 2006 and subsurface drainage began thereafter and the first samples were collected on April 1st. Forty-nine of the seventy-two plots had enough drainage to provide a sample on this date. Samples were collected on at least a weekly basis, and for most plots, drainage was sufficient for sampling through the first week of May. All drainage ceased on May 10, 2006. Table 4 lists drainage volumes by treatment in 2006 with statistical differences at p=0.05. Nine of the eighteen treatments had one of four replications removed due to erroneous (usually excessive because of pump malfunction in an adjacent sump) drainage volume values. No statistical differences among treatments were noted for drainage in 2006 (LSD=2.08 inches). Average drainage for all treatments was 3.60 inches. When the treatments were grouped by crop, no significant difference between crops was noted as was in 2005. With 15.70” of precipitation between March 1 and November 30 and using an overall drainage volume of 3.60”, approximately 23% of the precipitation became subsurface drainage. Nearly half of the precipitation amount that occurred between March and the middle of May, when drainage ceased, became subsurface drainage (see Table 5). The site was winterized on November 28, 2006. Soil temperature at 4” depth fell below freezing on December 3, 2006.

Table 4. Subsurface drainage volumes with statistical differences at p=0.05, by treatment in 2005 and 2006. Statistical comparisons are within years only.

Treatment	Description	Drainage (inches)	
		2005	2006
1	Fall 75 Corn	12.03a	3.81a
2	Fall 75 soybean	7.14ab	3.33a
3	Fall 125 Corn	11.07ab	3.23a
4	Fall 125 soybean[1,2]	7.31ab	3.85a
5	Spring 75 Corn	11.72ab	3.52a
6	Spring 75 soybean	5.27ab	3.63a
7	Spring 125 Corn[1,2]	4.70b	3.08a
8	Spring 125 soybean[2]	5.95ab	3.67a
9	Spring 150 Corn[2]	12.49a	4.21a
10	Spring 150 soybean[2]	7.55ab	3.07a
11	Strip 125 Corn[1, 2]	9.70ab	4.56a
12	Strip 125 soybean[1]	4.80b	3.91a
13	Cover Crop 125 Corn[1,2]	6.98ab	3.70a
14	Cover Crop 125 soybean[2]	10.53ab	3.30a
15	LCD 125 Corn	9.65ab	3.51a
16	LCD 125 soybean	6.78ab	4.04a
17	Kura clover	10.08ab	3.59a
18	Orchardgrass + Red/Ladino clover[2]	8.29ab	2.62a
LSD		7.22	2.08
average drainage		8.45	3.60
standard deviation		2.53	1.43
average for corn treatments		10.17	3.67
average for soybean treatments		7.19**	3.62

[1] one of four reps not included in 2005 because of erroneous drainage value.
[2] one of four reps not included in 2006 because of erroneous drainage value.
** significantly different from drainage for corn treatments at p=0.05.

Table 5. Average drainage for each month over all treatments with totals and percentage as drainage for April- July 2005 and 2006.

	2005			2006		
month	precipitation	drainage	percentage	precipitation	drainage	percentage
	------inches------			------inches------		
April	3.49	2.82	81	3.66	3.05	83
May	5.09	3.23	63	0.87	0.59	68
June	5.27	2.46	47	2.39	0.00	0
July	2.47	0.12	5	1.10	0.00	0
total	16.32	8.63	53	8.02	3.64	45

Nitrate Concentrations and Losses 2005 and 2006

Previous history of current plot treatments quite likely has influenced the nitrate-nitrogen concentrations observed during 2005 and to some extent those in 2006. The majority of plots received 150 or 200 lbs N/acre during the period of 2000-2004 either as manure or aqua ammonia in the spring or fall. Some plots would have received 225 lbs of ammonia, each season. The previous experimental phase also included a split plot methodology with both corn and soybean grown on each plot, as opposed to the current phase utilizing whole plots, which has also contributed to and confounded the 2005 results. No definitive treatment effect trends should be derived from 2005 concentration results. Some treatment effect trends began to emerge in 2006.

In 2005, 535 flow weighted water samples were gathered. Table 6 lists the treatment results. Only the highest and three lowest average concentrations, out of eighteen compared, exhibited significant differences at p=0.05 level. The highest NO_3-N average concentration (18.8 mg/L NO_3-N) was observed in a treatment that was in the soybean year of the rotation and received no nitrogen in 2005. In the previous phase, two of the four replications for this treatment received 225 lbs N/acre and is quite likely a major factor in the elevated levels of NO_3-N observed. Lowest concentration observed was for two treatments: strip tillage 125 and LCD 125 cropped to corn, both averaged 12.9 mg/L NO_3-N.

The highest concentrations in 2006 were recorded in the 150 rate treatment within the soybean year (N applied in 2005 and years prior) and lowest were found in the perennial systems, specifically the Kura clover treatment; all other values were between these treatments values. Annual flow-weighted concentrations ranged from 6.9 to 21.7 mg L^{-1}. Individual, flow weighted averages ranged from 4.5 to 30.1 mg L^{-1} and were recorded within the aforementioned treatments. Average flow weighted values for most treatments only showed minor differences in their NO_3-N concentrations when compared. No significant differences were noted when comparing the fall and spring applications to each other across rates or crops or when rates were compared within the spring application rate treatment only. Use of the LCD applicator compared to a conventional knife also showed no significant differences in resulting concentrations. The use of a cover crop or strip tillage system in either crop also did not exhibit any significant effects on NO_3-N concentrations. The only significance was shown when comparing the N rate treatments within the soybean year of the corn soybean cropping system; nitrate in drainage from the previous season(s) applications at the 150 rate was significantly different than the 75 and 125 rates. Table 6 lists all treatments by year and the statistical differences at the p=0.05 level.

Table 6. Nitrate concentrations by treatment in 2005 and 2006 with statistical significance at p=0.05. Statistical comparisons are within years only.

Treatment	Description	nitrate N (mg/L) p=0.05	
		2005	2006
1	Fall 75 corn	14.5ab	17.3abc
2	Fall 75 soybean	17.8ab	10.4efg
3	Fall 125 corn	14.5ab	16.0bcd
4	Fall 125 soybean	13.5ab	14.0bcdef
5	Spring 75 corn	13.5ab	18.3ab
6	Spring 75 soybean	18.8a	12.0def
7	Spring 125 corn	18.1ab	15.4bcd
8	Spring 125 soybean	17.0ab	13.6bcdef
9	Spring 150 corn	16.3ab	15.7bcd
10	Spring 150 soybean	15.8ab	21.7a
11	Strip 125 corn	12.9b	14.1bcdef
12	Strip 125 soybean	14.2ab	13.4cdef
13	Cover Crop 125 corn	13.9ab	15.2bcd
14	Cover Crop 125 soybean	14.4ab	11.4defg
15	LCD 125 corn	12.9b	14.8bcde
16	LCD 125 soybean	16.1ab	12.8cdef
17	Kura clover	13.1b	6.9g
18	Orchardgrass + Red/Ladino clover	14.7ab	9.7fg
	LSD	5.4	4.8

Table 7 lists NO_3-N losses by treatment in 2005 and 2006. Losses were calculated by multiplying subsurface drainage effluent concentration by drainage volume. Due to the inherent variability between experimental plots and among treatments, loss calculations for one year may not be the best indicator of treatment effect. Losses in 2005 ranged from 17.4 lbs/acre NO_3-N for soybean grown under a strip tillage system, with no fertilizer added in 2005 to 41.1 lbs/acre NO_3-N exiting the subsurface drainage system for an early season sidedress application of 150 lbs N/acre on corn. (Fertilizer was applied on May 12-13.) These two treatments were the only statistically different (p=0.05) treatments for loss in 2005.

Losses in 2006 were much below those recorded in 2005 not because of a major drop in concentrations (except for the perennial systems, which did drop substantially) but because drainage volumes were approximately 42% of those recoded in 2005. Losses ranged from 5.2 to 16.5 lbs/acre for the Kura clover treatment and 150 spring applied nitrogen treatment in the soybean year of the rotation, respectively (N applied on May 12-13, 2005 in the corn year). Statistical differences were noted when comparing the spring 150 soybean treatment to both the fall 75 soybean and the perennial systems as listed in Table 7.

Table 7. Nitrate losses by treatment in 2005 and 2006 with statistical significance at p=0.05. Statistical comparisons are within years only.

Treatment	Description	nitrate-N (lbs/acre)	
		2005	2006
1	Fall 75 Corn	38.4ab	15.3ab
2	Fall 75 soybean	23.9ab	8.0bc
3	Fall 125 Corn	35.4ab	11.4abc
4	Fall 125 soybean	23.7ab	12.4abc
5	Spring 75 Corn	35.3ab	14.3ab
6	Spring 75 soybean	23.6ab	10.3abc
7	Spring 125 Corn	21.8ab	11.5abc
8	Spring 125 soybean	23.7ab	13.0abc
9	Spring 150 Corn	41.1a	13.4abc
10	Spring 150 soybean	27.7ab	16.5a
11	Strip 125 Corn	27.8ab	14.2ab
12	Strip 125 soybean	17.4b	12.0abc
13	Cover Crop 125 Corn	20.0ab	12.6abc
14	Cover Crop 125 soybean	34.9ab	9.4abc
15	LCD 125 Corn	29.7ab	11.5abc
16	LCD 125 soybean	24.5ab	11.4abc
17	Kura clover	26.3ab	5.2c
18	Orchardgrass + Red/Ladino clover	26.1ab	5.3c
	LSD	22.9	8.4

Total Reactive Phosphorus 2005 and 2006

Total reactive phosphorus (TRP) concentrations were measured in tile drainage samples that were also tested for NO_3-N. Table 8 lists TRP concentrations by year for each treatment. Table 9 lists loss by year and treatment in grams per acre. The ascorbic acid method of phosphorus analysis from Standard Methods for the Examination of Water and Wastewater 20th edition was used to determine the concentration of TRP, also known as total orthophosphate. The test measures both dissolved and suspended orthophosphate. This test measures the form most available to plants and is a useful indicator of potential water quality impacts such as algae blooms and weed growth in surface waters. No specific trends were observed over the two year period of observation.

Table 8. Total reactive phosphorus concentrations by treatment in 2005 and 2006 with statistical significance at p=0.05. Statistical comparisons are within years only.

Treatment	Description	TRP (µg/L) p=0.05	
		2005	2006
1	Fall 75 corn	4.64cd	12.18ab
2	Fall 75 soybean	6.68cd	6.00b
3	Fall 125 corn	25.29a	11.19ab
4	Fall 125 soybean	17.24abc	9.99ab
5	Spring 75 corn	15.03abcd	6.47b
6	Spring 75 soybean	8.58cd	7.84b
7	Spring 125 corn	10.56cd	14.04ab
8	Spring 125 soybean	22.63ab	11.73ab
9	Spring 150 corn	13.85bcd	9.31ab
10	Spring 150 soybean	11.31cd	9.31ab
11	Strip 125 corn	9.84cd	9.05b
12	Strip 125 soybean	6.94cd	9.28ab
13	Cover Crop 125 corn	11.96bcd	17.12a
14	Cover Crop 125 soybean	13.80bcd	10.69ab
15	LCD 125 corn	12.63bcd	9.54ab
16	LCD 125 soybean	12.12bcd	6.71b
17	Kura clover	9.69cd	12.09ab
18	Orchardgrass + Red/Ladino clover	7.11cd	11.02ab
	LSD	11.30	8.10

Table 9. Total reactive phosphorus loss by treatment in 2005 and 2006 with statistical significance at p=0.05. Statistical comparisons are within years only.

Treatment	Description	TRP (grams/acre) p=0.05	
		2005	2006
1	Fall 75 corn	6.4b	4.3abc
2	Fall 75 soybean	4.3b	2.3c
3	Fall 125 corn	19.2ab	3.3abc
4	Fall 125 soybean	14.3ab	4.1abc
5	Spring 75 corn	13.0ab	2.4c
6	Spring 75 soybean	5.0b	2.8c
7	Spring 125 corn	6.2b	6.4ab
8	Spring 125 soybean	14.8ab	5.6abc
9	Spring 150 corn	15.4ab	4.4abc
10	Spring 150 soybean	8.6ab	4.2abc
11	Strip 125 corn	25.7a	3.1bc
12	Strip 125 soybean	3.0b	3.4abc
13	Cover Crop 125 corn	20.6ab	4.1abc
14	Cover Crop 125 soybean	12.5ab	49abc
15	LCD 125 corn	13.2ab	3.2bc
16	LCD 125 soybean	8.3ab	6.7a
17	Kura clover	9.6ab	3.1bc
18	Orchardgrass + Red/Ladino clover	5.9b	2.7c
	LSD	19.1	3.4

Late Spring Nitrate Test 2005

Each corn plot was sampled using the Late Spring Nitrate Test (LSNT) procedures for determination of nitrate-nitrogen concentrations in the top 12” of soil on June 17, 2005 when corn plants were approximately 10” tall. Table 10 lists soil test results and the additional application amount recommended. Test results were for information only and no additional N applications were made. Fall N application plots had lower test values than plots with N applied in the spring. The spring 150 (treatment 9) plots had the highest N concentrations and the fall 125 (treatment 3) the lowest.

Late Spring Nitrate Test 2006

Each corn plot was sampled using the Late Spring Nitrate Test (LSNT) procedures for determination of nitrate-nitrogen concentrations in the top 12” of soil on June 6, 2006 when corn plants were approximately 8” tall. Results are listed in Table 10. As in 2005, test results were for information purposes only. No additional N was applied to the treatment plots. Highest values were observed using the LCD applicator at 125 lbs/acre N rate, closely followed by the conventional knife applicator using 150 lbs N/acre. Lowest values were recorded for the Fall 75 treatment.

Table 10. Late Spring Nitrate Test (LSNT) nitrate-N concentrations and additional N recommended but not applied in 2005 and 2006.

Treatment	Description	nitrate-N (mg/L)	additional N rec. (lb/acre)	nitrate-N (mg/L)	additional N rec. (lb/acre)
		2005		2006	
1	Fall 75 Corn	8	136	12	106
3	Fall 125 Corn	6	150	17	62
5	Spring 75 Corn	10	122	19	52
7	Spring 125 Corn	9	132	26	0
9	Spring 150 Corn	18	54	48	0
11	Strip 125 Corn	10	122	16	72
13	Cover Crop 125 Corn	10	122	40	0
15	LCD 125 Corn	16	72	53	0

Stalk Nitrate Test 2005

Corn stalk nitrate test sampling protocols were followed to determine nitrate-N concentrations in corn stalk tissue from each plot. Results are listed in Table 11. Stalks were sampled on September 29, 2005. Stalk nitrate values can be divided into four categories: low (less than 250 mg/L-N) marginal (250-700) optimal (700 and 2000 mg/Kg). Only the spring 150 treatment was in the optimal range, all other treatments were in the marginal to low range.

Stalk Nitrate Test 2006

As in 2005, corn stalk nitrate test sampling protocols were followed in the fall of 2006 to determine nitrate-N concentrations in corn stalk tissue from each plot. Results are listed in Table 11 by treatment. Stalks were sampled on October 2, 2006. All treatments were in the marginal to low range indicating that additional N should have been supplied to the crop.

Table 11. Stalk nitrate test concentrations in 2005 and 2006. Optimal range is between 700 and 2000 mg/L-N.

Treatment	Description	nitrate-N* (mg/Kg)	
		2005	2006
1	Fall 75 Corn	32	238
3	Fall 125 Corn	67	484
5	Spring 75 Corn	83	171
7	Spring 125 Corn	186	310
9	Spring 150 Corn	1032	498
11	Strip 125 Corn	260	228
13	Cover Crop 125 Corn	178	167
15	LCD 125 Corn	178	95

* low (less than 250 mg/Kg) marginal (250-700) optimal (700-2000).

Grain Yield 2005

Corn and soybean yields, by treatment, are listed in Tables 12 and 13. Because of the plot configuration in 2004, when corn and soybean were both grown on the same plot, yields for 2005 could be separated into those that followed the same crop or were grown in rotation. Continuous corn yield depression ranged from 12-31%, with an average 18%. Soybean on soybean yield depression was 6-11%, with an average of 9%. Considering only the crops in rotation, yields ranged from 156-179 bu/acre; lowest yield was for Fall 75 treatment and highest for Spring 150. The comparison resulted in a significant difference at p=0.05. All other treatments were not statistically different from these two values. Soybean yield in rotation ranged from 48-53 bu/acre and no significant differences were noted. Pocahontas County corn and soybean yield for 2005 were 183 and 50 bu/acre, respectively.

Grain Yield 2006

Corn yields ranged from 68-157 bu/acre; if the strip crop treatment 11(strip crop with weed pressure) was not included (68 bu/acre), lowest yield was for Fall 75 treatment (138 bu/acre) and highest for Spring 150, as was the case in 2005. In addition, when treatment 11 was removed from the statistical analysis then treatments 1 and 13 both became statistically different from the others. Even in the dry season experienced, the rye cover crop in corn only diminished yields by 4 bu/ac compared to the spring 125 treatment without rye cover. Rye in soybean only lowered yield by 1 bu/ac compared to the spring 125 treatment. Soybean yield ranged from 40-55 bu/acre. The strip crop soybean treatment had the lowest yield due to weed pressure encountered. Highest yield was for the spring 75 treatment. Overall yields at the site were very acceptable considering precipitation in the drainage season (Mar-Nov) was 8.6 inches below normal. Pocahontas County corn and soybean yield statistics for 2006 were not available at the time of report preparation.

Table 12. Corn yield by treatment in 2005 and 2006 with statistical significance at p=0.05*.

		yield (bu/acre) p=0.05		
		2005		2006
Treatment	Description	continuous	rotation	rotation
1	Fall 75 Corn	108d	156b	138a
3	Fall 125 Corn	137abc	164ab	147a
5	Spring 75 Corn	134bc	162ab	148a
7	Spring 125 Corn	153ab	173ab	143a
9	Spring 150 Corn	156a	179a	157a
11	Strip 125 Corn	152ab	174ab	68b
13	Cover Crop 125 Corn	134bc	163ab	139a
15	LCD 125 Corn	125cd	163ab	154a
Pocahontas County average		183		

*significance within a system, i.e. within the rotation and within year. Note: Severe weed pressure (lambsquarter) encountered in 2006 for strip crop treatment.

Table 13. Soybean yield by treatment in 2005 and 2006 with statistical significance at p=0.05*.

		Yield (bu/acre) p=0.05		
		2005		2006
Treatment	Description	continuous	rotation	rotation
2	Fall 75 Soybean	47a	50a	43bc
4	Fall 125 Soybean	44a	48a	50ab
6	Spring 75 Soybean	46a	51a	55a
8	Spring 125 Soybean	44a	49a	48ab
10	Spring 150 Soybean	47a	53a	51a
12	Strip 125 Soybean	45a	50a	40c
14	Cover Crop 125	49a	53a	47abc
16	LCD 125 Soybean	46a	49a	51a
Pocahontas County average		50		

*significance within a system, i.e. within the rotation.

Rye Biomass Yield 2005

Rye for 2005 was planted on October 15, 2004. The rye in corn plots was burned down with RoundUp herbicide on April 14, 2005 and in soybean plots on May 24, 2005 to allow for these crops to flourish. Rye biomass in the soybean plots was allowed to grow 40 additional days resulting in 23.4 times as much dry matter being produced as compared to the rye in corn. Rye in corn produced 105 lbs of dry matter/acre and contained 5.5 lbs N/acre. Rye in soybean plots yielded 2464 lbs of dry matter/acre that contained 46 lbs of N/acre.

Rye Biomass Yield 2006

Rye for 2006 was planted on October 11, 2005. That in corn plots was burned down with RoundUp herbicide on April 26, 2006 and in soybean plots on May 17, 2006 to allow for these crops to flourish. Rye biomass in the soybean plots was allowed to grow 22 additional days resulting in 3.4 times as much dry matter being produced as compared to the rye in corn. Rye in corn produced 663 lbs of dry matter/acre that contained 22 lbs N/acre. Yield in soybean plots was 2227 lbs of dry matter/acre and contained 44 lbs N/acre

Summary

Crop year 2005 could be considered a ‘calibration’ year for the new treatments imposed at the research site. So, it is difficult to draw broad conclusions from crop year 2005. However, of note is that in the 1st year of conversion from a row-crop system to a perennial system we have seen little if any reduction in nitrate-N concentration. Another important observation is that during April 2005 approximately 81% of the precipitation was intercepted by and exited via the subsurface drainage system.

The 2006 crop season was marked by typical early-season drainage patterns starting late-March as soils thawed. Drainage and precipitation were slightly above average in late March and April; each month had nearly one-half inch of precipitation greater than normal. Approximately eighty-three percent of April precipitation was intercepted by the drainage system. Excess precipitation basically ceased in early May as did all drainage. The remainder of the season had enough timely precipitation to produce adequate crop yield, but no subsurface drainage. March through

November total was 8.59” below normal. Crop yield was very good considering the below normal precipitation experienced at the site. Nitrate-N concentrations the first year after perennial system establishment in 2005 dropped considerably; concentrations in the orchardgrass/clover system decreased by 33% from 14.7 to 9.7 mg/L, those in the kura system dropped from 13.1 to 6.9 mg/L. Of note for the rye cover crop system was that neither corn nor soybean grain yields were not adversely affected, even in a dry year, by the rye cover crop. Nitrate concentrations in subsurface drainage were not greatly reduced through the use of a cover crop.

Pekin Project Site

Drainage management practices are being evaluated at the Pekin school drainage facility. There are a total of nine plots at this facility. Three different management practices are being utilized and evaluated. The treatments include the following:

- 3 – plots with conventional drainage (Free flow (FF)).
- 3 – plots with controlled drainage with free flow in the spring (April –May) and fall (September-October) (Controlled drainage variable (CDV)). The outlet control will be set at 2 ft below the ground surface except during free flow.
- 3 – plots with controlled drainage with no free flow (Controlled drainage fixed (CDF)). This treatment would be used to represent a system similar to shallow drainage. The outlet control will be set at 2 ft below the ground surface.

These three treatments are being evaluated to investigate the impacts of drainage management practices on drainage volume, nutrient concentrations in the subsurface drainage, and grain yield. Again, these factors will be evaluated over the five year term of this project. Since significant climate variability exists and the response of variable weather conditions on drainage management systems is needed it is important to evaluate the treatment response over the entire duration of the project phase. In addition to drainage management practices, drainage from two plots flows through a passive biofilter. One of the plots is a FF plot and one is a CDF plot. The concentration of nutrients entering and exiting the biofilter is being monitored to document any reductions as a result of the passive biofilter.

Precipitation

Crop years 2005 and 2006 were both unusually dry years at the Pekin site. Precipitation in both years was much below the 25-year average for the region. On average, 842mm (33.15”) of precipitation is recorded for the region. In 2005, 451mm (17.76”) were recorded at the site. Precipitation from mid-March through the end of 2005 was less than 18 inches (Figure 1 and 3) with only about 8 inches from mid-March through the end of June. In 2006, slightly less was recorded. Only 423 mm (16.65”) of precipitation was recorded from January 1, 2006 to December 1, 2006; less than ½ of normal amounts. Drainage volumes were very similar for both years. There was on average slightly less than 4 inches of drain flow from the free flow plots and less than 2 inches of flow from the controlled drainage plots (Figure 2 and 4). It is likely that there is some lateral seepage from the controlled drainage plots to the free flow plots.

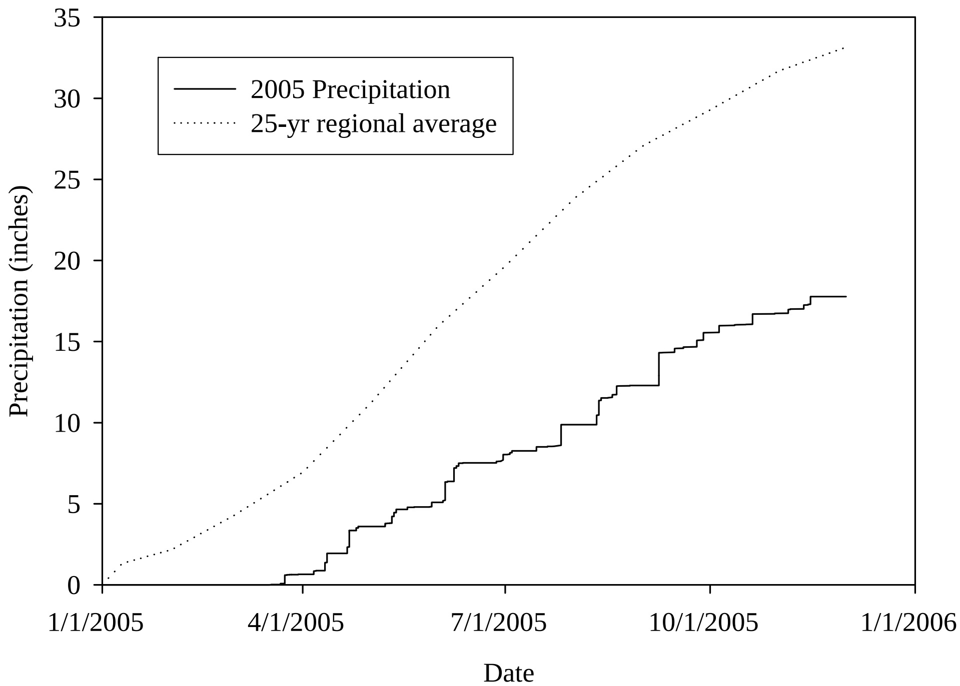

Figure 1. Precipitation in 2005 compared to the 25-year regional average.

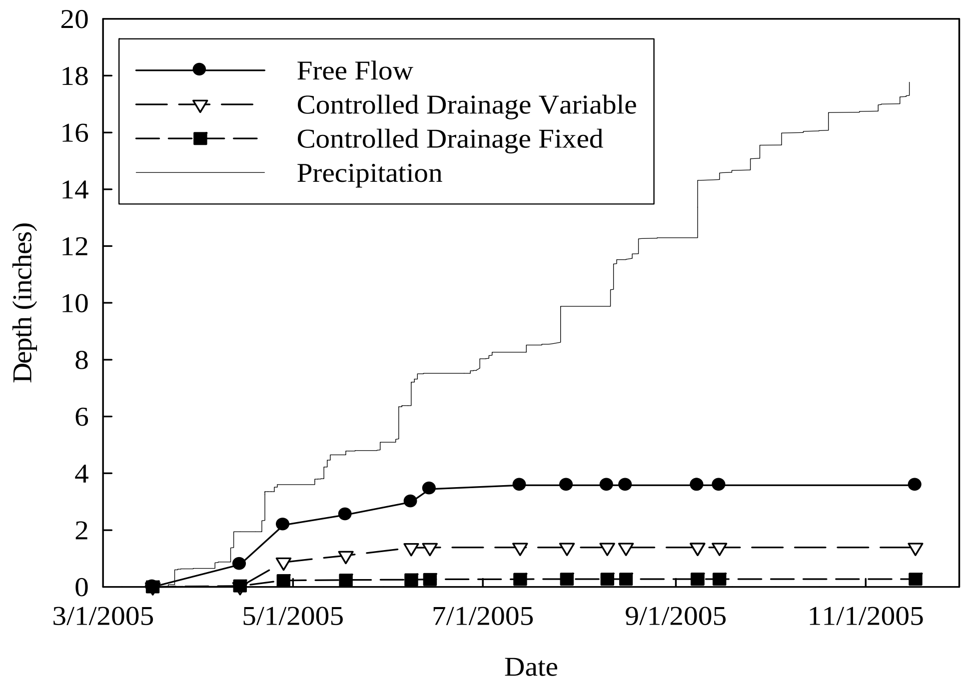

Figure 2. Precipitation and subsurface drainage at the Pekin site in 2005 during monitoring period.

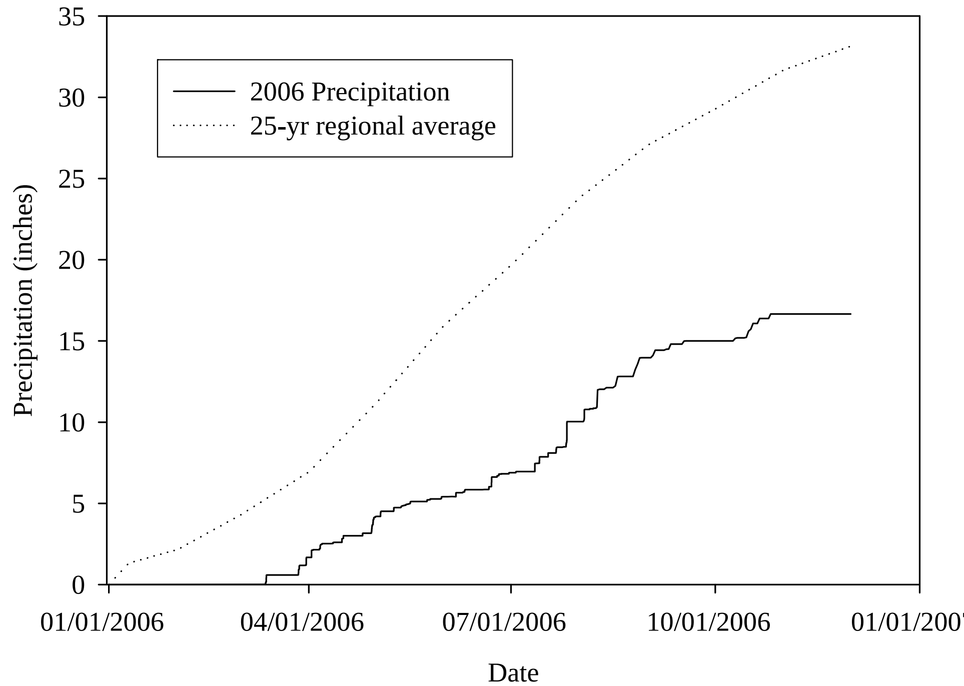

Figure 3. Precipitation in 2006 compared to the 25-year regional average.

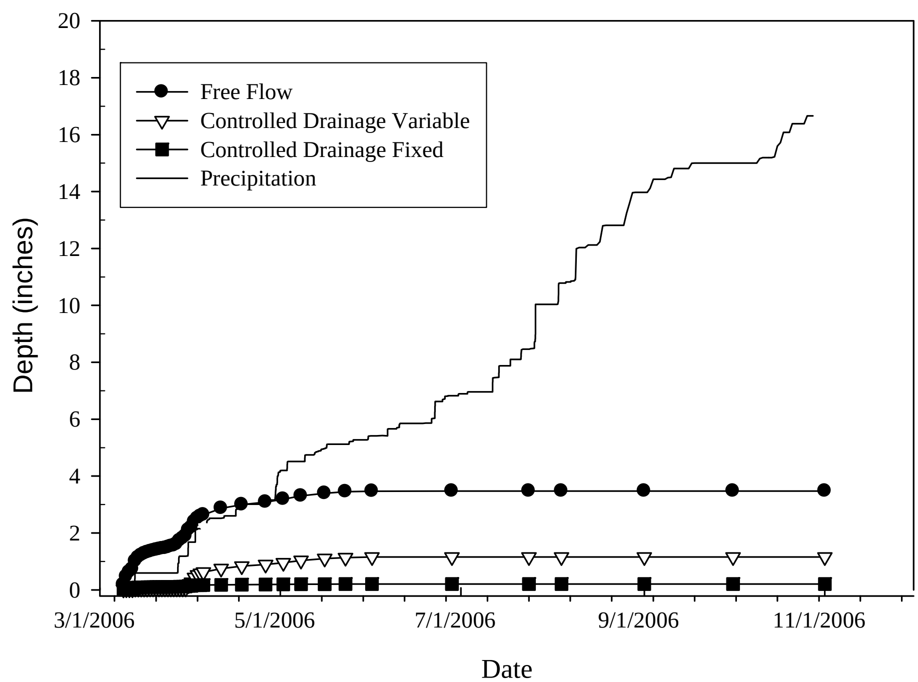

Figure 4. Precipitation and subsurface drainage at the Pekin site in 2006 during the monitoring period.

Nitrate-Nitrogen Concentrations
Water samples to determine nitrate-nitrogen (NO_3-N) concentration were only available in April and May, in both years, due to low flow conditions encountered. Listed in Table 14 are flow-weighted NO_3-N concentrations for all treatments. The use of a wood-based biofilter constructed at the time of subsurface drain installation and consisting of a wood chip trench receiving subsurface drainage decreased the concentrations being released from the standard installation, free drainage (FD) treatment. Results for individual years comparing the pre- and post-biofilter nitrate-nitrogen concentrations are illustrated in Figures 5 and 6.

Table 14. Flow-weighted nitrate concentration for all treatments (mg/L).

Treatment	Year	Average	Std. Dev.	Year	Average	Std. Dev.
FD	2005	6.71	1.16	2006	6.92	0.59
CDV	2005	6.40	2.14	2006	7.20	1.44
CDF	2005	4.57	2.49	2006	6.72	1.86

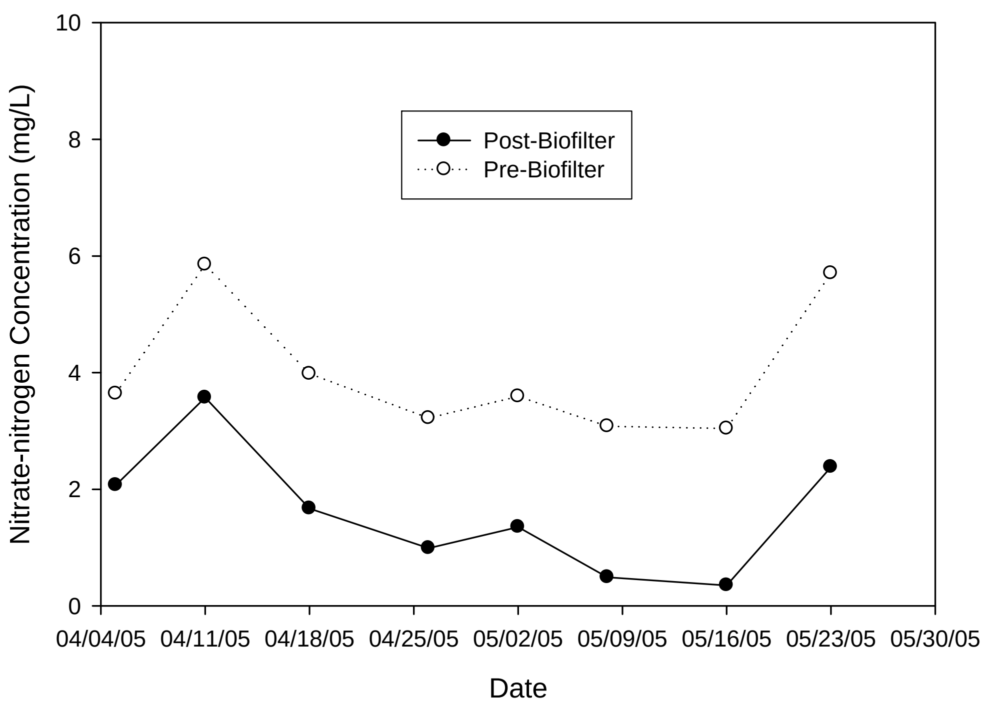

Figure 5. 2005 FD biofilter nitrate data.

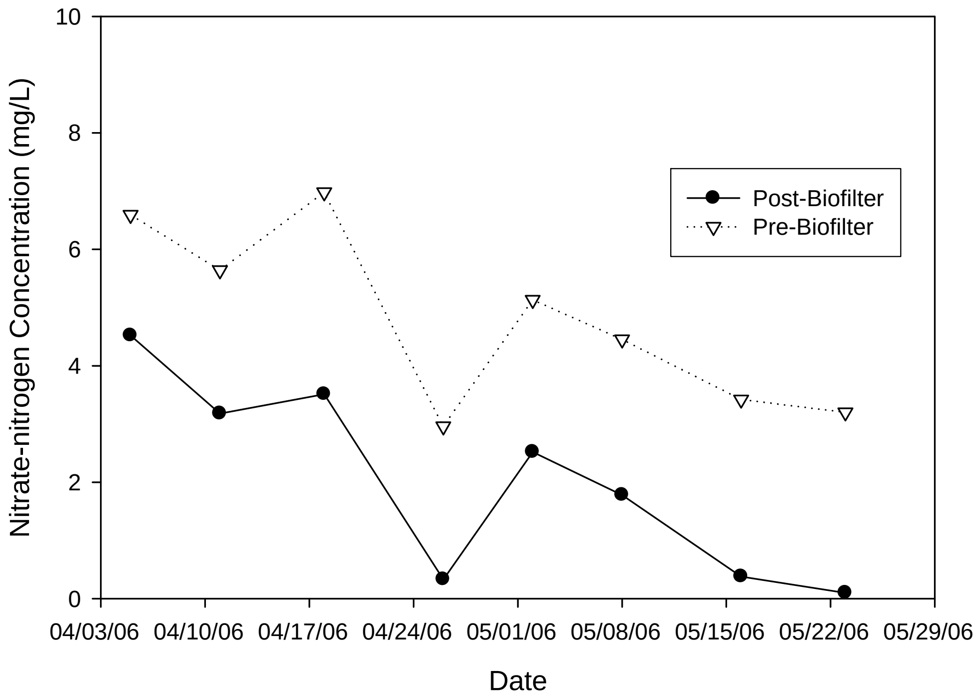

Figure 6. 2006 FD bio-filter nitrate data.

Additional Water Quality Testing

While tiles were flowing in 2006, three sets of grab samples were collected over a four- week period from the free flow biofilter plot and analyzed for the presence of additional contaminants that might be present. The results are presented in Table 15. Two useful measures of water quality are biological oxygen demand (BOD) and chemical oxygen demand (COD). They help measure the oxygen-depletion effect of a waste contaminant. The BOD test measures the oxygen demand of biodegradable pollutants whereas the COD test measures the oxygen demand of biodegradable pollutants plus the oxygen demand of non-biodegradable, oxidizable pollutants. COD is expressed as the mass of oxygen consumed per liter of solution. Biological oxygen demand (BOD) or biochemical oxygen is the amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water and used as a measure of the degree of water pollution. Ammonia, sulfate and chloride testing are also good indicators of water quality and were tested for in some of the samples. Ammonia is usually not found in large quantities in tile drainage because in the presence of oxygen rich water it will convert to nitrate. High levels of sulfate or chloride may be indicative of sewage contamination. None of the analytes were found to exceed water quality effluent or MCL standards. Additional testing in the future to detect any trends that may exist is needed.

Table 15. Additional analytical measurements performed on the 2006 FD biofilter plot.

Sampling Date Location	BOD	COD	Sulfate as SO_4	Ammonia as N	Chloride as Cl
	--- mg/L as O_2 ---		-------- mg/L --------		
4/18/2006					
pre-biofilter	<0.1	24.7	not tested		
post-biofilter	<0.1	45.7			
5/3/2006					
pre-biofilter	0.9	27.5	16.14	0.04	not tested
post-biofilter	1.6	46.2	18.08	0.11	
5/16/2006					
pre-biofilter	0.3	52.5	not tested	0.01	41.18
post-biofilter	0.6	62.7		0.10	34.74

Wetlands Performance Element

A unique aspect of the Iowa CREP is that nitrate reduction will not simply be assumed based on wetland acres enrolled, but will be calculated based on the measured performance of CREP wetlands. As an integral part of the Iowa CREP, a representative subset of wetlands will be monitored and mass balance analyses will be performed to document nitrate reduction. This will allow further refinement of modeling and analysis tools used to site and design CREP wetlands. A total of 20 Iowa CREP wetlands have been constructed to date (Figure 7), ranging in size from 1.4 to 7.5 ha. These 20 wetlands intercept flows from drainage areas ranging from 208 to 1478 ha and span the 0.5% - 2% range in wetland/watershed area ratio set by the program criteria (program data provided by IDALS).

During all or part of the 2003 through 2005 crop seasons, eight different wetlands have been monitored for the Iowa CREP. These include Finley Wetland, Hughes Wetland, Louscher Wetland, lower McLaughlin Wetland, upper McLaughlin Wetland, Schwartz Wetland, Triple I Wetland, and Van Horn Wetland. During 2006, ten wetlands were monitored for inflow and outflow nitrate concentration, and flow data was collected at four of these. These include Louscher Wetland, Schott Wetland, Elk Creek Marsh, Hendrickson Marsh, Hanlontown Slough, Renshaw Wetland, Schwartz Wetland, Dawes Wetland, Johnson Wetland, and Triple I Wetland. For close interval monitoring of nitrate-nitrogen concentrations, wetlands were instrumented with automated samplers that collected daily composite water samples at wetland inflows and outflows. Grab samples were collected at an approximately weekly interval at inflow and outflow locations, and from within the wetland near the outflow location when there was no outflow. Four wetlands were instrumented with Doppler flow meters for continuous measurement of water depth and flow velocity. These were combined with channel depth versus cross-sectional area to calculate discharge. Wetland water levels were monitored continuously using stage recorders in order to calculate pool volume and discharge at outflow structures. Starting in 2006, wetland water temperatures were recorded continuously for modeling nitrate loss rates. (Prior to 2006, water temperatures were estimated based on air temperature.)

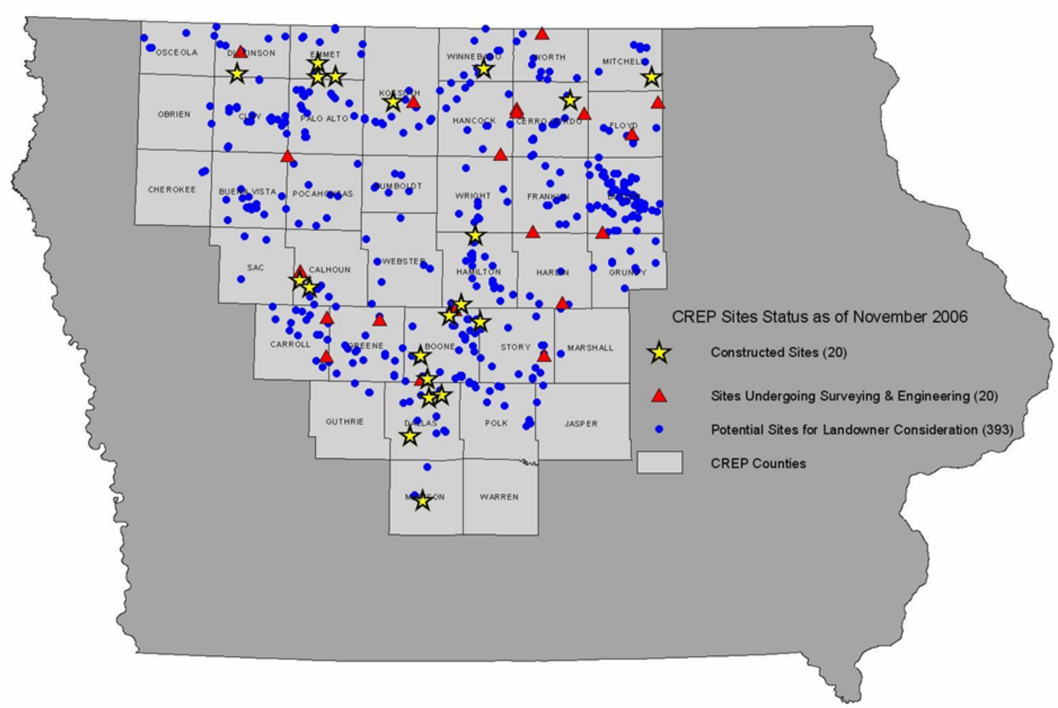

Figure 7. Counties eligible for IA CREP funding and status of Iowa CREP sites (figure provided by Iowa Department of Agriculture and Land Stewardship).

During all or part of the 2003 through 2005 crop seasons, eight different wetlands have been monitored for the Iowa CREP. These include Finley Wetland, Hughes Wetland, Louscher Wetland, lower McLaughlin Wetland, upper McLaughlin Wetland, Schwartz Wetland, Triple I Wetland, and Van Horn Wetland. During 2006, ten wetlands were monitored for inflow and outflow nitrate concentration, and flow data was collected at four of these. These include Louscher Wetland, Schott Wetland, Elk Creek Marsh, Hendrickson Marsh, Hanlontown Slough, Renshaw Wetland, Schwartz Wetland, Dawes Wetland, Johnson Wetland, and Triple I Wetland. For close interval monitoring of nitrate-nitrogen concentrations, wetlands were instrumented with automated samplers that collected daily composite water samples at wetland inflows and outflows. Grab samples were collected at an approximately weekly interval at inflow and outflow locations, and from within the wetland near the outflow location when there was no outflow. Four wetlands were instrumented with Doppler flow meters for continuous measurement of water depth and flow velocity. These were combined with channel depth versus cross-sectional area to calculate discharge. Wetland water levels were monitored continuously using stage recorders in order to calculate pool volume and discharge at outflow structures. Starting in 2006, wetland water temperatures were recorded continuously for modeling nitrate loss rates. (Prior to 2006, water temperatures were estimated based on air temperature.)

By design, the wetlands selected for monitoring span the 0.5% - 2.0% wetland/watershed area ratio range approved for Iowa CREP wetlands. The wetlands also span a 2-3 fold range in average nitrate concentration. The wetlands thus provide a broad spectrum of those factors most affecting wetland performance: hydraulic loading rate, residence time, nitrate concentration, and nitrate loading rate. Despite significant variation with respect to average nitrate concentrations and loading rates, the wetlands display similar seasonal patterns. These nitrate concentration and flow patterns are representative of the patterns that are expected for future wetlands restored as part of the Iowa CREP.

The wetlands selected for monitoring include CREP wetlands as well as wetlands restored under other programs but still meeting the CREP program criteria. This allows monitoring of some wetlands that have been in place much longer than CREP program wetlands. The wetlands also span a range in average nitrate concentration from less than 10 mg L^{-1} (Hanlontown Slough) to approximately 30 mg L^{-1} (Finley Wetland). The wetlands thus provide a broad spectrum of those factors most affecting wetland performance: hydraulic loading rate, residence time, nitrate concentration, and nitrate loading rate. In addition to weekly grab samples, a subset of wetlands is instrumented with automated samplers and flow meters at wetland inflows and outflows. Water levels are monitored continuously at outflow structures in order to calculate changes in pool volume and discharge.

Despite significant variation with respect to average nitrate concentrations and loading rates, the wetlands display similar seasonal patterns. Nitrate concentrations and mass loads are typically highest during high flow periods in spring and early summer, and decline with declining flow in late summer and fall. Figure 8 illustrates the seasonal patterns in nitrate concentrations and flows for four wetlands spanning a range of hydraulic loading rates (HLRs to Hendrickson Marsh < van Horn Wetland < Louscher Wetland < Triple I Wetland) and wetland:watershed area ratios (Table 16). Each of these wetlands has a single major inflow and discharges at a single outflow with a control structure. The inflow to each wetland is the combined surface and subsurface discharge from a drainage district of at least 200 ha in size planted primarily to corn and soybean. Hendrickson Marsh, van Horn Wetland, and Louscher Wetland follow the typical pattern for Iowa CREP wetlands with higher flows, concentrations, and nitrate loads in spring and early summer (Figure 8). Flows, nitrate loads and to a lesser extent nitrate concentrations decline after late summer and remain low through the remainder of the season. Inflows to Hendrickson Marsh, van Horn Wetland, and Louscher Wetland also display similar patterns with respect to variability in nitrate concentrations in response to flow variability. Nitrate concentrations in the inflows to these wetlands tend to be quite stable except for brief declines in concentration coinciding with some but not all flow events. The brief declines are probably a result of dilution by surface runoff water. In contrast, nitrate concentrations at the inflow to Triple I Wetland are much more variable and tend to rise in response to most flow events. The difference may well be related to differences in soils, topography, geomorphology, and/or drainage systems, but this has not yet been examined further.

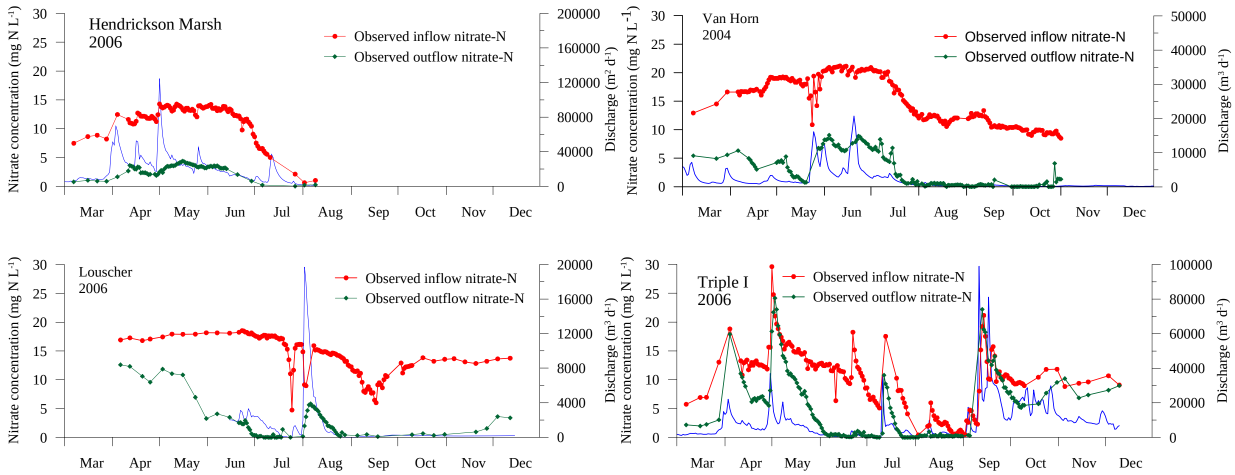

Figure 8. Nitrate concentrations and flows for “CREP” wetlands with different hydraulic loading rates (Hendrickson Marsh < van Horn Wetland < Louscher Wetland < Triple I Wetland).

Nitrate Loss from Wetlands

For Hendrickson Marsh, van Horn Wetland, and Triple I Wetland, mass nitrate loads and mass nitrate export were calculated based on the daily flow and concentration data for wetland inflows and outflows and summed to calculate annual mass balances (Table 16, based on estimated flows Louscher Wetland would have had mass loss rates similar to those measured at Triple I and higher % loss). These three wetlands were selected for calculating annual mass balances because monitoring was initiated soon enough after thaw to capture spring flows and continued through the season unless flows ceased. Because of delays in deploying monitoring equipment, annual mass balances for Louscher could not be calculated. In 2006, Triple I Wetland experienced rare, late season flooding that delivered the equivalent of a normal year’s flow within a few weeks. Triple I mass balances were calculated both for the entire season and for the period prior to the late season flood. Although the results for the late season flood fit the same functions as the remaining data (Figure 10), the hydraulic and nitrate loading rates are double those of any of the other systems considered and because of this the mass loss rates measured are probably much higher than could reasonably be expected for most systems. The flow to Triple I prior to the late season flood was near the 10 year average annual flow expected for this wetland. Hendrickson Marsh was drained for vegetation management after flows had declined to seasonal lows in August. As in the case of Louscher and van Horn, flows from the Hendrickson Marsh watershed remained low for the rest of the field season and would have contributed little to the annual mass balance had the wetland not been drained. Nitrate losses in seepage estimated based on volumetric seepage coefficients and nitrate concentrations were not a significant component of the nitrate budget (less than 7% at Hendrickson and less than 4% at van Horn and Triple I). These are lower rates of seepage loss than reported for many of the wetlands in the analyses that follow (Table 16 and Figures 11-13), but unlike most of those wetlands, the IA CREP wetlands are not built alongside rivers but rather at or above the headwaters of small streams. The stream begins as the wetland outflow. In this respect, the CREP wetlands are more like Eagle Lake Marsh (Davis et al. 1981) or the in stream wetland described by Hunt et al. (1999). Annual mass balance results for Hendrickson Marsh, van Horn Wetland, and Triple I Wetland are summarized in Table 16. (*Figure 10 includes the* annual *mass balance results from Table 16 for Hendrickson*

Marsh, van Horn Wetland, and Triple I Wetland for the periods both prior to and including the late season flood. Results of the late season flood at Triple I Wetland are not included in the subsequent analyses represented in Figures 11-14.)

In support of the CREP monitoring program, mass balance modeling was used to estimate the variability in performance of CREP wetlands that would be expected due to spatial and temporal variability in temperature and precipitation patterns. The percent nitrate removal expected for CREP wetlands was estimated based on hindcast modeling over the 10 year period from 1996 through 2005. Nitrate removal was modeled as a temperature-dependent first-order process (Crumpton 2001). Mass balance analysis and modeling were also used to calculate observed and predicted nitrate removal for Triple I Wetland, Louscher Wetland, and Hendrickson Marsh in 2006. Inflow and outflow nitrate concentrations measured in 2006 at Triple I (a high load site) and Hendrickson Marsh (a low load site) are illustrated in Figure 9. This figure also shows the range of outflow concentrations predicted for these wetlands by mass balance modeling with 2006 inputs and forcing functions. The range of outflow concentrations predicted for Triple I Wetland (a high loading rate site) and Hendrickson Marsh (a low loading rate site) based on modeling with 2006 inputs and forcing functions are illustrated in Figure 9 along with the observed concentrations and flows. The seasonal patterns of measured and modeled outflow concentrations show reasonable correspondence over the very broad range of flow conditions represented by these two sites. Comparison of the 10 year hindcast modeling results with the percent nitrate removal measured for three Iowa wetlands (Table 16) also illustrates reasonably good correspondence between observed and modeled performance of the wetlands (Figure 10).

Table 16. Nitrate mass balance, concentration and hydraulic load data for selected Iowa wetlands.

Wetland & Year	Wetland to watershed area ratio %	Load (kg N ha^{-1})	Removal (kg N ha^{-1})	Percent Removal	FWA Conc. (mg N L^{-1})	HLR (m)
van Horn, 2004	2.25	1314	897	68	18.0	7.3
Upper McLaughlin, 2004	0.36	2371	658	28	6.2	38
Hendrickson Marsh, 2006	2.16	469	368	78	11.8	4.0
Triple I, 2006 pre-flood	0.57	3807	1510	40	13.0	29.6
Triple I, 2006 including late season flood	0.57	9240	2310	25	11.9	78

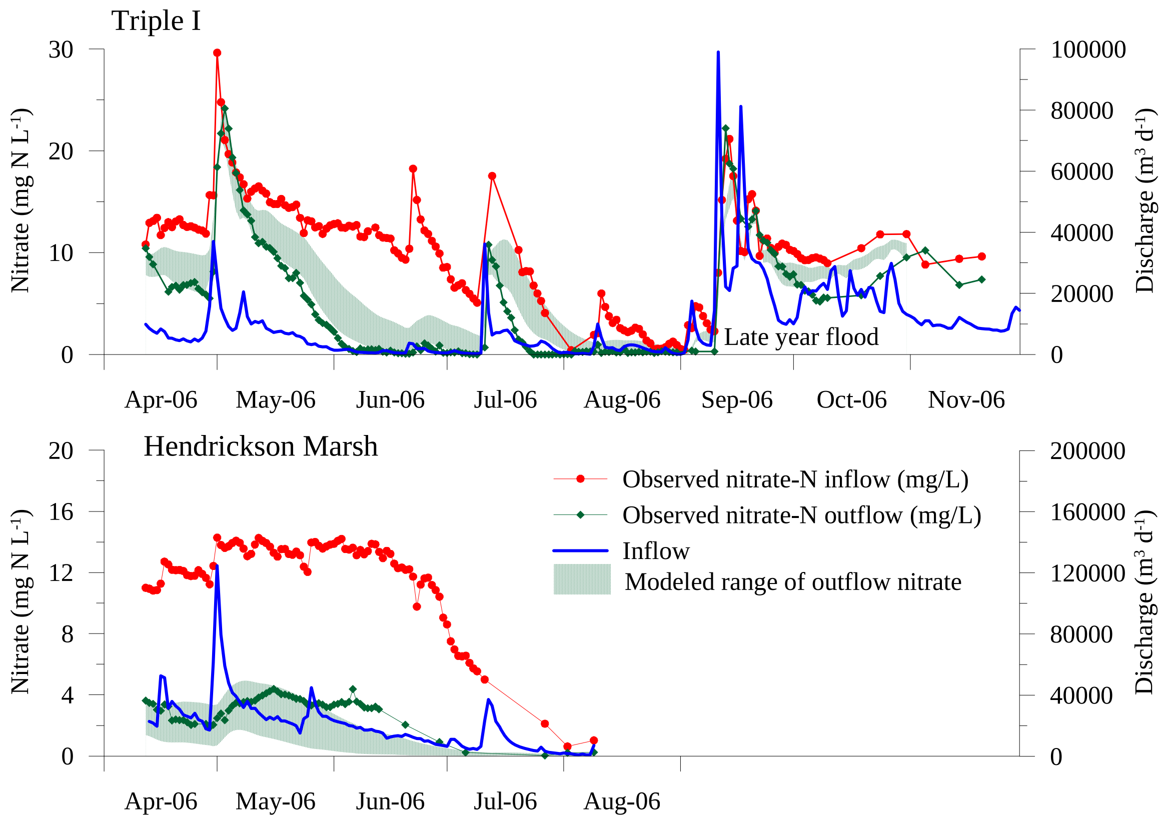

Figure 9. Measured and modeled nitrate concentrations and flows for Triple I Wetland and Hendrickson Marsh in 2006.

The CREP wetlands have performed predictably with respect to nitrate removal efficiency (expressed as percent removal) and mass nitrate removal. Wetland performance is a function of hydraulic loading rate, hydraulic efficiency, nitrate concentration, temperature, and wetland condition. Of these, hydraulic loading rate and nitrate concentration are especially important for CREP wetlands. The range in hydraulic loading rates expected for CREP wetlands is significantly greater than would be expected based on just the four fold range in wetland/watershed area ratio approved for the Iowa CREP. In addition to spatial variation in precipitation (average precipitation declines from southeast to northwest across Iowa), there is tremendous annual variation in precipitation. The combined effect of these factors means that annual hydraulic loading rates to CREP wetlands can be expected to vary by more than an order of magnitude, and will to a large extent determine nitrate loss rates for individual wetlands.

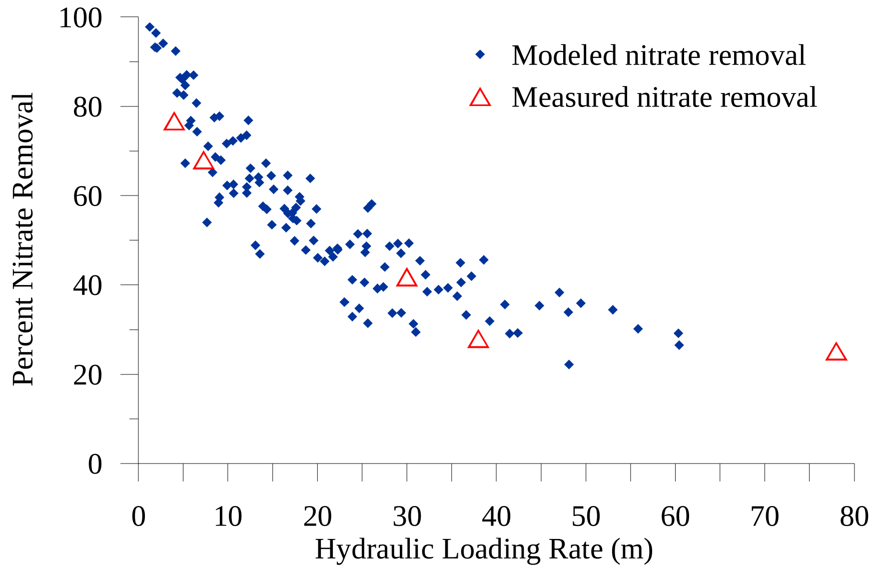

Figure 10. Modeled nitrate removal efficiencies for CREP wetlands based on 1996 to 2005 input conditions and measured nitrate removal efficiencies for CREP wetlands in 2004 & 2006.

Mass nitrate removal rates can vary considerably more than percent nitrate removal among wetlands receiving similar hydraulic loading rates. However, mass removal rates are predictable using models that integrate the effects of hydraulic loading rates, nitrate concentration, temperature, and wetland condition. Crumpton et al. (2006) developed and applied a model that explicitly incorporates hydraulic loading rate, nitrate concentration, and temperature to predict performance of US Corn Belt wetlands receiving nonpoint source nitrate loads. This analysis included comparisons for 38 “wetland years” of available data (12 wetlands with 1-9 years of data each) for sites in Ohio, Illinois, and Iowa, including four IA CREP wetlands (two low load and two high load sites). The analysis demonstrated that the performance of wetlands representing a broad range of loading and loss rates can be reconciled by a model explicitly incorporating hydraulic loading rates and nitrate concentrations (Figure 12, Crumpton et al. 2006).

Based on both the hindcast modeling results and on the measured performance of CREP wetlands, percent nitrate removal by CREP wetlands is clearly a function of hydraulic loading rate (Figure 10). The importance of hydraulic loading rate is confirmed by analysis of nitrate removal rates reported for wetlands in the UMR and Ohio River basins. Based on 34 “wetland years” of available data (12 wetlands, 1-9 years of data each; Table 2) for sites in Ohio (Mitsch et al 2005; Zhang and Mitsch 2000, 2001, 2002, and 2004), Illinois (Hey et al. 1994; Kovacic et al 2000; Phipps and Crumpton 1994; Phipps 1997), and Iowa (Table 16, this report; Davis et al 1981), percent mass nitrate removal is clearly related to hydraulic loading rate (Figures 10 & 11). When the analysis is restricted to only those wetlands meeting the 1 ha minimum size requirement for the IA CREP, a similar relationship is found but with slightly higher percent removal rates.

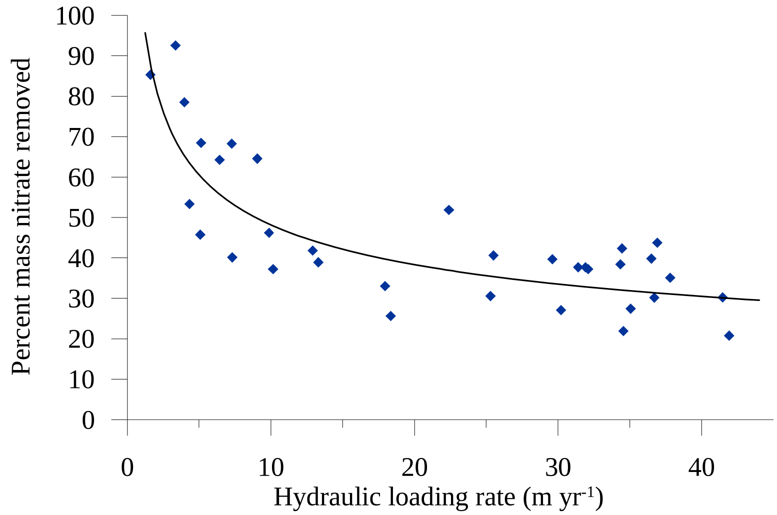

Figure 11. Percent mass nitrate removal in wetlands as a function of hydraulic loading rate. Best fit for percent mass loss = 103 × (annual hydraulic loading rate)$^{-0.33}$ (R^2 = 0.69).

In contrast to percent removal, hydraulic loading rate explains relatively little of the pattern in nitrate mass removal rates. Although mass removal will obviously be constrained at lower HLRs (because the mass load decreases with decreasing HLR), mass removal rates vary widely at higher HLRs. Mass nitrate removal rates can vary considerably more than percent nitrate removal among wetlands receiving similar hydraulic loading rates. Mass removal rates are the product of percent removal, hydraulic loading rate (HLR), and flow-weighted average (FWA) concentration, and as such include the variability in each of these. However, much of the variability in mass nitrate removal can be accounted for by explicitly and separately considering the effect of HLR and FWA concentration. For the wetlands considered here, mass nitrate removal rate = [103 × (HLR)$^{-0.33}$] × HLR × [FWA nitrate concentration] × [unit conversion factors]. Combining terms and incorporating unit conversion factors yields the function:

Mass nitrate-N removed = 10.3 × (HLR)$^{0.67}$ × FWA nitrate-N concentration

Where: mass nitrate removal is in kg N ha^{-1} yr^{-1}
HLR is in m yr^{-1} and
FWA nitrate-N concentration is in g N m^{-3} (=mg N L^{-1}).

A comparison of the measured and predicted nitrate removal for these wetlands demonstrates that the performance of wetlands representing a broad range of loading and loss rates can be reconciled by a model explicitly incorporating hydraulic loading rates and nitrate concentrations (Figure 12). This relationship can be further illustrated (Figure 13) by fitting the observed wetlands data to a surface plot of the mass nitrate removal function. The isopleths on the function surface illustrate the combinations of HLR and FWA that can be expected to achieve a particular mass loss rate. The function described above explains 94 % of the variability in mass removal rates for the wetlands considered here (Table 2, Figures 13 & 14).

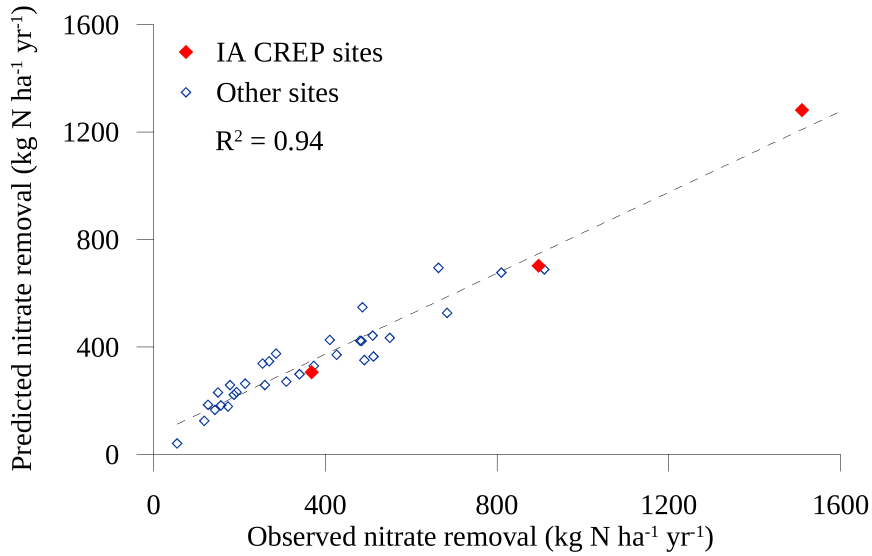

Figure 12. Observed nitrate mass removal in wetlands versus removal predicted from HLR and FWA nitrate concentrations. Predicted mass nitrate removed = 10.3 × $(HLR)^{0.67}$ × FWA.

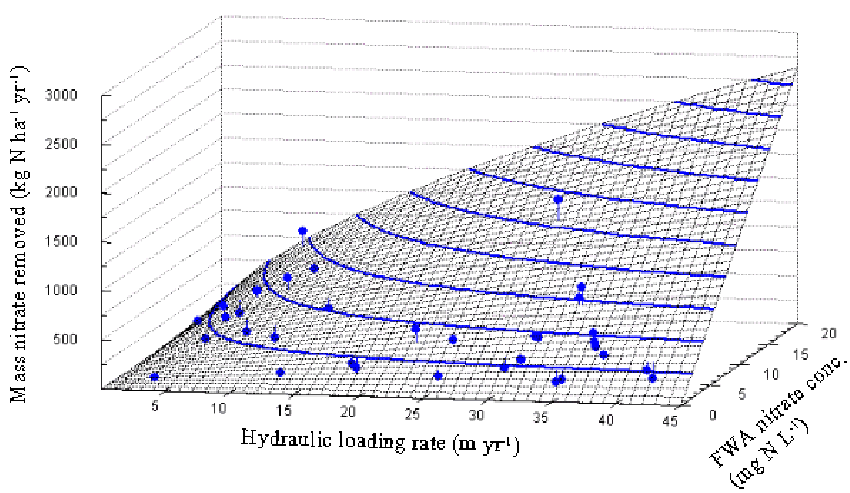

Figure 13. Observed nitrate mass removal in wetlands (points) versus removal rates predicted from HLR and FWA nitrate concentrations (surface). Predicted mass nitrate removed = 10.3 × $(HLR)^{0.67}$ × FWA.

Crumpton et al (2006, also Crumpton 2005) also combined a model of this form with GIS based estimates of water yield and nitrate concentrations to predict potential nitrate reductions for "CREP like" wetland restorations across the Upper Mississippi and Ohio River Basins. That analysis demonstrated significant potential for nitrate reductions if restorations were targeted to those areas of the Corn Belt with the highest nitrate concentrations and loads (Figure 14).

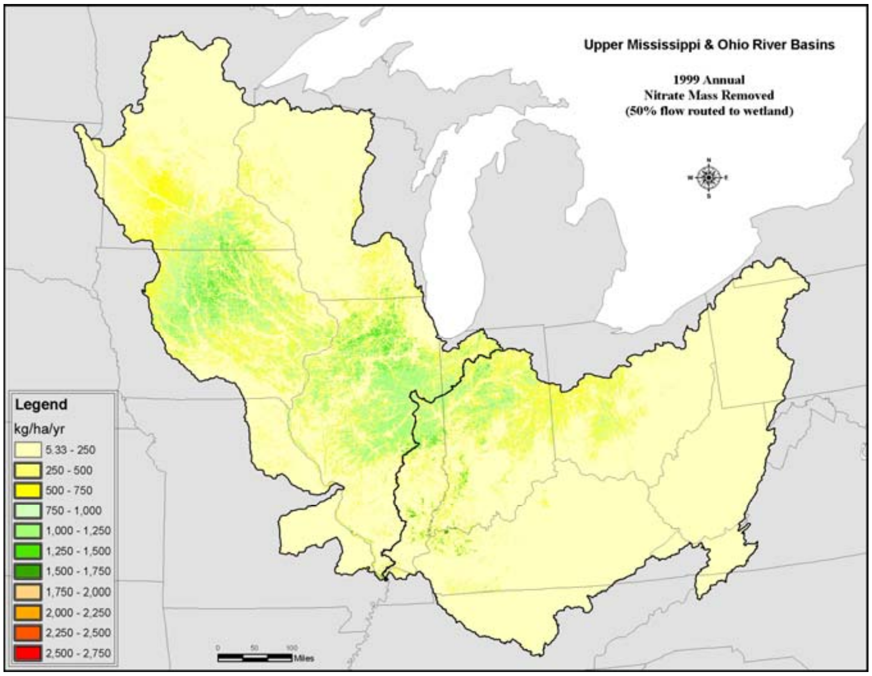

Figure 14. Estimated mass nitrate removal for "CREP like" restorations for 1999. Removal rates expressed in kg N ha^{-1} $year^{-1}$. Figure adapted from Crumpton et al. (2006).

Nitrate in Tile Drained Watersheds: Synoptic Sampling Program

Hydraulic loading rates are expected to vary significantly as a result of wetland/watershed ratios and temporal precipitation patterns even for identical watersheds. However, nitrate concentrations are thought to be primarily determined by agricultural practices and drainage patterns, and are expected to be similar for tile drained watersheds in the same geographic area and with similar agricultural practices. However, monitoring of CREP wetland inflows demonstrated a greater than three-fold range in average nitrate concentrations, with no clear relationship to agricultural practices or drainage patterns. It is possible that differences in nitrate concentration are related to underlying landscape characteristics and that if these could be identified and understood, CREP wetlands could be targeted even more effectively.

Over the past three field seasons, we have implemented a broad monitoring program in an effort to better understand and predict the variation in nitrate concentration from tile drained watersheds in the CREP service area. During the 2004 to 2006 growing seasons, samples were collected from tile drained watersheds at approximately weekly intervals and analyzed for nitrate. In 2004, 46 sites were sampled in four Iowa counties. During 2005 and 2006, sampling was continued at 23 sites in Cerro Gordo and Franklin Counties chosen to cover the range of concentrations found in the original 46 sites.

Water flow was estimated from nearby USGS gauging station discharge data adjusted to the estimated watershed area for each tile to allow a matching of temporal variation of nitrate concentrations with flow events and to allow estimation of flow-weighted average (FWA) nitrate concentrations for 2004 and 2005. Because the actual flow is not known, field notes describing flow at the time of sampling were useful in interpreting low nitrate values that were occasionally observed when the flow was either zero or very low, even though the nearby gauging station indicated flow might be occurring. FWA nitrate concentrations for 2006 were estimated as the average of the top ten measured concentrations because the 2004 and 2005 data show good correlation between these statistics. Correlation between the highest concentrations and the FWA is strong because nitrate concentrations tend to be high when flow is greatest during the spring and early summer in this landscape. FWA nitrate concentrations at each location remained relatively consistent between years and show a nearly three-fold range at these sites (Figure 15).

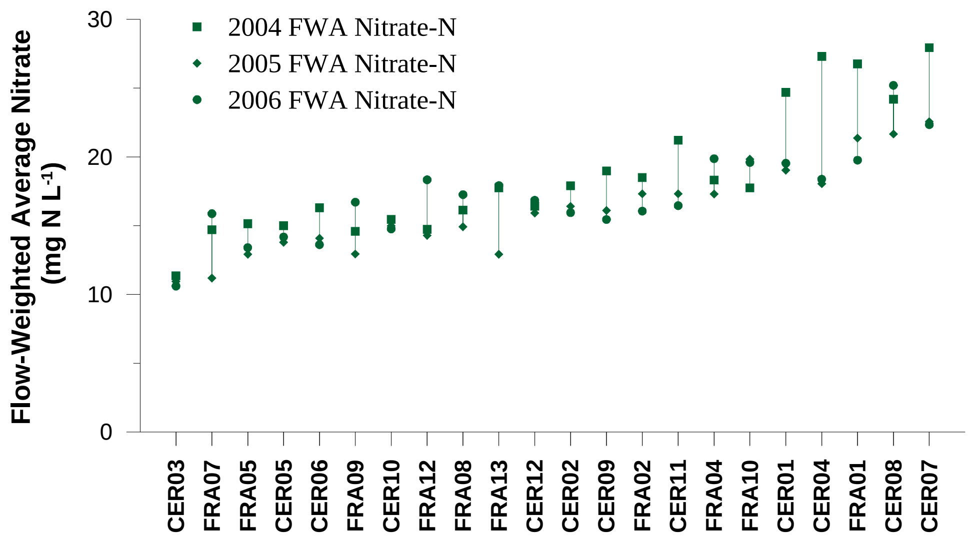

Figure 15. Estimated FWA nitrate-N for 2004 through 2006 at synoptic tile sampling sites.

Outreach Activities Year 2006

In addition to the evaluation that is taking place at the project sites in Gilmore City and Pekin we have an active outreach program associated with this project. This includes presentations at technical and Extension related meetings, field days, the Drainage Research Forum, and Extension and scientific publications. The activities that are directly associated with the outreach component of this project in 2006 are described below.

Events Organized

November 28, 2006 – Coordinated with Dr. Gary Sands from the University of Minnesota the 7th Annual IA-MN Drainage Research Forum in Owatonna, MN. There were approximately 85 attendees consisting of producers, contractors, and agency representatives from Iowa and Minnesota.

Oral Presentations at Extension Related Meetings

Extension Presentations (Iowa):

December 18, 2006 – Presentation “Pesticide movement in soils” at Agricultural Chemical Update in Denison, IA (40 attendees).

December 6, 2006 – Presentation “Pesticide movement in soils” at Agricultural Chemical Update in Ames, IA (10 attendees).

December 8, 2006 – Presentation “Drainage design now and in the future” at Iowa Drainage District Association annual meeting in Fort Dodge, IA (100 attendees).

November 30, 2006 – Presentation “Economic and environmental considerations for drainage design” at Integrated Crop Management Conference in Ames, IA (225 attendees).

September 7, 2006 – Presentation “Conservation systems and water quality” at Field Day in Hardin County (~45 attendees).

September 6, 2006 – Presentation “Conservation systems and water quality” at Field Day in Plymouth County (~100 attendees).

August 31, 2006 – Presentation “Conservation systems and water quality” at Farm Progress Show.

August 22, 2006 – Presentation “Beef manure and water quality issues” at Manure Management School in Ames, IA (50 attendees).

August 3, 2006 – Presentation “Subsurface drainage bioreactors” at Iowa Land Improvement Contractors Field Day (~65 attendees).

July 12, 2006 – Presentation “Benefits of tiling and drainage water management” at Drainage Field Day at Southeast Iowa Research Farm, CCA Session (50 attendees).

June 28, 2006 - Poster Presentation “Water and nutrient management: In-field strategies” Iowa Farm Bureau Ag. And Environment Conference (~65 attendees)

June 19, 2006 – Presentation “Water quality issues in Iowa” to Iowa Pork Industry Center Advisory Group.

March 13-17, 2006 – Presentation “Long-term benefits of tiling” at Iowa Drainage Design Workshops (~200 attendees).

March 13-17, 2006 – Presentation “Controlled drainage: water quality benefits and irrigation potential” at Iowa Drainage Design Workshops (~200 attendees).

March 7, 2006 – Presentation “Conservation systems: manure and drainage water quality” at Agriculture and the Environment Conference in Ames, IA (150 attendees).

March 7, 2006 – Presentation “Subsurface drainage and nitrate-nitrogen leaching from fifteen years in north-central Iowa” at Agriculture and the Environment Conference in Ames, IA (50 attendees).

March 2, 2006 – Presentation “Nitrogen timing effects on drainage water quality” to Iowa Farm Bureau Environmental Advisory Committee [Invited].

February 15, 2006 – Presentation “Drainage design” at Soil and Water Management Clinic in Ames, IA (10 attendees).

February 15, 2006 – Presentation “Drainage water management” at Soil and Water Management Clinic in Ames, IA (10 attendees).

January 24, 2006 – Presentation “Conservation systems: manure and drainage water quality” at Crop Advantage Series meeting in Storm Lake, IA (45 attendees).

January 19, 2006 – Presentation “Conservation systems: manure and drainage water quality” at Crop Advantage Series meeting in Spirit Lake, IA (50 attendees).

January 18, 2006 – Presentation “Agricultural drainage and water research” at Boone, IA weekly ag meeting (26 attendees).

January 13, 2006 – Presentation “Manure and drainage water quality” at North Central Iowa Crop Clinic (25 attendees).

January 12, 2006 – Presentation “Drainage water management” to Boone River Watershed Group (15 attendees).
January 10, 2006 – Presentation “Basic drainage design” at Iowa Land Improvement Contractors Association annual meeting in Des Moines, IA (80 attendees).
January 9, 2006 – Presentation “Drainage water management in Iowa” at Iowa Land Improvement Contractors Association annual meeting in Des Moines, IA (100 attendees).

<u>Extension Presentations (Regional):</u>
November 28, 2006 – Presentation “Drainage Water Management Update from Iowa” at IA-MN Drainage Research Forum in Dows, IA (85 attendees consisting of producers, contractors, and agency representatives from Iowa and Minnesota).
October 16, 2006 – Presentation “Effects of Manure on Drainage Water Quality” to Nebraska Livestock and Environment Issues Committee (~40 participants) [Invited].
March 9, 2006 – Invited presentation “Wetland design for drainage water treatment” at Minnesota Agricultural Drainage Design Workshop in Mankato, MN (50 attendees).

Technical Papers
Lawlor, P. A., M. J. Helmers, J. L. Baker, S. W. Melvin, and D. W. Lemke. Nitrogen application rate effects on nitrate-nitrogen concentrations and losses in subsurface drainage. *Trans. ASABE* (in review).

Singh, R., M. J. Helmers, and Z. Qi. 2006. Calibration and validation of DRAINMOD to design subsurface drainage systems for Iowa’s tile landscapes. *Agricultural Water Management*. 85: 221-232. [*0.835/0*]

Singh, R., M. J. Helmers, W. G. Crumpton, and D. W. Lemke. 200X. Predicting effects of drainage water management in Iowa’s subsurface drained landscapes. *Agricultural Water Management* (in review).

Helmers, M. J**.** and R. Singh. 2006. Economic and environmental considerations for drainage design. In *Proceedings of the 18th Annual Integrated Crop Management Conference* (November 29 and 30, 2006, Iowa State University, Ames, IA), pp. 239-244. [Oral Presentation]

Singh, R. and M. J. Helmers. 2006. Subsurface drainage and its management in the upper Midwest tile landscape. In *Proceedings of the EWRI Congress, ASCE* [Oral Presentation].

Singh, R. and M. J. Helmers. 2006. Shallow and controlled drainage systems in Iowa’s tile landscapes. *In:* ASA-CSSA-SSSA Annual Meeting Abstracts. Nov. 12-16, 2006, Indianapolis, IN.

Lemke, D.W., R. L. Cooney, S.L. Richmond, W.G. Crumpton, and M. J. Helmers. 2006. A new vision for federal policy to facilitate restoration and development of wetlands as off-field nitrogen sinks for cropped landscapes. *In:* ASA-CSSA-SSSA Annual Meeting Abstracts. Nov. 12-16, 2006, Indianapolis, IN.

Qi, Z., M. Helmers, and R. Singh. 2006. Evaluating a drainage model using soil hydraulic parameters derived from various methods. ASAE Meeting Paper No. 062318. St. Joseph, Mich.: ASAE.

Planned Outreach Activities
Presentations at various Extension, technical, and general audience venues will continue to broaden the impact from this study.

A general summary report for the Gilmore City project through 2004 is being prepared and is expected to be released in 2007. At present the report is being edited.

Technical publications that examine the effects of nitrogen source and application timing on nitrate leaching are being prepared. At present they are going through internal review by co-authors (data from 2000-04).

Field day at the Gilmore City project site.

References

Crumpton, W.G. 2005. Water Quality Benefits of Wetland Restoration: A performance Based Approach. Pages 181-190 in Allen, A.W. and Vandever, M.W. (eds.), *The Conservation Reserve Program-Planting for the future: Proceedings of a National Conference*. U.S. Geological Survey, Biological Resources Discipline, Scientific Investigations Report 2005-5145, 248p.

Crumpton, W.G., G.A Stenback, B.A. Miller, and M.J. Helmers. 2006 (pending). Potential benefits of wetland filters for tile drainage systems: Impact on nitrate loads to Mississippi River subbasins. Project completion report, US Department of Agriculture CSREES.