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Introduction

Subsurface agricultural drainage has allowed for enhanced agricultural production in many areas of the world including the upper Midwest, United States. However, the presence of nitrate-nitrogen (nitrate-N) in subsurface drain water is a topic of intense scrutiny. Many studies have been done looking at ways to reduce nitrate-N in tile drainage (Baker et al., 1975; Baker and Johnson, 1981; Hanway and Laflen, 1974; Kanwar et al., 1988).With the growing concern for the health of the Gulf of Mexico (Mitsch et al., 2001; Rabalais et al., 1996), there is still a need to study and recommend nitrogen management practices that have the potential to reduce nitrate-N concentrations and loss through subsurface drainage systems. One practice is to apply the appropriate amount of nitrogen and previous work has found a relationship between nitrogen application rate and drain nitrate-N concentration showing (Figure 1). Another commonly discussed practice is to apply nitrogen in the spring as close to the time that the corn crop needs nitrogen as possible. The objectives of this study were to evaluate timing and rate of nitrogen application on nitrate-N leaching and crop yield.

Materials and methods

The study site was in Garfield Township in Pocahontas County, Iowa. Soils are of the Nicollet-Webster-Canisteo (clay loam) series with average slope around 1%. The site is divided up into 78 separate 0.14 ac plots, of which 32 were used for this study. Each plot is subsurface drained at a depth of approximately 3.5 ft with one drain down the center of the plot and a drain on each edge to eliminate lateral flow between plots. This setup resulted in a drain spacing of 25 ft.

Numerous application rates have been investigated at this site in the past; however the focus here is on application timing and two nitrogen rates. Nitrogen rates being investigated include 75 lb/ac and 125 lb/ac. Each rate was applied during the corn year of a corn-soybean rotation either in the fall or spring with four replicates per rate per application time. These treatments, and the plots associated with them, did not change during the study duration. Fall fertilizer application consisted of injecting aqua ammonia in mid to late November of each year while spring fertilization occurred just after crop emergence in late May to early June.

The center drain of each plot was monitored for flow and nitrate-N concentrations. Nitrate-N concentrations for each plot were weighted based off the amount of flow between sample dates and the annual flow to determine an average annual flow-weighted nitrate-N concentration to be used for comparison. Concentrations were also weighted with respect to monthly flow to evaluate monthly concentrations. Nitrate-N samples were collected in all years regardless of crop. Data presented here show results from the corn year, the soybean year, and the full rotation.

Climatic conditions over the study period included two relatively dry years, 2005 and 2006, a wet year, 2007, a moderate to wet year, 2008, and another dry growing season in 2009. Subsurface drainage patterns followed precipitation patterns in almost all cases. The first year of the study, 2005, is considered an adjustment period, as other nutrient application rates were applied prior to this study. This year will be included for reference; however, results from this year are not considered in evaluating the overall treatment impacts.

Treatments were statistically analyzed with the Statistical Analysis Software (SAS) package (version 9.1) using the Generalized Linear Model (GLM) procedure.

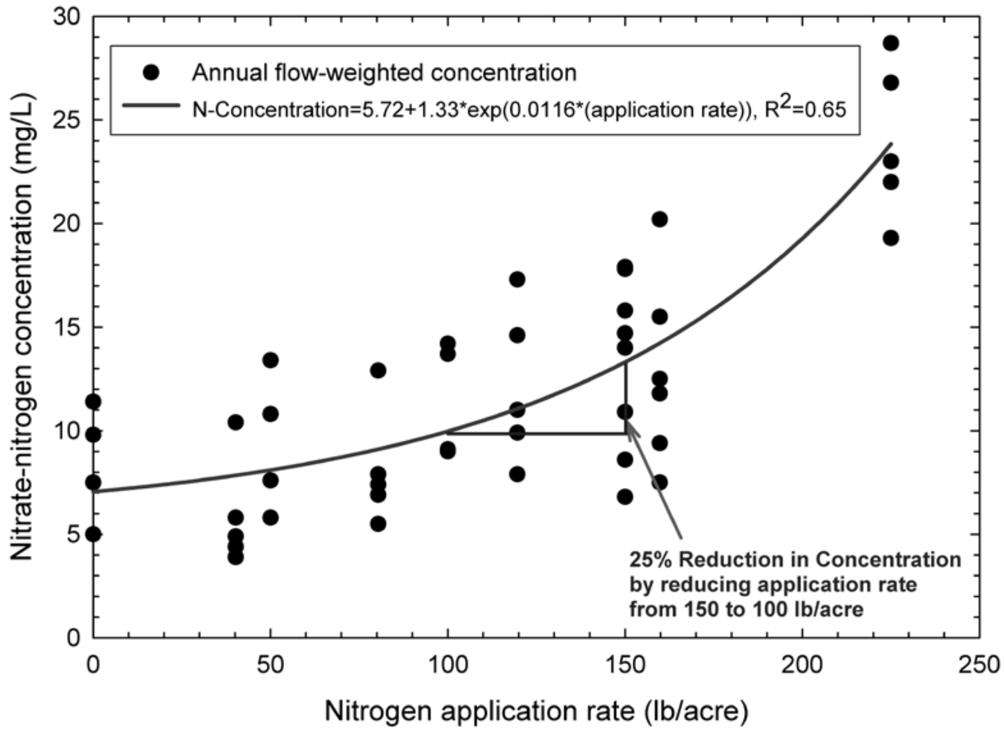

Figure 1. Overall Nitrogen Application Rate Effect on Nitrate-N Concentration for Corn-Soybean Rotation 1990-2004 (not all rates present in each year).

Results

When all plots are considered together, there is a trend of increasing nitrate-N concentrations when annual drainage volume decreases. This phenomenon has been shown previously in Lucey and Goolsby (1993) and suggests nitrate-N storage in the soil profile during dry years. Wet years provide dilution and leaching, which drops the observed concentrations.

Looking at individual treatments from 2005 to 2008, no statistical differences are found in resulting subsurface drain water from the different nitrogen application timings (Table 1 and Table 2). When removing the adjustment year, 2005, adding current data from 2009, and investigating individual months, five months emerge as being significant at the $p = 0.1$ level and one month at the $p = 0.05$ level (Figure 2). Although only a few points, these observations suggest fall application of fertilizer may be slightly "riskier" than spring application. However, any significance is lost when looking at treatments on an annual basis.

Table 1. Annual subsurface flow weighted nitrate-N concentrations in the corn year of the rotation for 75 lb/ac and 125 lb/ac. Significance is within each year only.

Treatment	Nitrate-N (mg/l)			
	2005	2006	2007	2008
Fall 84	14.5a	17.3a	10.6b	15.7a
Spring 84	13.5a	18.3a	10.0b	14.5a
Fall 140	14.5a	16.0a	13.8a	14.9a
Spring 140	18.1a	15.4a	12.9ab	13.0a

Note: means with the same letter within years (i.e., within columns) are not significantly different at $p = 0.05$.

Table 2. Annual subsurface flow weighted nitrate-N concentrations in the soybean year of the rotation for 75 lb/ac and 125 lb/ac. Significance is within each year only.

Treatment	Nitrate-N (mg/l)			
	2005	2006	2007	2008
Fall 84	17.8a	10.4a	11.1a	9.5a
Spring 84	18.8a	12.0a	13.5a	9.7a
Fall 140	13.5a	14.0a	11.6a	11.5a
Spring 140	17.0a	13.6a	12.9a	12.1a

Note: means with the same letter within years (i.e., within columns) are not significantly different at p = 0.05.

Considering nitrate-N concentrations from each rotation (2006 to 2008) (Figure 3), there are no statistical differences between either nitrogen application timing or application rate. There were also no statistical differences in nitrate-N loss (Figure 4).

There is some evidence, although not significant, that drain nitrate-N concentrations in the soybean year are lower when fertilizer was applied the previous year in the fall. This could be due to more leaching in the spring of the corn year, uptake of nitrogen by the corn, and more time available for denitrification.

There were few consistently significant differences in crop yields between treatments (Table 3 and Table 4) except that in 2007 the spring-125 treatment had statistically lower corn yield than the fall-125 treatment. Following nitrogen application in June of 2007 there was little rain at the project site until August 2007 which may have limited movement of the nitrogen down to the primary root zone for the growing corn crop and resulted in less access to the applied nitrogen. Overall, the results indicate limited yield impact due to timing of nitrogen application or, in this study, application rate from crop years 2006 to 2008.

Conclusion

There were no statistically significant differences in drain nitrate-N concentrations due to application of fertilizer in the fall versus the spring when considering annual flow weighted nitrate-N concentrations. However, during some of the spring months there were significantly greater monthly nitrate-N concentrations from the fall nitrogen application treatments indicating fall application of fertilizer may be slightly “riskier” than spring application. Findings from this study are consist with other studies at this project site (Lawlor et al., 2004) but differ from studies in Minnesota that found greater nitrate-N leaching with fall application in some years (Randall and Vetsch, 2005 and Randall et al., 2003). Likely the largest factor when looking at fertilizer application timing is when precipitation and associated nitrate-N loss occurs.

Acknowledgements

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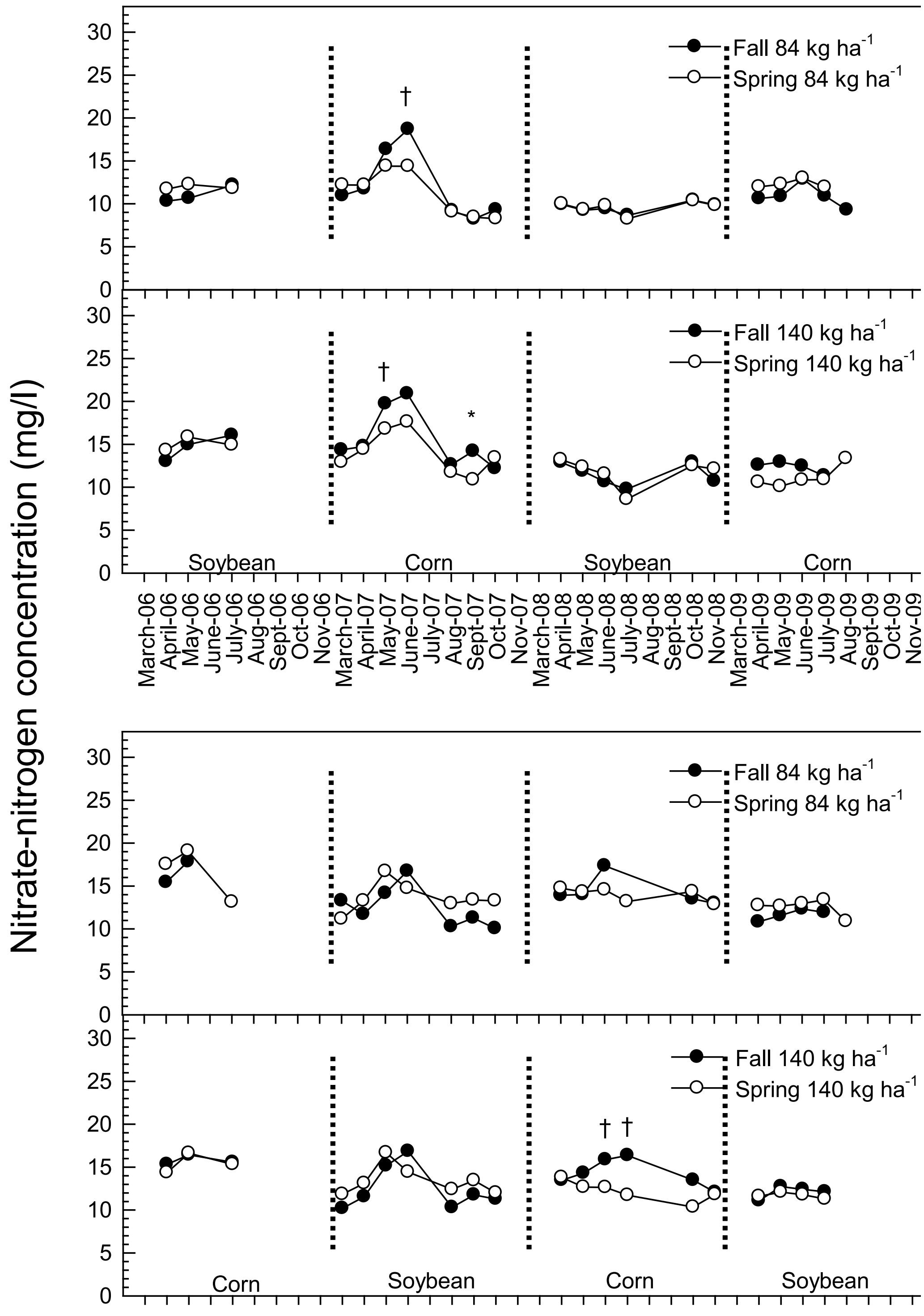

Figure 2. Monthly drain nitrate-N response to fertilizer application timing for 2006, 2007, 2008 and through August of 2009. The symbols represent significance where † denotes p = 0.10 and * denotes p = 0.05.

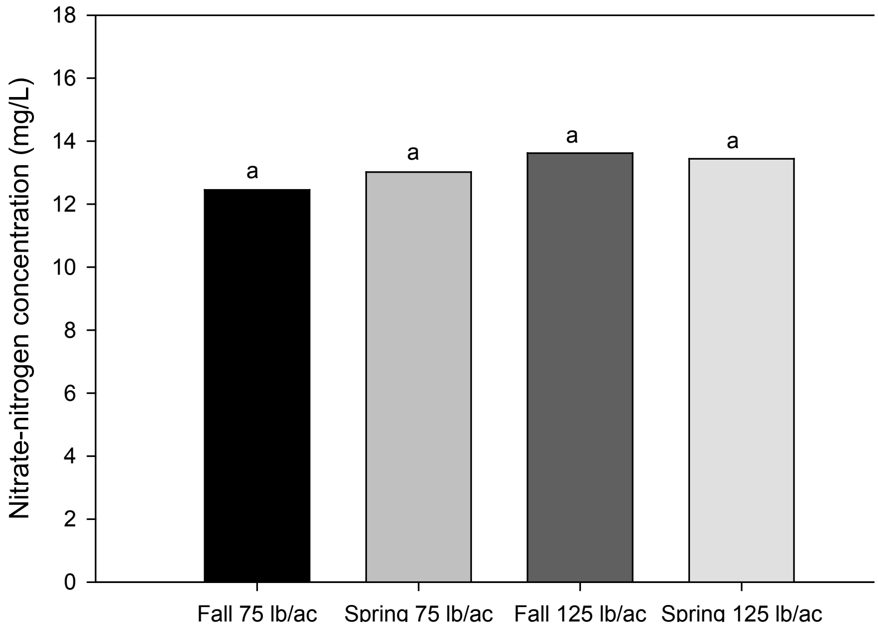

Figure 3. Three year (2006 to 2008) average flow-weighted nitrate-N concentration for fall and spring fertilizer application averaged over the corn-soybean rotation. Same letters indicate no statistically significant difference (p=0.05).

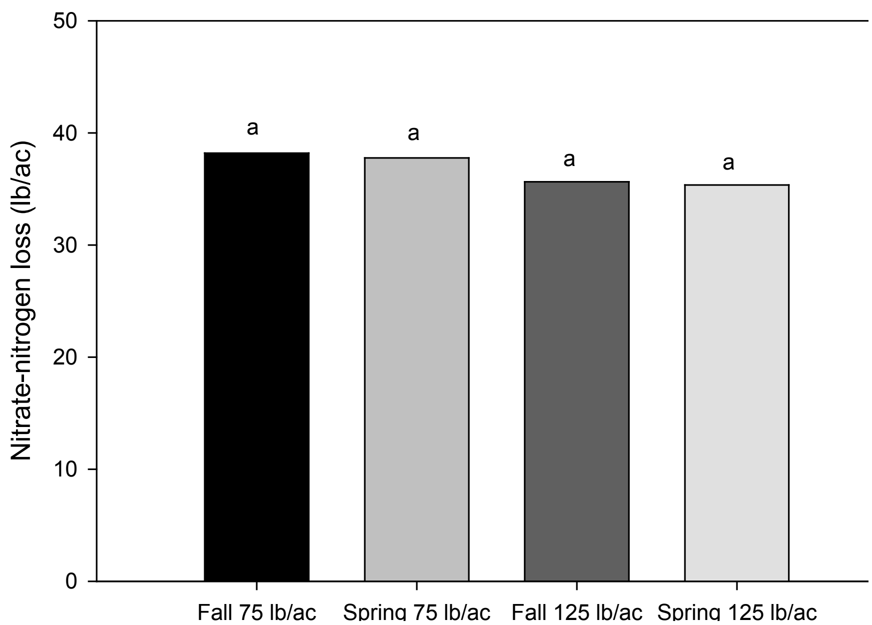

Figure 4. Three year (2006 to 2008) average nitrate-N loss for fall and spring fertilizer application averaged over the corn-soybean rotation. Same letters indicate no statistically significant difference (p=0.05).

Table 3. Corn yields for the 75 lb/ac and 125 lb/ac nitrogen application rates. Significance is within each year only.

Treatment	Yield (bu/ac)			
	2005	2006	2007	2008
Fall 84	156a	138a	138ab	163a
Spring 84	162a	148a	121bc	164a
Fall 140	164a	147a	143a	172a
Spring 140	173a	143a	116c	151a

Note: means with the same letter within years (i.e., within columns) are not significantly different at p = 0.05.

Table 4. Soybean yields for the 75 lb/ac and 125 lb/ac nitrogen application rates. Significance is within each year only.

Treatment	Yield (bu/ac)			
	2005	2006	2007	2008
Fall 84	50a	43b	36ab	36a
Spring 84	51a	55a	32b	45a
Fall 140	48a	50ab	37ab	45a
Spring 140	49a	48ab	44a	45a

Note: means with the same letter within years (i.e., within columns) are not significantly different at p = 0.05.

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