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Nitrate loss in subsurface drainage as affected by nitrogen application rate and timing under a corn-soybean rotation system

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Introduction

Subsurface agricultural drainage has allowed for enhanced crop production in many areas of the world including the upper Midwest, United States. However, the presence of nitrate-nitrogen (nitrate-N) in subsurface tile drainage water is a topic of intense scrutiny due to several water quality issues. Many studies have been conducted 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) and local water quality concerns, there is a need to understand how recommended nitrogen management practices, such as through nitrogen rate and timing, impact nitrate-N concentrations from subsurface drainage systems. The objective of this paper is to summarize results of studies from within Iowa and nearby states that have documented the impact of nitrogen application rate and timing on tile drainage nitrate loss.

Results from nitrogen rate studies

From 1990-2004, the impact of various nitrogen application rates on nitrate-N concentrations in subsurface drainage were studied at a site near Gilmore City, Iowa (Lawlor et al., 2008). From this work, the relationship shown in Figure 1 was developed relating nitrate-N concentration in a corn-soybean rotation to nitrogen application rate to corn. This relationship is useful to assess how changes in nitrogen application rate could positively or negatively impact nitrate-N concentration. Since this study was at only one location in Iowa, it is important to know if the nitrate-N concentration response is similar to that at other locations and soils. If so, then the relationship from Lawlor et al. (2008) can be used to estimate tile flow nitrate losses in other areas of Iowa. That comparison is shown in Figure 2. Results presented in Jaynes and Colvin (2006), Jaynes, et al. (2001), Jaynes et al. (2004), Kaspar et al. (2007), Weed and Kanwar, 1996, Bakhsh et al. (2002), Sawyer and Randall (2008), Randall and Sawyer (2008), as well as additional data from Walnut Creek Station 310 in Story County all show consistently similar trends of nitrate-N concentration with nitrogen application rate regardless of whether the study was plot or watershed scale (Figure 2). Consequently, the application rate and nitrate-N concentration relationship developed by Lawlor et al. (2008) seems to be applicable in general across Iowa. The relationship shown in Figures 1 and 2 can be useful in estimating potential changes in nitrate-N concentration as a result of changing nitrogen application rate. For example, an estimated state-wide average nitrogen application rate to corn in a corn-soybean rotation, considering fertilizer and manure nitrogen, might be in the range of 158 lb N/acre and the Maximum Return to Nitrogen from the nitrogen rate calculator (Sawyer et al., 2011) might be approximately 133 lb N/acre at $5.00 per bushel corn prices and nitrogen fertilizer costing $0.50 per pound N. Implementing a reduction in nitrogen application rate from 158 to 133 lb N/acre would be expected to result in a 15% decrease in tile flow nitrate-N concentration based on the relationship in Figures 1 and 2.

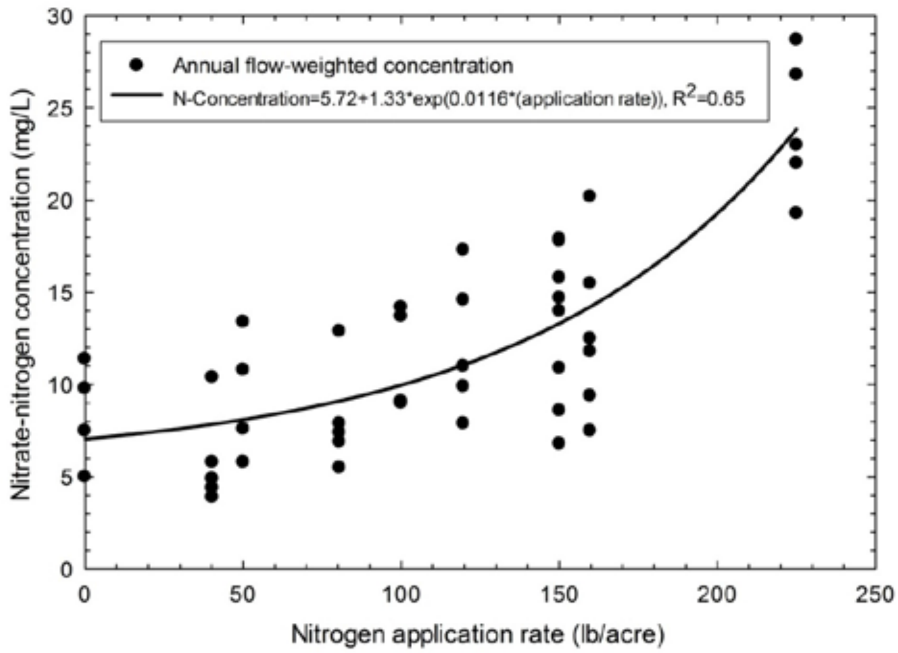

Figure 1. Overall nitrogen application rate effect on nitrate-N concentration in tile drainage for a corn-soybean rotation 1990-2004 (not all rates present in each year) from Gilmore City, IA (Lawlor et al., 2008).

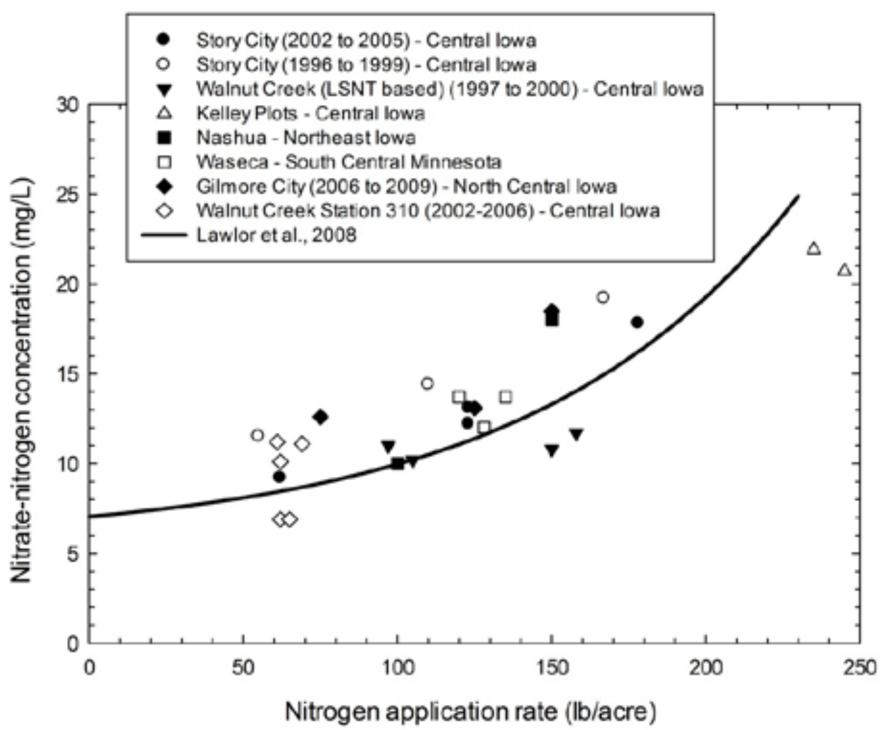

Figure 2. Nitrogen application rate effect from various studies on nitrate-N concentration for a corn-soybean rotation compared to the rate response curve developed by Lawlor et al. (2008).

Results from nitrogen timing studies

For timing of nitrogen application, a best management practice would be to apply nitrogen as close as possible to when the crop can use the nitrogen. However, there may be logistical reasons why this cannot be accomplished. As a result, there is a need for studies that investigate the impact of timing of nitrogen application on nitrate-N concentrations in subsurface drainage. The question of nitrogen application timing, fall versus spring or early season sidedress, has been studied for extended periods of time at sites near Waseca, Minnesota with anhydrous ammonia in a corn-soybean rotation (Randall and Mulla, 2001; Randall and Vetsch, 2005; Randall et al., 2003) and near Gilmore City, IA with aqua ammonia in a corn-soybean rotation.

The studies at Waseca have shown mixed results, with Randall and Mulla (2001) reporting a 20% load reduction when moving from fall to spring nitrogen application to corn in a corn-soybean rotation, and Randall and Vetsch (2005) and Randall et al. (2003) showing a combined average of 10% concentration reduction over the collective ten years of the study. Additionally, there were several years when nitrate-N concentrations were higher in the soybean year when nitrogen was applied in the spring to the preceding corn crop compared to when nitrogen was applied in the fall to the preceding corn crop. The range of observations for an individual year in these studies was an 80% increase in nitrate-N concentration to a 36% decrease for fall relative to spring application.

From 2001-2004, fall versus spring application of both liquid swine manure and aqua ammonia to corn in a corn-soybean rotation was investigated at the drainage research site near Gilmore City, IA (Lawlor et al., 2011). In this study aqua-ammonia was applied at nitrogen application rates of 150 lb N/acre and 225 lb N/acre and liquid swine manure was applied at a total nitrogen application rate of 200 lb N/acre. Results from this study indicated that timing of nitrogen application had little differential effect on nitrate-N concentrations in subsurface drainage (Table 1). The largest effect was rate of application.

Table 1. Flow-weighted nitrate-N concentrations for a corn-soybean rotation from 2001-2004 at Gilmore City, IA. Means within years and on average with the same letter are not significantly different at p = 0.05

Treatment	2001	2002	2003	2004	Average (2001-04)
		----- Nitrate-N concentration (mg L^{-1}) -----			
Fall 150	14.8d	11.7c	14.7b	15.7c	14.2c
Spring 150	18.0bcd	10.9c	15.0b	15.8c	14.9c
Fall 225	19.5bcd	17.4ab	19.7ab	19.9ab	19.0b
Spring 225	28.7a	19.3ab	23.0a	21.9a	23.2a
Fall Manure 200	17.0cd	15.6bc	18.6ab	16.0bc	16.8bc
Spring Manure 200	24.6abc	18.7ab	15.0b	15.1c	18.4b

Similar to the studies from 2001-2004 at Gilmore City, recent research from 2006-2009 also indicated little difference in fall versus spring application on nitrate-N concentrations in subsurface drainage (Tables 2 and 3). Studying monthly flow-weighted nitrate-N concentrations, there were some months where the concentrations of nitrate-N were higher when the nitrogen had been applied in the fall rather than the spring (Figure 3). While not different on an annual basis, these results suggest fall fertilizer nitrogen application may be slightly "riskier" than spring application.

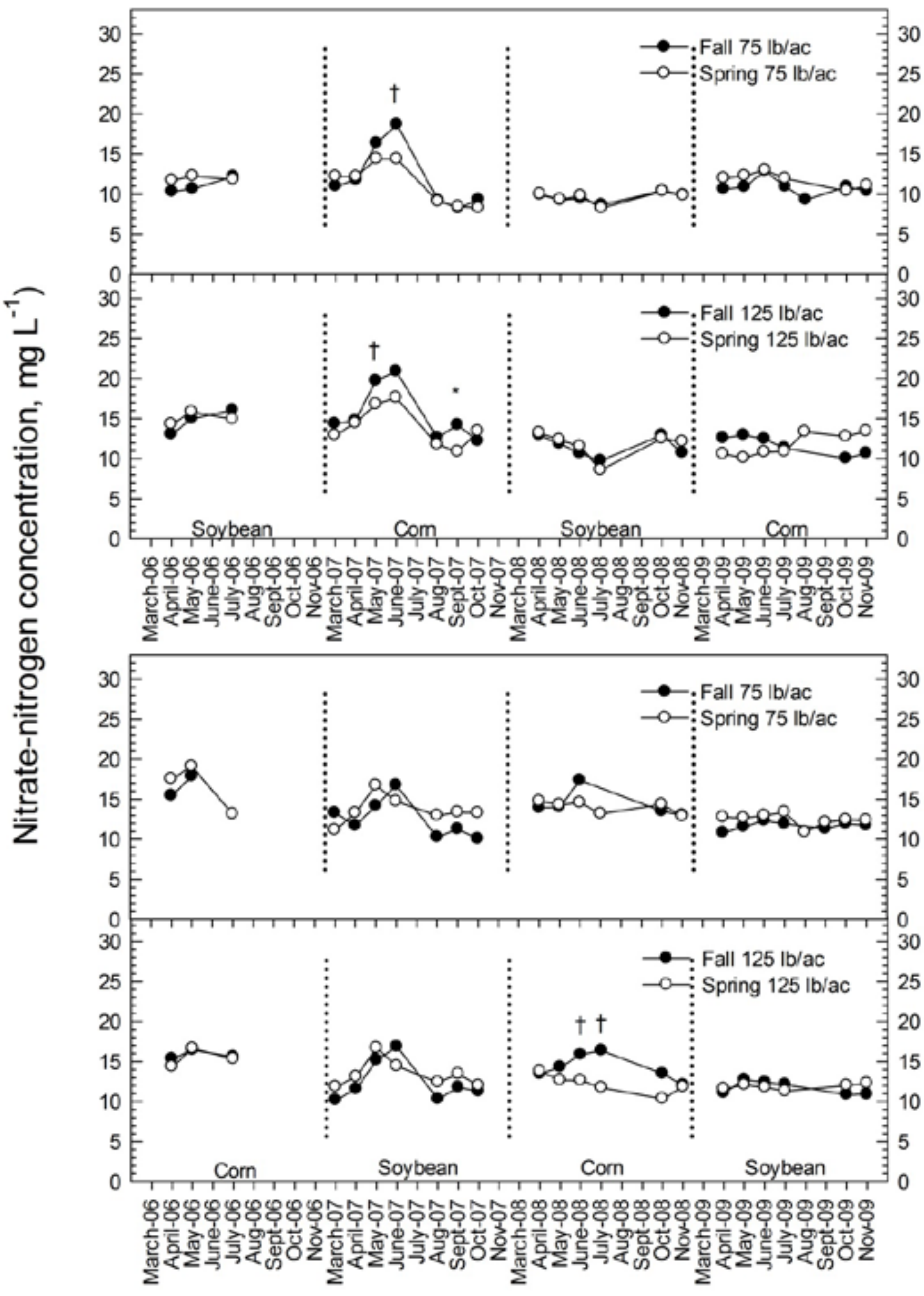

Figure 3. Monthly tile drainage nitrate-N response to fertilizer application timing for 2006-2009, Gilmore City, IA. The symbols represent significance where † denotes p = 0.10 and * denotes p = 0.05.

Table 2. Annual subsurface tile flow weighted nitrate-N concentrations in the corn year of the rotation for 75 lb N/ac and 125 lb N/ac from 2006-2009, Gilmore City, IA. Means within years with the same letter are not significantly different at p = 0.05.

Treatment	2006	2007	2008	2009
		----- Nitrate-N concentration (mg L^{-1}) -----		
Fall 75	17.3a	10.6b	15.7a	10.8a
Spring 75	18.3a	10.0b	14.5a	11.2a
Fall 125	16.0a	13.8a	14.9a	11.2a
Spring 125	15.4a	12.9ab	13.0a	13.0a

Table 3. Annual subsurface tile flow weighted nitrate-N concentrations in the soybean year of the rotation for 75 lb N/ac and 125 lb N/ac to preceding corn crop from 2006-2009, Gilmore City, IA. Means within years with the same letter are not significantly different at p = 0.05.

Treatment	2006	2007	2008	2009
		----- Nitrate-N concentration (mg L^{-1}) -----		
Fall 75	10.4a	11.1a	9.5a	11.9a
Spring 75	12.0a	13.5a	9.7a	11.8a
Fall 125	14.0a	11.6a	11.5a	10.9a
Spring 125	13.6a	12.9a	12.1a	11.9a

Conclusion

Studies that have examined nitrate-N concentrations in subsurface drainage using various nitrogen management practices are important for assessing the impact of in-field nitrogen management on water quality. Two management practices that receive considerable attention relative to nitrogen management are rate and timing of application. As expected, as nitrogen application rate to corn increases, the nitrate-N concentrations in subsurface tile drainage water increase. This highlights the need for appropriate nitrogen application to corn and to avoid over application. However, it is important to note that even when recommended nitrogen application rates are used, nitrate-N concentrations in subsurface drainage are still elevated and may exceed the EPA drinking water standard for nitrate-N of 10 mg L^{-1}. Relative to timing of nitrogen application, i.e. moving from fall to spring application, studies conducted in north-central Iowa and south-central Minnesota have documented little to moderate potential to decrease nitrate-N concentrations. Likely the largest factor when looking at the effect from fertilizer application timing is when precipitation and associated nitrate-N loss occurs. Although timing of nitrogen application is important, much of the research collected would tend to support conclusions reached by Power and Schepers (1989) that perhaps the most important factor is to apply the correct amount of N.

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