Nitrates in Drainage Water in Minnesota

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THE SITUATION

Nitrogen (N) is the single largest component of the atmosphere, and is an important building block for all living organisms. It is found in many different forms in the soil depending on the Nitrogen Cycle (*Understanding Nitrogen in Soils*, O'Leary et al., 1994). It is taken up by crops in greater quantities than any other added nutrient. Grass crops, such as corn and wheat, require the addition of N-based fertilizers to maximize productivity. Legume crops, such as soybeans and alfalfa, do not require additional N inputs because they have the ability to fix N from the atmosphere in their root systems. Overall, N sourced by crops for plant growth comes from fertilizer, soil organic matter, atmospheric deposition, animal manure, and fixation (for legumes only).

Losses of nitrate, a mobile form of N, to water systems have been a concern for many years because of human health issues. Ingestion of nitrate by mammals, especially human infants < 6 months old, interferes with the blood's ability to carry oxygen. Thus, a standard of 10 parts per million (ppm) of nitrate-N has been established for drinking water by the USEPA (http://water.epa.gov/drink/contaminants/basicinformation/nitrate.cfm). For decades, the primary focus has been on ground water because of its connection with drinking water. Less attention has been given to nitrate levels in surface water because of decreased dependence on surface water for drinking. This is also because phosphorus is typically the limiting nutrient in surface waters in Minnesota, meaning that excess nitrate does not usually lead to increased plant and algae growth (considered significant surface water quality problems). For decades, there has been no established contaminant standard for nitrate-N in class 2 (aquatic life and recreation) waters in Minnesota (*A Minnesota Farmer's Guide to Federal and State Clean Water Law*, Carlson et al., 2012). Standards are currently under development, though, and are being phased in over the next few years.

Artificial drainage is not the only source of nitrate to surface waters, but it is the most easily seen, and measured, and therefore under more scrutiny than other transport mechanisms.

Recently, Hypoxia in the Gulf of Mexico has led to increased scrutiny on nitrate contributions to surface waters from agricultural systems (*Gulf Hypoxia Action Plan,* USEPA, 2008). Subsurface agricultural drainage or "tile drainage" has been the primary focus of the scrutiny. Tile drainage is a highly visible pathway of water transporting nitrate from the landscape to surface waters. Other pathways of water movement from the landscape, such as leaching, shallow groundwater flow, and surface runoff, are less visible and more difficult to sample and quantify.

The University of Minnesota established Best Management Practices (BMPs) for the application of N fertilizer in the early 1990s; they were updated in 2008 (*Best Management Practices for Nitrogen Use in Minnesota*, Lamb et.al.). These region-specific BMPs are detailed guidelines designed for the efficient use of N fertilizer to maximize profit, while minimizing N loss to the environment. The BMPs focus on management factors like N application timing, N fertilizer source, and the use of nitrification inhibitors (which delay the conversion of ammonium to nitrate). Additional aspects include soil nitrate testing, split applications, and the use of supplemental N under certain circumstances. Other extension bulletins (*Fertilizing Corn in Minnesota*, Rehm et al., 2006, and *Fertilizer Guidelines for Agronomic Crops in Minnesota*, Kaiser et al., 2011) provide N rate recommendations for most agronomic crops grown in Minnesota.

The increased attention being placed on the loss of nitrate via agricultural drainage has led many to call for significant changes in both management of N fertilizer, and of agricultural drainage systems. It is essential that if improvements are to be made, there is a full understanding of nitrate fluxes from agricultural systems in Minnesota, as well as how N management can affect losses. Plans to reduce nitrate in surface waters will need to account for inputs, set reduction goals, and develop management strategies on both a watershed and an individual farm level. Several conservation technologies have been developed which reduce nitrate from surface waters after it is already present (https://engineering.purdue.edu/watersheds/conservationdrainage/index.html.). This publication looks at the impact that management of N fertilizer inputs can have *prior* to loss to surface water.

A LOOK AT OVERALL N LOSS

Corn is the most important crop in Minnesota in terms of total acreage and economic value (*Minnesota Agricultural Statistics*, USDA NASS, 2012). In addition, it is the single largest user of N fertilizer on the Minnesota landscape. Most of the corn in Minnesota is either continuous (corn following corn), or in a rotation following soybeans. Investigations on nitrate loss from cropping systems in Minnesota have looked at all aspects of a crop rotation, but have focused on corn, for the afore mentioned reasons.

Research data on nitrate loss from cropping systems through drainage systems is not as common as one might think. In Minnesota there are plots used to measure drainage water quantity and quality located at the University of Minnesota Research and Outreach Centers in Waseca (SROC) and Lamberton (SWROC). These were established in the early 1970s. In the nearly 40 years that these plots have been used, they have examined many of the aspects of N management including: rate, application timing, source, and the use of nitrification inhibitors. In addition, they have looked at various crops grown in rotation, tillage practices, and mineralization of N from soil organic matter.

Plots to collect drainage water were established at the Southern Research and Outreach Center in Waseca in 1975. The collection of data was automated in 2009.

The drainage plots at the ROCs measure the total discharge of drainage water and the nitrate concentration of the water. These numbers are used to calculate the total edge-of-field outflow of N via the drainage system. Nitrate loss from tile drainage water varies greatly from year to year, primarily based on the total outflow of water from the tiles. In addition, Randall (2004) showed an increase in soil nitrate stored in the soil profile following dry years was then subject to loss during wet years. For this reason, total nitrate-N loss is usually presented as either an average across years or a total amount over several years. Another method is to calculate nitrate concentration as a flow weighted (FW) mean (which accounts for variability of total water flow from individual plots).

A literature review of a large number of drainage studies worldwide shows annual nitrate-N loss via tile lines varies from 0 lb/A to 124 lb/A (Randall and Goss, 2008). Plots kept devoid of vegetation (fallow) at Waseca measured an average annual loss of nearly 20 lb. nitrate-N/A from bare ground (G.W. Randall, personal communication, 2013). The source of this nitrate loss was from N mineralized from organic matter. Corn grown without the addition of N fertilizer lost around 10 lb. nitrate-N/A annually (Randall and Vetsch, 2011). Loss rates from soybeans (which received no N fertilizer) were nearly identical (Table 1). Generally, annual losses with row crops, where corn received near-optimum rates of N, ranged from 15 lb. nitrate-N/A (Table 1) on the low end at Waseca to 40 lb/A on the high end (Table 2) at Lamberton during four wet years. A separate project at the SROC using larger plots located approximately one mile away confirmed annual losses ranging from approximately 10 to 18 lb./A (Sands, et.al., 2008). Over the 40+ years of drainage research at the ROCs the only method shown to drastically reduce nitrate loss was to use perennial vegetation (as either native prairie plants or alfalfa) at the Lamberton site (Randall and Mulla, 2001). Over a four year period these plots had an annual average flow weighted nitrate concentration ranging from near zero to a high of 4 ppm. In addition, because the total drainage volume was greatly reduced, loss rates of nitrate-N averaged only 1 – 1.5 lb./A (Table 2).

Crop Rotation	N Rate	N Time	Nitrate-N 4-Yr Avg. Conc.	4-Yr Total
	lb/A		ppm	lb/A
C-S-Corn	0		6.1	37.7
	60+40	SPL	7.8	44.8
	120	PP	8.2	52.1
S-C-Corn	0		4.6	34.0
	60+80	SPL	7.9	64.2
	160	PP	8.8	62.8
C-C-Soybeans	0		5.5	30.5
	0		8.4	40.9
	0		8.7	38.3

SPL – Split Applied, PP – Pre-Plant Application

Table 1. Four year nitrate-N loss from a corn-corn-soybean cropping system at Waseca from 2007 – 2010. Nitrate losses calculated for the crop underlined in the Crop Rotation column. (Randall and Vetsch, 2011)

Cropping System	Total Discharge 4-Yr. Cumulative	Nitrate-N 4-Yr Avg. Conc.	4-Yr Total
	Inches	ppm	lb/A
Continuous corn	30.4	28	194
Corn – soybean	35.5	23	182
Soybean – corn	35.4	22	180
Alfalfa	16.4	1.6	6
CRP	25.2	0.7	4

Table 2. Effect of cropping system on cumulative drainage volume, nitrate-N concentration and N loss in subsurface tile drainage during a 4 – year period (1990 – 1993) at Lamberton. (Randall, et. al., 1997)

THE EFFECT OF RATE

Crop response to fertilizer N rate generally follows a curve, where yield is maximized at some point and additional N inputs do not increase crop yield. The point where additional N inputs no longer produce an economic return is called the Economic Optimum N Rate (EONR). Recommendations are based on EONRs from a large number of sites and years. Further examination of the response curve relationship (Figure 1) shows how adding additional fertilizer N at or above the EONR results in little or no additional yield. This is accompanied by greater accumulation of residual soil nitrate after harvest which is susceptible to environmental loss. This relationship shows the importance of rate, as excessive N inputs are highly likely to be lost to the environment.

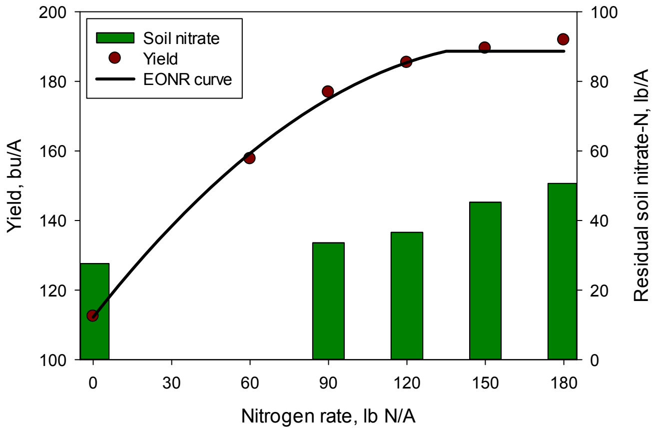

Figure 1. Corn grain yield and residual soil nitrate-N response as affected by fertilizer N rate on a Webster clay loam soil near Waseca, MN, averaged from 2001 - 2003. Note that the amount of residual N follows a similar curve but inverse to yield response to N (Vetsch and Randall, Unpublished).

APPLICATION TIMING AND THE USE OF INHIBITORS

Fall application of N fertilizer is a common practice in much of Minnesota. However, current BMPs do not recommend fall application in the southeastern part of the state (where there is very little artificial drainage) (*Best Management Practices for Nitrogen Use in Southeastern Minnesota*, Randall et.al, 2008). The use of urea as a fall fertilizer source is recommended only in the western part of the state where annual precipitation averages < 26 inches. A nitrification inhibitor is recommended with fall application of anhydrous ammonia (AA) in South Central Minnesota where annual precipitation is around 35 inches.

A recent trend toward more continuous corn has resulted in less fall application of N. Most farmers find fall application of AA difficult due to the presence of corn residue from the previous year, especially with conservation tillage. A survey conducted in 2011 showed approximately 40% of N fertilizer was applied in the fall in Southwest, West Central and South Central Minnesota (Bierman, et. al, 2011).

Research has shown, on average, fall applications of AA with a nitrification inhibitor (where recommended) have similar nitrate-N losses as spring applications (Randall and Vetsch, 2005). This, of course, varies from year to year based on climatic conditions. Mild falls and wet springs tend to increase nitrate loss. Randall (unpublished data) showed that spring applications had greater corn yields than fall applications of AA with an inhibitor (Table 3). Increased yield (although not always statistically significant) is likely indicator of decreased loss of N into the environment.

				2000-2003			4 Year
N application			FW NO_3-N	NO_3-N Lost			Corn Yield
Rate	Time	N-Serve	Conc.	C	Sb	Total	Avg.
lb N/A			mg/L	-- lb/A/4 cycles - -			bu./A
80	Fall	Yes	11.5	115	90	205	144
120	Fall	Yes	13.2	121	99	220	166
160	Fall	Yes	18.1	142	139	281	172
120	Spr.	No	13.7	121	98	219	180

Table 3. Nitrate-N concentrations, losses in tile water, and corn grain yield as affected by rate and time of N application (as anhydrous ammonia) at Waseca (2000–2003). (Randall, Unpublished)

THE IMPACT OF CLIMATE AND A GROWING CROP

The volume of water moving through tile lines is determined by available water in the soil profile, evapotranspiration (plant water use and evaporation), and precipitation. Therefore, movement of water through artificial drainage can be thought of as episodic, or characterized by events. An actively growing crop also affects this as root penetration into the soil profile and water demand by the growing plant decreases available water in the soil profile (making saturation and therefore movement by artificial drainage less likely). In Southern Minnesota, soils are typically frozen from early December until late-March. Examination of 15 years of drainage records from the SROC show that the majority of tile drainage occurs in April, May and June (Figure2). While there can be drainage events in the later months of the growing season, they are unpredictable, and tend to be shorter in duration and volume. One set of drainage plots at the SROC showed a 15-year average of 50% of total drainage volume occurring in just 7 days annually (Randall, 2004).

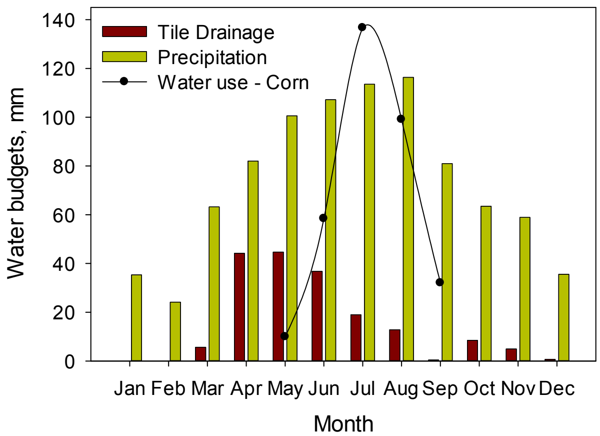

Figure 2. Relationship between monthly subsurface tile drain flow from facility B in 1987 – 2001 and 30 year normal monthly precipitation and water use (ET) by corn at Waseca, MN. (Randall, 2004. Used with permission.)

The loss of N via tile drainage is not only the result of water movement, but also the presence of nitrate in the soil profile. Total N losses on a lb/A basis mirror drainage volumes when looked at on a month by month basis (Table 4). Drainage research at Waseca showed over 70% of all N lost through tile lines occurs in the April – June window (Randall, 2004).

Month	Drain Flow	Nitrate Loss
	----------% of Annual Total----------	
January	0	0
February	0	0
March	3	2
April	25	17
May	25	29
June	21	27
July	11	14
August	7	6
September	<1	<1
October	5	3
November	3	2
December	<1	<1

Table 4. Monthly Distribution of annual subsurface tile drainage and nitrate–N losses for corn in a corn/soybean crop rotation for a 15 yr (1997 – 2001) period at Waseca, MN (adapted from Randall, 2004).

MANAGING TO MINIMIZE NITRATE LOSS

The well documented increase in the amount of artificial drainage in significant portions of Minnesota can be attributed to the overall profitability of this practice, as well as the increased efficiency of farmer's time (*Drainage Fact Sheet*, Sands, 2011). This has been accompanied by scrutiny regarding potential negative impacts; nitrate loss being one of the primary concerns. Minimizing nitrate loss via artificial drainage is in the best interest of everyone. It not only makes sense from an environmental standpoint, but also from an economic one.

Glacial till soils found in much of Minnesota are very important to agriculture because of their high organic matter content, available water holding capacity, and fertility. These soils have the potential to mineralize significant amounts of nitrogen from their organic matter. About 20 lb nitrate-N /A are lost through drainage systems annually when the soil is kept bare. This represents the soil's contribution from soil organic matter which is typical in much of the agricultural portions of Minnesota. Corn grown with no N fertilizer inputs still loses an average of about 10 lb. nitrate-N/A. Soybeans, despite being a legume that receives no N inputs, lose about the same amount. The bottom line is that our current crop rotations involving corn and soybeans are leaky with respect to nitrogen.

The N cycle dictates that conversion of the various forms of organic N must occur before nitrate is present in the soil. This conversion, caused by the actions of microorganisms, is dependent on temperature and time. The subsequent movement of nitrate is dependent on the presence of water in excess of field capacity. The water demand of a growing crop lessens the likelihood of a drainage event. This timing also corresponds with the plant's need for N. Logically, placement of N into the soil profile as a fertilizer addition would ideally be as close to the time that a plant needs the nutrient as possible to minimize the chance for loss into the environment. Best Management Practices dictate the minimum requirements to prevent excessive N loss. By further delaying application to better correspond with planting, or even split-applying so that some of the application occurs to a growing crop, chances of a significant leaching event are lessened. However, caution must be taken when late side dress (in-season) applications are surface-applied and not incorporated, as without meaningful rainfall for 10 to 20 days, this N could be lost to the atmosphere. In addition it could become positionally unavailable to roots. In either case, yields will suffer due to lack of available N.

Over-application of N fertilizers is another factor within the farmer's control. Generally, nitrogen loss through tile drainage increases as N rate increases, especially at N rates greater than the economic optimum. As illustrated above (Figure 1), changing the N rate from 120 lb/A to 150 lb/A in corn following soybeans only increased yield by 4 bushels per acre, but increased the amount of residual N left in the soil profile (which is then subject to leaching) by 40%. The application of nitrogen at rates higher than the EONR represents both an economic risk associated with higher than necessary fertilizer costs and a local environmental risk associated with potential losses and should be avoided. As the departure from EONR grows, so does the risk of nitrate loss to the environment.

There is the potential to fine tune rates and timing to provide some nitrate reduction in surface waters, but time, climatic, and crop growth constraints set limits on how much can be achieved. Ultimately, technology and methods to mitigate nitrate in drainage and surface water may be necessary to achieve overall reduction goals from row crop systems.

The USEPA has set a target for a long term reduction of nitrates in the Mississippi River of 45% (*Gulf Hypoxia Action Plan, USEPA,* 2008). Logically, following BMPs with respect to rate, source, timing and the use of nitrification inhibitors is an important first step in reaching this goal. Current rates of adoption of BMPs are not well documented. Moreover, model projections by Fabrizzi and Mulla (*in* Wall, 2013) suggest only modest improvements can be achieved by further BMP adoption. Delaying applications until later in the season may also achieve some reductions, but need to be evaluated accounting for the farmer's ability to accomplish the application at the desired timing. These recommendations correspond with the national campaign for fertilizer applications to follow the 4Rs. The 4Rs include: the Right Fertilizer Source at the Right Rate in the Right Place at the Right Time. To learn more about the 4Rs visit www.nutrientstewardship.com.

In the end, our current cropping systems leak N and only perennial vegetation has been shown to be effective at scouring N from the soil profile. It needs to be noted, though, that while the environmental benefits of this practice are clear, an economic system to support these crops does not exist, and therefore the cost is high.

It is beyond the scope of this publication to consider a landscape-wide plan to achieve desired reductions, but many theories, suggestions, and plans for accomplishing this will be forthcoming. In the mean time, farmers and their ag advisors need to focus on making both economically and environmentally sound management decisions. These practices are easily within their control. They should also stay informed on new developments or practices that might achieve further reductions.

What About Manure?

Research conducted at the SROC found no differences in nitrate-N loss via agricultural drainage between manure and commercial fertilizer, provided recommended rates and application methods were used (Randall, et al., 2000). You can find a detailed discussion on manure management in "Manure Management in Minnesota" by Hernandez and Schmitt (2012).

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For more information on agricultural drainage visit: www.drainageoutlet.umn.edu.

For more information on nitrogen and nutrient management visit: www.swac.umn.edu/ExtensionandOutreach

This publication was supported by Minnesota corn growers and their check-off.

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