Nitrogen BMP's for Corn in Minnesota

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The purpose of this report, prepared for the Minnesota Center for Environmental Advocacy, is to review and assess the Minnesota Department of Agriculture's ("MDA") current proposal (Nitrogen Fertilizer Rule) to adopt restrictions on the fall and winter application of nitrogen fertilizer and adopt a "menu" of potential water resource protection requires ("WRPR") that could be required in specific areas of the state via an order of the Commission of the Department of Agriculture.

MDA is currently proposing to:

1) Restrict application of nitrogen fertilizer in the fall or to frozen soils in areas of the state overlying vulnerable groundwater.
2) Identify mitigation level areas based on well water sampling for nitrogen-N concentrations and adopt WRPR's for mitigation levels 3 and 4.

While MDA's proposal for adoptions of WRPRs is directionally correct, MDA's proposed WRPRs are not designed to, and cannot independently, prevent and minimize the nitrate pollution to the extent practicable; or prevent nitrate pollution from exceeding the health risk limit.

The University of Minnesota's recommended Best Management Practices (BMP's) for nitrogen fertilizer use are found in a series of University of Minnesota Extension bulletins written for specific geographic areas of the state and were published in 2008. These recommendations fall within and provide specifics for the currently popular 4R approach (right application rate, right source, right time of application and right placement). These BMP's were developed from research based on yield optimization and the production economics of corn and not specifically on water quality indices. Environmental metrics such as nitrate concentration in drainage water or in the soil at the end of the growing season have been frequently measured along-side of agronomic and production metrics over a 33-yr period by this scientist in research studies located at Waseca, Lamberton and in southeastern Minnesota. In the future, scientists must collect agronomic and environmental data side by side in numerous studies located around the state if a robust data set is to be built, allowing N BMP's for Minnesota to be based on agronomic, economic and environmental water quality measurements.

Summary

General Recommendations

- Using the right/correct rate of N is a foundational BMP from an economic and water quality perspective. Of all fertilizer N management practices, rate of application has the greatest potential for influencing nitrate losses to ground and surface waters. When determining the total N rate to apply, all forms of N should be included, i.e., N in starter fertilizer, weed and feed N, and ammonium-N in phosphate fertilizers. Nitrogen credits from previous crops and manure applications, requiring record keeping by the farmer, should also be included. Two additional practices that are sometimes associated with N rate decisions must be discontinued. They are: (a) application of excess “insurance” N generally associated with fall application and (b) using yield goal multiplied by a set K factor to determine the N rate needed. Neither of these practices is economically or environmentally sound.

- Spring application of N fertilizers is highly recommended regardless of N source. Corn grain yields are higher and nitrate losses are lower.

- No N is to be fall-applied to medium-textured SE Minnesota soils, coarse-textured sandy soils, and vulnerable soils throughout the state.

- Use split applications of N on coarse-textured soils.

- Incorporate broadcast or inject sidedress applications of urea and UAN into moist soil to a minimum depth of three inches.

- Restrict present “Acceptable, but with risk” BMPs if nitrate levels in ground and surface waters increase or BMPs are not used.

- Ag advisers (retailers, consultants, etc.) play a huge role in educating farmers and in advocating universal use of the 4Rs (right rate, right time, right source and right placement).
  - record keeping may be needed and should be considered in the more vulnerable areas and for fall application

- Cover crops perform quite well in Minnesota if planted by Sept. 1 when following sweet corn, peas, small grains, or corn harvested for silage. Innovative, newly developed planting equipment or aerial seeding may be successful for establishing cover crops in corn and soybeans well before harvest but risk of failure needs to be acknowledged.

- Use nitrification inhibitors (NI’s) such as N-Serve and urease inhibitors (UI’s) such as Agrotain and Limus when they are appropriate for reducing losses of yield and N.

- Shifting a small portion of Minnesota's corn acres to other non-N demanding crops, such as alfalfa into crop rotations or establishing perennials on marginal land areas would likely reduce nitrate losses more than simply implementing N BMPs for the current corn and soybean dominated landscape.

Primary BMP recommendations for southern Minnesota

Recommended

- Spring preplant application of ammonia and urea or split applications of ammonia, urea, and UAN are highly recommended.
- Under rain-fed (non-irrigated) conditions, apply sidedress N before corn is 12 inches tall (V7 stage).
- When soils have a high leaching potential (sandy texture), nitrogen application in a split application or sidedress program is preferred. Use a nitrification inhibitor (N-Serve) on labeled crops with early sidedressed N.

Acceptable, but with greater risk

- Fall application of ammonia + N-Serve after soil temperature at the 6-inch depth is below 50ºF in south-central Minnesota.
- Late fall or spring preplant application of ESN in south-central Minnesota.
- Spring preplant application of ESN in southeastern Minnesota.
- Spring preplant application of UAN.

Not Recommended

- Fall application of ammonia, urea, and UAN, with or without a nitrification inhibitor (N-Serve) in the 7-county area of southeastern Minnesota.
- Fall application of N to coarse-textured (sandy) soils.
- Application of any N fertilizer including MAP or DAP on frozen soils. (runoff in spring snow melt can be significant)
- Fall application of urea and ammonia without N-Serve and urea with N-Serve in south-central Minnesota.
- Fall application of UAN (28-0-0).

Field research recommendations

- Continue to conduct N rate research studies to determine corn yield response, net return to fertilizer N, N recovery in the corn plant, and residual soil nitrate in the soil profile in the fall after harvest and again the following spring (to determine leaching losses) on the medium-textured soils of SE Minnesota and similar vulnerable soils of the state. Collection of soil water at 5' or tile drainage would be helpful. These complete sets of production and environmental data will be relied upon and necessary to make improved N management decisions for Minnesota in the future.

- Conduct cover crop research to increase the success of earlier fall establishment or to select/develop those cover crops that tolerate limited light in dense corn stands in August. Perhaps combining cover crops with lower vegetative biomass corn hybrids would allow for improved early fall establishment. Research comparing the economic risk of reduced corn yields with different N management and cover crop scenarios vs. the environmental benefit of reduced nitrate losses to ground water should be conducted

- Crop rotation research involving a year or two of alfalfa in a rotation such as C-S-C-A-A or other crops is encouraged. Determining the efficacy of these rotations to reduce nitrate losses to ground and surface waters while optimizing net return would be particularly valuable in the vulnerable soils within areas of "high dairy cattle numbers".

General Conclusions

Will the 4R approach be successful in reducing nitrate-N losses to surface and ground water to meet the goals of Nitrogen Loss Reduction Strategies being established?

My answers are:

1) The 4R approach is directionally correct and helpful but will not accomplish the goal by itself in a landscape almost completely dominated by corn and soybean.
2) Universal commitment will be needed within the agricultural community (ag advisers, retailers, consultants, farmers, land owners, commodity groups, agricultural interest groups, etc.) to advance the 4R concept consistently and quickly.
3) Shifting acreage away from corn to other crops not requiring N or other cropping systems is the most effective strategy as it decreases N inputs to the landscape consequently reducing N losses significantly to ground and surface water.
4) Nitrate losses to ground and surface water are quickly and substantially reduced by perennial crops compared to annual crops. Shifting some of the least productive row-crop acreage to perennial-based conservation practices could reduce nitrate losses significantly while minimizing soil erosion and sediment losses to water bodies. Crop diversification has numerous ecosystem benefits compared to the current and dominant corn-soybean rotation.

<u>Review of Current Draft NFR</u>

After thoroughly reviewing the 5/24/17 version of MDA's NFR, the following three statements register my concerns and suggested revisions that should be considered.

1) The statement "after no fewer than three growing seasons, the commissioner shall conduct a re-evaluation" appears in lines 9.2-9.3, 9.12, 9.20, 14.17, 14.21 and 15.20. This seems to be an easy way to simply extend it to 4, 5, 6 or more growing seasons. Or will three growing seasons be firm unless extenuating conditions occur? Deleting "no fewer than" is suggested.

2) On page 11, line 11.19 states "i. for corn, using the *acceptable range* for the 0.10 ratio for corn at a minimum as defined in Fertilizing Corn in Minnesota". Because the N rate range often has a range of 20 to 30 lbs. N/acre, I am concerned that the high end of the N rate range will often be used by corn producers. Using the high N rate in this range is not likely to reduce nitrate concentration below the health risk level as frequently as the low end of the N rate range. Therefore, I would strongly suggest replacing *acceptable range* with <u>MRTN (Maximum economic Return to N</u>). Making this change to MRTN would mean using the N rate that is midway between the high and low N rates of the range. For instance, if the range is from 140 to 170 lb. N/acre the MRTN would be 155 lb. N/acre. The 155 lb. N rate is the most economically optimum rate and would be a better environmental rate than the highest N rate (170 lb.) in the range. This change is especially important when dealing with mitigation levels 3 and 4. It is likely that the highest N rate in the range would lead to increased nitrate concentrations rather than reduced concentrations.

   The N rate situation becomes worse when southern Minnesota producers use Iowa State University base MRTN recommendation rates, which are 20 to 30 lb N/A greater than Minnesota's recommendations. If the producers or retailers use the high end of the Iowa MRTN range, the application rate becomes 30 to 40 lb N/A greater compared to Minnesota's base MRTN rate recommendation.

3) Under Subpart 1. **Mitigation level 3** on pages 24 & 25, another BMP should be added. I suggest: <u>M. crop diversification including perennial crops and alternative species not requiring N fertilization such as a 5-yr crop rotation with at least one year of alfalfa, grass-dominated cover-crops, and perennial grasses on buffers and marginal land areas.</u>

History

A series of BMP's were identified and assembled by the University of Minnesota and the Minnesota Department of Agriculture (MDA) as part of the Nitrogen Fertilizer Management Plan developed by the Nitrogen Fertilizer Task Force coordinated by MDA in 1990 and 1991. A series of seven (7) bulletins were developed for specific areas of the state (generally based on specific soil and climatic conditions) and were published by the Minnesota Extension Service in 1993. These N BMPs were broadly defined as "economically and environmentally sound, voluntary practices that are capable of minimizing nutrient contamination of surface and groundwater".

Based on numerous N research experiments between the early 1990's and 2005, involving both crop production and nitrate-N loss data, another set of management guidelines were developed to assist crop producers to manage their nitrogen in ways that optimize profitability, reduce risk, and minimize loss of nitrate to surface and groundwater. Similar to the 1993 publications, these voluntary management practices were published in a series of U of M Extension bulletins in 2008 to be adopted on a statewide as well as a regional basis. In these publications, the management practices (BMP's) have been divided into three categories: (1) recommended, (2) acceptable but with greater risk, and (3) not recommended. The risks can be either economic (input cost or yield) or environmental (potential for loss of nitrogen to ground or surface waters).

Nitrogen Management Practices

Rate of N Applied

Using the correct amount of N as opposed to extra "insurance" N optimizes crop yield while minimizing N loss to the environment. However, there are two factors leading to the optimum N rate: (1) N becoming available from the soil and (2) N added as fertilizer N to meet the crop's total N need. Unfortunately, two uncontrollable factors (precipitation and temperature) affect the release of N from the soil as well as the amount of N needed by the crop.

For many years the optimum N rate for corn in the Midwest was determined by multiplying the yield goal times a factor of 1.2, i.e., 160 bu/A x 1.2 = 192 lb N/A minus N supplied by the previous crop. Nitrogen fertilizer recommendations in Minnesota used a somewhat similar process, but they also included the level of soil organic matter. By the late 1990's this method of determining the rate of N to apply was being questioned by Minnesota and Midwest agronomic scientists. Consequently, a massive effort by them involved the collection and interpretation of data from hundreds of fertilizer N rate response studies with corn in Illinois, Iowa, Minnesota, and Wisconsin. The data showed yield goal was not a good predictor of the N rate needed. Instead, the recommended rate of N to apply was determined to be within a range of N rates, depending on the productivity of the soil, previous crop, and the ratio of the price of fertilizer N to corn price. Each year additional N rate studies are conducted in all states to increase the size and value of the database and to include the newest corn genetics and higher yield potentials.

For southern Minnesota with 109 sites, the range of N rates for corn after corn and corn after soybeans using a fertilizer N price of $0.35/lb and a corn price of $3.50/bu is 141-160 lb/A and 98-122 lb/A, respectively. The maximum economic return to N (MRTN) is 149 and 108 lb/A, respectively. Thus, on highly productive soils a N rate of 149-160 lb/A is recommended for corn after corn and 108-122 lb/A for corn after soybeans. On lower productively soils where the yield potential is less due to limited water holding capacity, the recommended N rates are 141-149 lb/A for corn after corn and 98-108 lb/A for corn after soybeans.

As one can see from this discussion the recommended N rates for corn are based totally on the production economics of corn as influenced by a large N rate response database and soil productivity. The economics or risk of N loss to ground or surface waters is not included because it is an uncontrollable factor and is not predictable at the time of N application.

Rate of N application has a huge effect on corn yield/production and on nitrate-N losses on both well-drained and poorly-drained soils. On a well-drained Port Byron soil in Olmsted Co., three-year average continuous corn yields ranged from 65 bu/A with 0 lb N/A to 164 bu/A with 140 lb N/A. Residual nitrate-N in the 0-7' soil profile after harvest with the 0, 90, 120, 150 and 180 lb N/A rates averaged 35, 45, 65, 110 and 140 lb nitrate-N/A. These data clearly show the huge yield response to fertilizer N coupled with the large amount of nitrate-N remaining in the soil in the fall when the applied N rate was above optimum. These high levels of residual N would be expected to leach from the 0-7' profile into the groundwater acquifers between Nov. 1 and mid-June the next year when corn roots would be taking up soil N and fertilizer N again. In a 5-yr study on the same soil, corn yields following soybeans averaged 72% of maximum yield with no fertilizer N (In other words, the soil supplied 72% of the N needed for maximum yield. The remaining 28% would come from fertilizer N). When 90 lb N/A was applied, yields reached 97% of maximum yield. When rates of 120 and 150 lb N/A were applied, yields attained 100% of maximum. Residual nitrate in the 0-5' soil profile after harvest (Nov. 1) totaled 30, 40, 75 and 95 lb NO_3-N/A for the 0, 90, 120 and 150 lb N/A fertilizer N rates. These data also support the high potential for large leaching losses of nitrate to groundwater acquifers when N rates applied are in excess of optimum.

In poorly drained soils the effect of N rate on corn yield, profitability, and nitrate loss to tile drainage is shown in Table 1. Compared with the standard 120-lb N rate applied in the fall, adding an additional 40 lb N/A (160-lb N rate) increased yield 6 bu/A (4%), increased net profit by $7/A (5%), and increased NO_3-N concentration in tile water by 4.9 mg/L (37%). In other words, the economic gain from excess N was small compared to the large environmental effect of increased nitrate loss to water. On the other hand reducing N rate from 120 lb N/A to 80 lb/A reduced yield 22 bu/A (13%), reduced net profit $63/A (45%), and reduced NO_3-N concentration in the water by 1.7 mg/L (13%). Greatest yield and profit with a minimal increase in NO_3-N concentration (4%) was found with the spring-applied 120-lb N rate. (Net profit was calculated using corn = $3.50/bu, N fertilizer = $0.35/lb N, and N-Serve @ $10/A). These data clearly demonstrate two fundamental findings: (1) the importance of using the correct N rate as a cornerstone BMP from an economic and water quality perspective and (2) the net return advantage (42%) of applying the correct rate of N in the spring compared to the fall with minimal effect on NO_3-N concentration (4%).

Table 1. Effect of N rate on yield of corn after soybean and nitrate-N concentration in tile drainage at Waseca (2000-2003).

N Treatment			4-Yr Yield	4-Yr FW
Time	Rate	N-Serve	Avg.	NO_3-N conc.
	lb/A		bu/A	mg/L
---	0	---	111	---
Fall	80	Yes	144	11.5
Fall	120	Yes	166	13.2
Fall	160	Yes	172	18.1
Spr.	120	No	180	13.7

Compliance with applying the correct rate ("Right Rate") of fertilizer N does not come easily and without well-ingrained attitudes, thoughts, perceptions, and challenges from a variety of positions. First, because the price of N fertilizer has generally been low compared to crop price and because wet growing season conditions can cause loss of N, farmers will often apply an extra 20 to 50 pounds of "insurance N" to ensure that yield-limiting conditions not occur due to insufficient N. This is particularly true in years when crop prices are high and the potential exists for a high net economic return to fertilizer. Second, no farmer, dealer, ag adviser/consultant or landlord likes to see N deficiency symptoms (yellow corn) occurring, especially early in the season. Dark green, robust, even-looking corn is a "hallmark" visual assessment of a grower's ability to profitably produce corn. Yellow, N deficient corn has been known to terminate land rental agreements. Third, N credits from previous crops and previous manure applications vary if various crops were grown and manure sources and rates differed from field to field. This requires careful record keeping if correct N rates are to be applied for each field. Fourth, the amount of soil N mineralized to become available for the growing crop can be variable and is at this time not easily predictable. Thus, applying a slightly greater amount of fertilizer N is often done. Fifth, farmers often do not make their own fertilizer N rate recommendations; they rely on their retailer/dealer or on an ag advisor/consultant. This can present a problem, especially for the retailer who has a service and a product to sell. Trimming the "safe" higher-than-recommended rate to the correct/right rate of fertilizer N may be good for the farmer and the environment, but it may not be good for the retailer's bottom line because of reduced fertilizer sales volume - - - a primary profit stream for them. This can put the retailer on a slippery slope especially if part of the service required by the farmer is to minimize loss of nitrate to ground and surface waters. Consultants on the other hand have a service to provide and sell, but no fertilizer product to sell. Thus, they can adopt their fertilizer recommendations more easily to a correct/right rate of application that considers the risks of both profitability and environmental losses of N to ground and surface waters. Sixth, the total N rate should include any N applied in a starter, weed and feed program, and contributions from phosphorus fertilizers such as MAP and DAP. Also, appropriate credits must be taken for previous legume crops and any manure used in the crop rotation. Seventh, historically fertilizer N recommendations have been made only from the production perspective. Combining an environmental perspective with the production perspective may take time for some fertilizer N advisers, but adapting to change rather quickly with good record keeping will be a successful approach for improved water quality and profitable production.

In summary using the correct/right rate of N has a high potential for improving net economic return for farmers while minimizing the loss of nitrates to ground and surface waters.

Time of N Application and N-Serve

Time of N application has been an issue in the northern latitudes of the U.S. since anhydrous ammonia (AA) became available in the 1950's. The thinking was that fall N would not be lost from soils that were frozen for 3-4 months during the winter. As a result, AA was being applied as early as the first week of October in the 1970's. Under warm conditions when the fall soil temperature was in the 60's, significant conversion of AA to nitrate (nitrification) occurred, which was then lost via leaching or denitrification. Since the rate of AA nitrification is a function of soil temperature, research on the process indicated that nitrification was slowed substantially at soil temperatures < 50ºF. Research on nitrification inhibitors (NI's) such as N-Serve in the 1970's and 80's in Minnesota showed that they significantly inhibited nitrification. As a result the following BMP guidelines for fall application of N in southern Minnesota have existed since 2008:

Not Recommended

- Fall application of ammonia, urea, and UAN, with or without a nitrification inhibitor (N-Serve) in the 7-county area of southeastern Minnesota.
- Fall application of N to coarse-textured (sandy) soils.
- Application of any N fertilizer including MAP or DAP on frozen soils. (runoff in spring snow melt can be significant)
- Fall application of urea and ammonia without N-Serve in south-central Minnesota.
- Fall application of UAN (28-0-0).

Acceptable, but with greater risk

- Fall application of ammonia + N-Serve after soil temperature at the 6-inch depth is below 50ºF in south-central Minnesota.
- Late fall or spring preplant application of ESN in south-central Minnesota.
- Spring preplant application of ESN in southeastern Minnesota.
- Spring preplant application of UAN.

Recommended

- Spring preplant applications of ammonia and urea or split applications of ammonia, urea, and UAN are highly recommended.
- Under rain-fed (non-irrigated) conditions, apply sidedress N before corn is 12 inches tall (V7 stage).

- When soils have a high leaching potential (sandy texture), nitrogen application in a split application or sidedress program is preferred. Use a nitrification inhibitor (N-Serve) on labeled crops with early sidedressed N.

As one can see by the above Time of N recommendations, the influence of soil texture (coarse, medium, and fine), precipitation and characteristics of the N source are dominating factors when determining the suitability of fall-applied N.

The following text describing some of the research conducted in southern Minnesota contains corn production and water (soil and tile drainage) data that support the above Time of N Application recommendations. Southeastern Minnesota is characterized by permeable silt loam soils with underlying fractured limestone bedrock. This "Karst" region, which also receives the greatest amount of annual precipitation in the state, is very susceptible to ground water contamination. Consequently, few studies have examined fall application with spring and in-season N applications receiving most attention. A 4-yr study conducted in Olmsted Co. showed little yield average difference among the time of application treatments, but in the wet year (1990, 1987-89 were dry) fall-applied AA with and without N-Serve produced lower yields and greater NO_3-N concentrations in the soil water at 5' than did spring applications (Table 2).

Table 2. Corn yield and NO_3-N concentration in the soil water at 5 feet as affected by rate and time of application in Olmsted Co., 1987-90.

Nitrogen Treatment		Grain Yield		Nitrate-N Conc. in Soil Water[1/]
Rate	Time/Method	1990	1987-90	
lb N/A		- - - - - - bu/A - - - - - -		ppm
0	--	76	84	1
75	Spr., preplant	145	156	11
150	" "	155	172	29
225	" "	156	167	43
150	Fall	145	169	43
150	Fall + N-Serve	148	169	50
75 + 75	Spr. + SD (V7)	154	168	47

[1/] Fall, 1990. Determined using porous cup suction samplers.

A long-term study on poorly drained soils in south-central Minnesota, comparing late-October application of ammonia with and without N-Serve with a spring pre-plant application without N-Serve, showed distinct yield and environmental advantages for spring application, but not in all years (Table 3). Across the 15-yr period, corn yields averaged about 10 bu/A greater for the fall N + N-Serve and spring N treatments compared with fall N without N-Serve. Also, compared with fall application of N without N-Serve, NO_3-N losses in the drainage water were reduced by 14 and 15% and N recovery in the grain was increased by 8 and 9% for fall N + N-Serve and spring N, respectively. However, corn yields were significantly affected by the N treatments in only 7 of 15 years. In those seven years, when April, May and/or June were wetter-than-normal, average corn grain yield was increased by 15 and 27 bu/A for the fall N + N-Serve and spring N treatments, respectively. In summary, the 15-yr data suggest that applications of ammonia in the late fall + N-Serve or in the spring preplant were BMP's. However, when spring conditions were wet, especially in May and June, spring application gave substantially greater yield and profit than the fall N + N-Serve treatment. Therefore, fall N + N-Serve application is considered to be more risky than a spring, preplant application of ammonia. Moreover when N-Serve was not used, fall application of ammonia was more risky (lower yields) compared with fall application + N-Serve.

Table 3. Corn yield and NO_3-N loss to drainage water as affected by time of application and N-Serve at Waseca, 1987-2001.

Parameter	Time of Application[1/]		
	Fall	Fall + N-Serve	Spring
15-Yr Avg. Yield (bu/A)	144	153	156
7-Yr Avg. Yield (bu/A)[2/]	131	146	158
Flow-weighted NO_3-N concentration in tile drainage from the corn-soybean rotation (mg/L)	14.1	12.2	12.0
Nitrogen recovery in the corn grain (%)[3/]	38	46	47

[1/] Rate of applications for 1987-1993 and 1994-2001 were 135 and 120 lb N/A, respectively.
[2/] Only those seven years when a statistically significant yield difference occurred among treatments.
[3/] Nitrogen recovery in the corn grain as a percent of the amount of fertilizer N applied.

A split application of ammonia with 40% applied pre-plant and 60% applied sidedress at the V8 stage was compared with late October and spring preplant applications of ammonia (Table 4). In this 7-yr period, grain yields were significantly greater (6 bu/A) for the split-applied treatments, resulting in slightly greater N recovery in the grain compared with the fall and spring treatments. However NO_3-N concentrations in the tile drainage were also slightly higher with split-applied N than for the spring N and fall N + N-Serve treatments.

Table 4. Corn production after soybeans and nitrate loss as affected by time of N application and N-Serve at Waseca, 1987-93.

N Treatment		7-Yr Average		Flow-weighted NO_3-N conc. in tile drainage
Time	N-Serve	Corn yield	N recovery	
		bu/A	%	mg/L
Fall	No	131	31	16.8
"	Yes	139	37	13.7
Spring	No	139	40	13.7
Split	No	145	44	14.6
	LSD (0.10):	4		

A 6-yr study comparing fall versus spring application of N-Serve with ammonia showed a statistically and economically significant 10 bu/A yield response to N-Serve applied in the fall (Table 5). The 4 bu/A yield increase to spring-applied N-Serve was not statistically significant and is considered economically neutral. However, a yield response to spring-applied N-Serve occurred in years when June rainfall was excessive. Because these data do not suggest a consistently significant and economical response to N-Serve applied in the spring and because excessive June rainfall can not be predicted at the time of spring ammonia application, adding N-Serve to spring-applied ammonia is not considered to be a BMP at this time.

Table 5. Corn grain yield after soybeans as affected by fall and spring application of N-Serve with anhydrous ammonia at Waseca, 1994-99.

	N-Serve	
Time of application	No	Yes
	- - - - - - - - 6-Yr. Avg. Yield (bu/A) - - - - - -	
Fall	161	171
Spring	172	176

The corn yield data obtained in the above studies clearly support spring applications over fall applications regardless of N source (ammonia or urea). This is especially true when April-June rainfall was above average, causing denitrification and leaching losses of N. In addition, nitrate-N concentrations in tile drainage water were reduced (14 to 18%) with the fall N + N-Serve and spring N applications.

With spring application of N showing these increased corn yields and reduced nitrate losses to water, one would expect most fertilizer N to be spring applied. This is not true in Minnesota, however, as there has been a historic, fall application culture for fall-applied AA by both retailers and farmers when fall conditions allow (crops harvested, soils relatively dry, and soil temperatures cooling to below 50ºF). Fall application is often considered an advantage to either the retailer and/or farmer for the following reasons:

- Logistics – The workload is spread out for the retailer when a portion of the N is fall applied.
- Less storage space is required with a combination of fall and spring application. Storage space can be refilled during the winter.
- Less worry by the retailer about being able to receive and deliver the total amount of N needed in a timely manner. They question whether the fertilizer N infrastructure is able to supply and deliver the fertilizer in a timely manner when only spring applied?
- Fall application is often preferred by the farmer because more time is usually available in the fall.
- If the N is fall applied, the farmer does not need to worry about it in the spring when tillage and planting are the highest priorities. The worries only begin to occur later in the spring if the soils are warm and rainfall is plentiful, causing loss of the fall-applied N.

- Soils are generally more firm and better suited for application without compaction in the fall - - favored by both farmers and retailers.
- Fertilizer N is often somewhat cheaper in the fall - - - an economic plus for the farmer.

N Source and Time of Application

The N source used must also be considered when selecting the proper time of application. Studies at Waseca in 1981 and 1982 compared fall application of anhydrous ammonia and urea, with and without N-Serve, to spring application of the same. Two-year average corn yields (Table 8) indicate: (a) broadcast and incorporated urea was inferior to anhydrous ammonia when fall-applied, (b) spring application of urea was superior to fall application, and (c) a slight yield advantage for spring-applied ammonia compared with fall application was found when averaged across N-Serve treatments.

A subsequent study evaluated late October application of urea (4” deep band) and anhydrous ammonia with and without N-Serve compared to spring preplant urea and anhydrous ammonia. Three-year average yields show a 33 bu/A advantage for urea and a 14 bu/A advantage for ammonia when applied in the spring (Table 6). Nitrogen recovery in the corn plant ranked: spring ammonia = spring urea > fall ammonia > fall urea. The effect of N-Serve in this study was minimal. Yield response to the spring treatments were greatest in 1998, when April and May were warm and late May was wet, and in 1999 when the fall of 1998 was warm and April and May, 1999 were very wet. Significant yield differences were not found in 1997 when the fall of 1996 was cold and the spring of 1997 was cool and dry.

In summary, these studies clearly show reduced corn yield and N recovery for fall-applied urea regardless of N-Serve use. Thus, fall application of urea with or without a nitrification inhibitor (NI) should not be recommended in south-central Minnesota.

Table 6. Corn yield and N recovery in the whole plant as influenced by time of application and N source at Waseca, 1997-1999.

Nitrogen Management			3-Yr Average	
Time	Source	N-Serve	Yield	N Recovery
			bu/A	%
Fall	Urea	No	152	43
“	“	Yes	158	47
“	An. Ammonia	No	168	60
“	“	Yes	170	63
Spr. Preplant	Urea	No	185	76
“	An. Ammonia	No	182	84
--	None	--	112	--
	LSD (0.10):		8	

Preplant-applied urea gave significantly greater continuous corn yields in a 3-yr study in southeastern Minnesota than did preplant-applied UAN (28%N). Yields for a split application of UAN were not significantly different from the preplant urea treatment. A 4-yr study in south-central Minnesota showed greatest corn yields following soybeans with preplant-applied urea (182 bu/A), followed by preplant and incorporated UAN (181 bu/A), and poorest yields with broadcast pre-emergence UAN (166 bu/A).

The results from the four above studies are not surprising and could have been predicted given the characteristics of the three primary sources of fertilizer N in Minnesota - - - anhydrous ammonia, urea, and UAN (a 50:50 blend of urea and ammonium nitrate). These three sources currently occupy 39, 50, and 11% respectively, of the fertilizer N used for crop production in Minnesota. Ammonium forms of N fertilizer such as anhydrous ammonia with a nitrification inhibitor should be used for fall applications. Urea and anhydrous ammonia (both ammonium forms) should be used for spring preplant applications to reduce the potential for early-season nitrate loss. Urea-ammonium nitrate (UAN) contains 25% nitrate, which is immediately susceptible to leaching, performs best when split applied or applied in-season. Under normal spring conditions anhydrous ammonia will take up to six weeks to nitrify from ammonium to nitrate while urea may take up to three to four weeks. This delay decreases the potential for leaching of nitrate during the last part of April and in May, when precipitation is greatest and crop demand for nitrogen and water is low.

<u>Method of Application – Placement</u>

Method of application or placement choices are generally not large contributing factors in the management of anhydrous ammonia or urea. Anhydrous ammonia is usually knifed into the soil about 7” deep. The only time AA placement becomes a decision factor is when sidedressing where the AA is usually knifed in between each of the rows but can be knifed in between every other row. The latter method is easy and requires less tractor horsepower. Yield comparisons show no difference between the two. Urea is usually broadcast on the soil surface and then incorporated with tillage. In some cases, urea is knifed in about 4” deep. Yield differences are generally not found between the two placement methods. UAN has myriad placement options ranging from broadcast on the soil surface with or without incorporation by tillage, to dribbling in bands on the soil surface, to being knifed in about 2-3” deep with preplant, pre-emergence, and sidedress application times or with a combination of split applications. Yield differences among placement systems show little consistency except that incorporation of UAN produces greater yields than UAN left on the soil surface and not incorporated. Dribbling UAN within 2” of the corn row at a rate of 20-30 lb N/A has also been quite effective.

Although not a specific application/placement method, incorporation of urea and UAN is generally recommended because of the possibility of volatilization losses of ammonium if rainfall does not occur within a few days of application. Broadcast application of urea for no-till corn is a problematic application method likely to result in ammonia volatilization especially under high urease conditions [high levels of surface residue and calcareous soils (pH>7.4)]. Urease inhibitors such as Agrotain and other products, reduce the potential of volatilization losses of N to the atmosphere. These products should be impregnated into the urea before broadcast application.

In other studies, sidedress application of urea and UAN at the V6 stage followed by cultivation a few days later resulted in corn yield reductions of 12 to 17 bu/A. These data suggest that the urea and UAN had not been incorporated sufficiently deep into moist soil to move down into the active root zone, thereby remaining positionally unavailable.

In summary, these data for southern Minnesota support the recommendation of incorporating or injecting broadcast or sidedress applications of urea or UAN into moist soil to a minimum depth of three inches.

Relative Effectiveness of Management Practices to Reduce Nitrate Losses

Various N and crop management systems can be employed to reduce the potential of nitrate loss from corn production systems to ground and surface (tile drainage) waters. The N management practices are commonly referred to as BMP's (best management practices) - - - the ones discussed within the preceding portion of this document. The following discusses each of the management practices shown in Table 7 and their relative effectiveness at reducing nitrate losses. The estimates are based on my experience and professional judgment.

Nitrogen Management Practices

Rate of N: Of the five N management practices, rate of N application has the greatest potential for reducing nitrate losses. The data shown earlier in this document clearly shows the huge impact of fertilizer N rate on nitrate concentrations and losses in drainage and soil water. The wide range in effectiveness is related to the amount of excess N above the recommended rate, ranging from minimal effectiveness if the excess rate is small (10-20 lb N/A) to substantial if the applied excess N rate is large (>100 lb N/A). These large excess rates could occur from a combination of fertilizer N coupled with manure N including the buildup of labile soil N from high rates of past manure and fertilizer applications. Discontinuing the application of 20-50 lb of excess "insurance" N for corn would significantly reduce nitrate losses.

In looking to the future, it is important to continue N rate research studies to determine yield response, net return to fertilizer N, N recovery in the corn, residual soil nitrate in the profile of medium-textured soils of SE Minnesota, and nitrate concentration in soil water or tile drainage when growing new highly productive corn hybrids. These complete sets of production and environmental data will be relied upon and necessary to make improved N management decisions for the future in Minnesota. Research on remote sensing and in-season adaptive models may be helpful to provide diagnostic information to improve N rate decisions. It will be particularly useful to focus some studies on slightly less-than-recommended N rates for corn on highly productive soils to more clearly define the yield and economic effects/risk relative to the environmental effects/risk with this reduced N rate approach.

Another factor that clouds the optimum N rate picture is the high levels of labile organic N, which have accumulated in soils that have received long-term abundant to excessive rates of manure or fertilizer N over the years. Because significant amounts of the labile organic N can be mineralized into available N each year from these soils, optimum fertilizer N rates could be rather small due to the large amounts of available soil N, yet nitrate concentrations leached into ground and surface waters could be large.

Time of N: Time of N application also can have a significant impact on reducing nitrate losses. This is particularly true if growers were to discontinue this application of extra "insurance" N when fall applying their fertilizer. Growers have additional options, - - - either add a nitrification inhibitor (NI) such as N-Serve to the recommended N rate and fall apply after the soil temps remain below 50ºF or switch to spring or in-season applications involving various N sources. The data shown throughout the earlier portion of this document consistently show the corn yield and economic advantage to spring application of N. Reductions in nitrate concentrations and losses are much smaller than the large and consistent yield advantages for spring-applied N. The greater effect of Time of Application for ground water under well-drained soils is the dominance of leaching and absence of denitrification on these soils.

As fall application of N becomes less popular, especially on vulnerable soils, due to economic and environmental risks and challenges, new Time of Application research must consist of various spring and in-season application times coupled with various N sources, placements, and inhibitors - - - both NI's and UI's. It is unlikely that these "new" combinations of sources, placement, timing, and inhibitors/additives will show a large advancement of reduced nitrate losses. But, it is important to identify combinations that improve net economic return for the farmer and improve logistics for the retailer.

Source of N: In the big picture source of N has little effectiveness on reducing nitrate losses. However, two examples stand out where N source plays a significant role: (1) urea applied in the fall with or without a NI in south-central Minnesota. With this treatment, corn yields are reduced, largely due to nitrate losses. (2) UAN applied in the spring to well drained soils may be lost due to excessive spring rainfall, necessitating an additional in-season application of N that leads to the total N rate exceeding the original rate recommended.

Method/Placement of N: The method or placement of N generally has very little effect on nitrate losses even though it may affect grain yield some. An exception could be the broadcasting of urea or UAN without a urease inhibitor (UI) for no-till corn where surface residues are abundant and/or soil pH is high. Significant volatilization of ammonium could occur requiring a supplemental application of additional fertilizer, which would bring the total N rate applied to exceed the recommended N rate.

Inhibitors (NI & UI): Nitrification inhibitors (NI) such as N-Serve and Instinct currently play a role of improving the performance of fall-applied ammonia and hog manure. Urease inhibitors (UI's) such as Agrotain and Limus reduce volatilization losses of ammonium fertilizers applied to the soil surface. Proper use of NI's and UI's allows improved N management, which in turn often improves corn yield but the effect on nitrate losses to water is yet unknown.

Table 7. Relative effectiveness of management practices to reduce nitrate losses to ground and surface waters in Minnesota

Practice	Tile Drainage Poorly drained	Ground Water Well drained
Rate of N	L-H (10-60)*	L-H (10-70)*
Time of N	L (10-30)	M-H (30-80)
Source of N	VL (0-10)	VL (0-10)
Method/Placement	VL (0-10)	VL (0-10)
Inhibitors (NI & UI)	L (10-20)	L (10-20)
Fall tillage	VL (0-10)	VL (0-10)
Cover crops	L (0-30)	L (0-30)
Cropping system	VH (100)	VH (100)

* = Effectiveness (0 = VL to 100 = VH)

<u>Crop Management Practices</u>

Fall tillage: A 11-yr study was conducted at Waseca comparing no tillage with moldboard plowing for continuous corn. Moldboard plowing produced higher corn yields and slightly higher nitrate concentrations in the tile drainage but lower drainage volume. No tillage produced lower corn yields and slightly lower nitrate concentrations but greater drainage volume. Thus, nitrate loads (drainage volume X nitrate concentration) were not different between the two tillage extremes. This study conducted where soils are frozen from December through March produced data much different than are found in warm climates, where fall tillage stimulates nitrification of soil organic matter and hence greater nitrate concentrations and losses.

Cover crops: Cover crops are getting much notoriety in the U.S. for their ability to take up residual N remaining in the soil after corn. The cover crops (mainly cereal rye plus a host of other crops) are established in the fall for nitrate uptake in the fall, winter in some cases, and the spring before the next crop is planted. These cover crops perform well at more southern latitudes (below I 80) where fall establishment is successful. This is not the case in Minnesota where the window for establishment in the fall between corn harvest and fall freezing is small. Successful establishment occurs when the cover crops can be planted rather early, when soils are warm, when soil moisture is plentiful, and when the first fall frost is delayed. Additionally, the window in the spring for uptake of nitrate is often quite short between warm temps for uptake and planting of the next crop. A 3-yr study at Lamberton for soybean following corn showed excellent cover crop growth in one year (both fall and following spring) with superb uptake of nitrate. In another year, establishment of the cover crop was not possible due to the cold fall. In the third year, the crop was adequately established but further growth and N uptake was marginal at best. Examination of the 3-yr results and the 40-yr fall weather history at Lamberton led the scientists to predict that cover crops in a corn-soybean rotation would work well in 1 of 4 years in southern Minnesota. Cover crops can work extremely well in Minnesota if planted by September 1 when following sweet corn, peas, small grains, and corn removed for silage. Additional research on adopting cover crops for a corn-soybean rotation in Minnesota is needed. Developing or selecting species that can germinate and then tolerate dense corn growth, limiting light in August and early September, is needed. Establishing a cover crop in mid-June and getting it to live within the dense and shaded conditions from mid-July until early September would be ideal. Also, out –of-the-box research such as planting a high yielding corn hybrid that has a low biomass characteristic at various reduced populations to provide sufficient light for growth of cover crops seeded in mid-June would be valuable. Depending on corn grain yield, N rate, net economic return, and cover crop sustainability, growth and N uptake, this could be an alternative to simply reducing or shifting X amount of corn acres to another non-N demanding crop to achieve meeting the goals of the N Reduction Strategy.

Cropping Systems: Cropping system really is the primary factor that controls the input of nitrogen, the management of nitrogen, and nitrate losses to ground and surface water systems. Corn-based production systems, whether they are continuous corn, a C-C-soybean rotation, or a simple C-S rotation all require large input loads of fertilizer N. To determine the influence of cropping system on drainage volume, nitrate concentration, and nitrate loss in tile drainage, a 6-year study (1988-93) was established at Lamberton, MN. Drainage occurred in 1990-93, and the results are shown in Table 8. Based on these seminal, well cited data, it is fair to say that cropping system has a greater effect on hydrology and nitrate losses than any other management practice. The perennial crops [alfalfa and Conservation Reserve Program plants (brome grass, orchard grass, timothy and alfalfa)] reduced drainage volume by 25 to 50% due to greater transpiration and reduced nitrate loses by >95%. Thus, shifting some of Minnesota's approximately 8 million areas of corn to other crops requiring substantially less to no nitrogen would likely reduce nitrate losses more than implementing all of the previous nitrogen BMP's and crop management practices discussed earlier.

Rather than simply shifting one or two million acres to another non-N demanding crop, it may be wise to encourage crop rotation research involving a year or two of alfalfa such as a C-S-C-A-A rotation or perhaps other crops to determine their efficacy at reducing nitrate losses to ground and surface water systems while optimizing net return. Because alfalfa requires different seeding and harvesting machinery and storage facilities than row crops, perhaps "neighbor" farmers could be incentivized to fulfill the alfalfa needs of the system. This may have merit especially in vulnerable soils within areas of "high dairy cattle numbers".

Table 8. Effect of cropping system on drainage volume. NO_3-N concentration, and N loss in subsurface tile drainage during a 4-yr period (1990-93) in MN.

Cropping System	Total discharge	Nitrate-N Conc.	Nitrate-N Loss
	inches	mg/L	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

Emerging 4R Practices Water Quality Research

In the October, 2015 issue of the Journal of Environmental Quality, a Technical Report was published by L.E. Christianson (U of Illinois) and R.D. Harmel (Texas A & M) entitled "4R Water Quality Impacts: An assessment and synthesis of forty years of drainage nitrogen losses". They reviewed and quantitatively analyzed nearly 1000 site-years of subsurface tile drainage N load data to develop a more comprehensive understanding of the impacts of 4R practices (application of the right source of nutrients, at the right rate and time, and in the right places) within drained landscapes across North America.

They concluded that some of the 4R practices for reducing nitrate-N loads were stronger than others.

- Optimizing N rate was important and will continue to receive primary research and regulatory focus.
- The lack of significant difference between N application timing or application methods (placement and source) was inconsistent with the current emphasis placed on timing as a WQ improvement strategy.
    - Application timing analysis were complicated by differences in application rates between timing treatments; highest application rates resulted in greatest N losses.

Editorial Comment

Will the 4R approach be successful in reducing nitrate-N losses to surface and ground water to meet the goals of Nitrogen Loss Reduction Strategies being established?

My answers are:

1) They are directionally correct and helpful but will not accomplish the goal by themselves.
2) Universal commitment will be needed within the agricultural community (ag advisers, retailers, consultants, commodity groups, agricultural interest groups, etc.) to advance the 4R concept consistently and quickly.
3) Shifting acreage away from corn to other cropping systems is the most effective strategy as it decreases N inputs to the landscape and significantly reduces N losses to ground and surface water.

<u>References</u>

Carlson, B., J. Vetsch, and G. Randall (retired). 2013. Nitrates in drainage water in Minnesota. Univ. Minn. Ext. Pub.

Christianson, L.E., and R.D. Harmel. 2015. 4R Water Quality Impacts: An assessment and synthesis of forty years of drainage nitrogen losses. J. Environ. Qual. October Technical Report.

Mitsch, W.J., J.W. Day, J.W. Gilliam, P.M. Grofman, D.L. Hey, G.W. Randall and N. Wang. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to counter a persistent ecological problem. BioScience 51:373-388.

Randall, G.W., and M.A. Schmitt. 1993. Best management practices for nitrogen use in southeastern Minnesota. Minn. Ext. Serv. AG-FO-6126B.

Randall, G.W., and M.A. Schmitt. 1993. Best management practices for nitrogen use in south-central Minnesota. Minn. Ext. Serv. AG-FO-6127C.

Randall, G.W., and T.K. Iragavarapu. 1995. Impact of long-term tillage systems for continuous corn on nitrate leaching to tile drainage. J. Environ. Qual. 24:360-366.

Randall, G.W., D.R. Huggins, M.P. Russelle, D.J. Fuchs, W.W. Nelson, and J.L. Anderson. 1997. Nitrate losses through subsurface tile drainage in Conservation Reserve Program, alfalfa, and row crop systems. J. Environ. Qual. 26:1240-1247.

Randall, G.W., and D.J. Mulla. 2001. Nitrate-nitrogen in surface waters as influenced by climatic conditions and agricultural practices. J. Environ. Qual 30:337-344.

Randall, G.W., J.A. Vetsch, and J.R. Huffman. 2003. Corn production on a subsurface-drained mollisol as affected by time of nitrogen application and nitrapyrin. Agron. J. 95:1213-1219.

Randall, G.W., J.A. Vetsch, and J.R. Huffman. 2003. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by time of nitrogen application and use of nitrapyrin. J. Environ. Qual. 32:1764-1772.

Randall, G.W. and J.A. Vetsch. 2005. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by fall and spring application of nitrogen and nitrapyrin. J. Environ. Qual. 34:590-597.

Randall, G.W. and J.A. Vetsch. 2005. Corn production on a subsurface-drained mollisol as affected by fall versus spring application of nitrogen and nitrapyrin. Agron. J. 97:472-478.

Randall, G.W., G. Rehm, and J. Lamb. 2008. Best management practices for nitrogen use in southeastern Minnesota. Univ. Minn. Ext. Pub. #08557.

Randall, G.W., G. Rehm, J. Lamb, and C. Rosen. 2008. Best management practices for nitrogen use in south-central Minnesota. Univ. Minn. Ext. Pub. #08554.

Randall, G.W. and M.J. Goss. 2008. Nitrate losses to surface water through subsurface, tile drainage. In Nitrogen and the Environment: Sources, Problems, and Management. J.L. Hatfield and R.F. Follett. (ed.) p. 145-175. Elsevier Sciences B.V.

Rehm, G., G.W. Randall, J.A. Lamb, and R. Eliason. 2006. Fertilizing corn in Minnesota. Univ Minn. Ext. Pub #3790-C.

Sawyer, J., E. Nafziger, G. Randall, L. Bundy, G. Rehm, and B. Joern. 2006. Concepts and rationale for regional nitrogen rate guidelines for corn. Iowa State Univ. Ext. PM 2015.