From:	Betsy Lawton
To:	Gunderson, Larry (MDA)
Cc:	Kris Sigford
Subject:	MCEA comments on MDA"s proposed Nitrogen Fertilizer Rule
Date:	Friday, January 29, 2016 4:24:15 PM
Attachments:	2016-1-29 FINAL MCEA Comments on Draft NFM Rule.pdf 2016-1-29 FINAL Expert Report DR Gyles Randall N BMPs for Corn.pdf GWR CV 2 page.pdf

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Good afternoon Larry -

Please find attached MCEA's comments on MDA's proposed Nitrogen Fertilizer Rule, along with an accompanying expert report of Dr. Gyles Randall.

Once you've had a chance to review these comments I'd like to set up a time to discuss, and Gyles has indicated he is likely available to attend a meeting later in February. In the meantime feel free to contact me with any questions.

Have a great weekend,
Betsy

Betsy Lawton
Water Quality Associate
Minnesota Center for Environmental Advocacy
26 E. Exchange St., Suite 206
St. Paul, MN 55101
651-287-4866
blawton@mncenter.org
www.mncenter.org

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Minnesota Center for Environmental Advocacy
26 East Exchange Street • Suite 206 • Saint Paul, MN 55101-1667 • 651.223.5969

January 29, 2016

VIA EMAIL

Larry Gunderson
Minnesota Department of Agriculture
625 Robert Street North
St. Paul, MN 55101
larry.gunderson@mn.state.us

RE: MCEA Comments on MDA's Proposed Rule Governing Nitrogen Fertilizer

Dear Mr. Gunderson,

Thank you for the opportunity to submit the following comments on behalf of the Minnesota Center for Environmental Advocacy (MCEA) on the Minnesota Department of Agriculture's Proposed Rule Governing Nitrogen Fertilizer, Revisor's ID Number R-04337. MCEA is a Minnesota non-profit environmental organization whose mission is to use law, science and research to preserve and protect Minnesota's wildlife, natural resources and the health of its people. MCEA has statewide membership. MCEA has been concerned about the impacts on Minnesota's waters from agriculture, point source discharges and other sources for many years, has made pollution prevention and resource restoration a significant component of its work, and has been engaged with MDA on issues related to nitrogen fertilizer management for a number of years.

In 1990 MDA developed a Nitrogen Fertilizer Management Plan (NFMP), and as required under the Groundwater Protection Act, has developed and promoted nitrogen fertilizer management practices. In 2013, when MDA proposed revisions to the 1990 NFMP, MCEA urged the MDA to adopt water resource protection requirement (WRPRs) because voluntary implementation of the University of Minnesota nitrogen fertilizer use BMPs, promoted by MDA for decades, were ineffective and had failed to prevent or mitigate nitrate contamination in groundwater. MCEA, and other interested stakeholders, also expressed concern with MDA's snail's pace proposal for adopting WRPRs.

Despite urgings to require more, MDA continued with its preferred approach – continued voluntary implementation of nitrogen fertilizer use practices, and a proposal to cement the slow and cumbersome process for moving to WRPRs into rule. MDA is now requesting public comment on its generalized proposal to develop new rules to: 1) restrict the application of nitrogen fertilizer in the fall and on frozen ground in vulnerable areas when it is "not recommended" by the University of Minnesota; 2) establish a process for

moving to regulation based on the process outlined in the NFMP; and 3) adopt a "menu" of site specific regulations that could become WRPRs via order of the Commissioner.

MCEA is concerned that MDA's proposal fails to *prevent* groundwater contamination and will leave existing contamination unmitigated for many years. These concerns are detailed below and MCEA incorporates by reference the attached expert report and recommendations of Dr. Gyles Randall, Soil Scientist and Professor Emeritus from the University of Minnesota.

MDA's proposal is neither reasonable nor consistent with the Groundwater Protection Act because it applies only to drinking water; limits MDA's authority to impose WRPRs until groundwater is already unsafe to drink; precludes adoption of WRPRs in areas where the U of M nitrogen fertilizer use BMPS have been adopted; and fails to establish WRPRs that are designed to prevent nitrate pollution from exceeding the Health Risk Limits in vulnerable areas of the state.

MCEA recommends that MDA amend its rule proposal to:

- Authorize the use of WRPRs in all areas with documented groundwater contamination.
- Remove arbitrary constraints on the adoption of WRPRs, including the thresholds based on the percentage of groundwater contamination and BMP adoption rates.
- Establish WRPRs that can effectively prevent and mitigate groundwater contamination in vulnerable areas of the state.

MDA's Proposal

MDA proposes to establish a process for implementing the agency's NFMP, and to define the prevention steps or mitigation response that could occur both before and after MDA enforces WRPRs in areas with nitrate groundwater contamination. MDA's proposal creates "levels" of response based on two criteria, breadth or severity of *drinking water* contamination and the extent to which farmers have adopted nitrogen fertilizer use practices recommend by the University of Minnesota (U of M). The basis for determining what activities to prevent and mitigate groundwater contamination should be promoted, or required, is deeply flawed, unreasonable, and contrary to the goals of the Groundwater Protection Act.

MDA's proposal is short sighted and precludes WRPRs in all but a small portion of the state - leaving the vast majority of the state subject only to voluntary adoption of nitrogen fertilizer management practices even if groundwater contamination exists. First, MDA's proposal does not require a mitigation response in areas where contaminated groundwater is not a source of drinking water; and MDA's Township Testing program proposal further limits the agency's capacity to respond to contamination of private drinking wells in all but approximately 300 townships in which 20% of the land is in row crop agriculture and 30% of the township is in a vulnerable groundwater area.[1] Once

[1] https://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/townshiptesting.aspx

contamination of drinking wells has been confirmed, MDA's proposal delays any regulatory response for at least 3 years and recommends an unnecessary and redundant 14 step process that includes:

- Formation of a local advisory team;
- Selection of a project lead and development of a work plan;
- Establishment of a local nitrate monitoring network;
- Public information meetings;
- Selection of the "right" nitrogen BMPs from the U of M guidance;
- A survey of adoption of these voluntary BMPs;
- Consideration of Alternative Management Tools (AMTs) in high risk areas;
- Assessment of the need for demonstration projects;
- Planning for educational activities;
- Obtaining funding for implementation of voluntary BMPs or AMTs;
- Work with farmers to implement BMPs;
- A follow-up survey to BMP adoption after 3 seasons of implementation;
- Evaluation of BMP adoption; and
- Determination of appropriate mitigation level using nitrate concentration and BMP adoption criteria.

Where private drinking water wells are contaminated but the number of contaminated wells does not amount to 10% of the sampled wells in a township, MDA will simply continue to promote voluntary practices. Under MDA's proposal, mitigation would only be required if over 10% of the private wells that are voluntarily tested exceed the Health Risk Limit, or exceedance of the Health Risk Limit is imminent in a public drinking well, *and* where the U of M's nitrogen fertilizer use BMPs are not adopted on 80% of eligible land.[2] In these areas, MDA's regulatory response will depend on the percentage of private wells voluntarily sampled that exceed the Health Risk Limit. Where 10-15% of drinking wells exceed the Health Risk Limit, MDA will limit any regulatory response to record keeping and reporting requirements; the development of management plans such as irrigation, water management or nutrient management plans; and attendance at one educational activity. MDA only proposes to mandate compliance with the U of M nitrogen fertilizer use BMPs in areas where farmers have not voluntarily adopted those practices and over 15% of private wells exceed the Health Risk Limit of 10 mg/L, or where public wells exceed 9 mg/L nitrate.[3]

In addition, the U of M's nitrogen use BMPS, which relate only to the use of nitrogen fertilizers (timing, rate, source and placement) and have been promoted by MDA for years, are not capable of mitigating or preventing groundwater contamination in many

[2] However where 10% of private wells are contaminated, or concentration of nitrate in public drinking water are > 5.4 mg/L, and BMPs are not adopted, MDA proposes to *promote* the following activities: irrigation well water sampling, determine proper crediting for nitrogen sources, record keeping of rate, timing, placement and source of nitrogen use, development of management plans for irrigation, water, and nutrients. In addition MDA may develop demonstration sites and provide annual farmer updates.
[3] NFMP at 70-71.

areas of the state.[4] Where the U of M nitrogen fertilizer use BMPs have been adopted, but drinking water contamination still exists, MDA's proposed rule would insulate the agency and area farmers from any additional mandatory action, despite clear proof that the use recommendations are ineffective. This is based on MDA's belief, albeit incorrect belief, that it lacks any legal authority to 1) prohibit activities that cause groundwater contamination; or 2) create standards or require actions that could effectively mitigate or prevent nitrate groundwater contamination, but that may impact cropping practices.[5]

MDA's proposal is needlessly complicated, time consuming, and expensive to implement, and places the burden of obtaining clean drinking water on those least capable of controlling the contamination and most likely to be impacted: water users.

MDA's Proposal Establishes Impediments to Preventing and Remediating Groundwater Contamination

MDA's proposal unreasonably limits the agency's authority under the Groundwater Protection Act because it limits MDA's authority to impose WRPRs where nitrate groundwater contamination is detected but 1) the groundwater is not a drinking water source, 2) less than 10% of drinking wells voluntarily sampled in a township are contaminated, 3) public drinking water supplies are contaminated but exceedance of the Health Risk Limit is not imminent, or 4) the U of M nitrogen fertilizer use BMPs have been adopted.

MDA Must Adopt WRPRs in Areas with Groundwater Contamination.

The Groundwater Protection Act requires MDA to promote implementation of BMPs to prevent and minimize the source of pollution if "groundwater pollution is detected."[6] Where the implementation of these best management practices is "proven to be ineffective" MDA may adopt WRPRs with the goal of maintaining groundwater in its natural condition. The Act clearly envisions a process for prevention and mitigation of groundwater contamination even if that groundwater is not a direct source of drinking water. However, MDA's proposal prevents the use of WRPRs where groundwater contamination is detected but less than 10% of wells voluntarily tested exceed the Health Risk Limit or where exceedance of the Health Risk Limit is not imminent in public drinking wells.

According to MDA's data it is common for shallow groundwater wells in agricultural areas in Minnesota to exceed the Health Risk Limit for nitrate and in 2014 86% of

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[4] The U of M nitrogen rate recommendations are not meant to prevent groundwater pollution but are "based on a grouped economic approach that determines nitrogen rates by applying economics to large sets of nitrogen response data." NFMP at 42. These recommendations are based on a ratio of nitrogen fertilizer costs to corn prices. See *Best Management Practices for Nitrogen Use in Southeastern Minnesota*, University of Minnesota Extension, at. 2, Table 1.
[5] NFMP at 79-80; personal communications.
[6] Minn. Stat. § 103H.275, Subd. 1(a).

shallow groundwater samples had detectable levels of nitrates.[7] Although these shallow groundwater wells are essential to detecting groundwater contamination early,[8] MDA's proposal would eliminate the use of WRPRs in areas with significant groundwater contamination where the shallow groundwater wells are not a source of drinking water.[9] As the Minnesota Department of Health has explained, groundwater may be contaminated even in areas with a low percentage of nitrate impacted drinking wells because these low percentages may "primarily be due to the reduced use of shallower aquifers by well drillers in certain areas of the State."[10]

MCEA encourages MDA to prioritize mitigation efforts in areas where drinking water is impacting the human population. However such prioritization cannot be at the expense of addressing nitrate groundwater pollution in shallow groundwater – this water is both an early indicator of potential pollution of drinking water wells and an indicator of contamination in areas where drinking wells may have been re-drilled to deeper depths or individuals have tapped into an alternative source of drinking water.[11] The Groundwater Protection Act requires protection of all groundwater resources.[12]

MDA should revise its proposal to authorize the use of WRPRs in areas with groundwater contamination, regardless of the whether that groundwater is currently a drinking water source.

WRPRs Must Be Available Regardless of the Percentage of Drinking Wells Contaminated or the Severity of Public Drinking Water Contamination.

Contrary to the goals and mandates of the Groundwater Protection Act, MDA's proposal allows significant groundwater contamination before any mandatory action to remedy the contamination is even contemplated. MDA acknowledges that "once groundwater is contaminated, the remediation process can be extremely slow, difficult, and expensive."[13] According to the United States EPA, clean-up of contaminated drinking water wells costs anywhere from 10-30% more than taking steps to prevent the contamination. These significantly higher costs for remediating contamination are borne by individuals that simply live in an area where those responsible for the contamination have opted not to incur the much lower costs of preventing this contamination.

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[7] MDA 2013 Annual Monitoring Report, at 84; 2015 EQB Water Policy Report, Beyond the Status Quo, Appendix A: Five-year Assessment of Water Quality Degradation trends and Prevention Efforts, at 7.
[8] NFMP at 21.
[9] See Minnesota Department of Health comments on 2013 Draft Revision to the NFMP, at 1.
[10] Id.
[11] As MDA notes, water at greater depths in aquifers entered the ground 50 or more years ago before the increase in nitrogen fertilizer application. Water that enters the ground more recently, after the increase in nitrogen fertilizer application may eventually reach these greater depths which are now being used to drill deeper drinking water wells where shallower wells have shown nitrate contamination. MDA believes that the nitrate reaching lower areas in the aquifer may be converted to gas due to low oxygen content in the aquifer in some aquifers and under some conditions.
[12] Minn. Stat. § 103H.005, Subd. 8, Minn. Stat. § 115.01, Subd. 6.
[13] NFMP at 5.

The costs of treating nitrate contaminated drinking water for private well-owners ranges from an initial cost between $250 and $2200, with additional annual costs in the range of $100-$500, depending on the type of treatment chosen.[14] Private well-owners who opt to drill a new well to avoid drinking nitrate contaminated groundwater will incur costs ranging from $7,200-16,000.[15] To avoid treatment, well-owners could choose to drink bottled water, which would cost $530-1590 annually.[16] For users of public water supply systems forced to install treatment to remain below the Health Risk Limit, the annual costs per household ranges from $35-305.[17] MDA's proposal fails to identify areas where immediate implementation of WRPRs could prevent further groundwater contamination, and treatment costs could be avoided.

In addition requiring private well samples before imposing WRPRs, even where MDA has clear evidence of nitrate groundwater contamination, is inefficient and further delays mandates needed to meet the Health Risk Limit in groundwater. Changes to land use and cropping practices between 2007 and 2012 are already expected to result in a 29% increase in private wells over the Health Risk Limit.[18] However a 20% reduction in annual average nitrate application could decrease the number of wells exceeding 10 mg/L by 57%.[19] MDA's proposal will delay preventative measures and increases costs to communities in areas vulnerable to groundwater contamination, such as the Central Sands, that need mandatory action to mitigate extensive and well documented groundwater contamination.[20] This delay will result in increased and unnecessary expenditures of agency time and resources.

Moreover, voluntary private well testing cannot adequately identify areas in need of WRPRs. For example, MDA data shows that 62% of its monitoring wells in the Central Sands exceeded the Health Risk Limit, however of the private wells sampled 4.6% exceeded the Health Risk Limit. In MDA's pilot Township Testing program in Dakota County in 2013-2014, less than 30% of the private well owners that were offered free well testing responded.[21] Of the wells tested that exceeded the Health Risk Limit, 20%, or 192 wells, were located in townships that would not qualify for WRPRs because less than 10% of the wells sampled exceeded the Health Risk Limit. The number of wells that exceed the Health Risk Limit but are located in towns ineligible for WRPRs is likely much higher. For example, in Eureka and Rosemount, 2 townships in vulnerable groundwater areas, WRPRs would not be considered because less than 10% of the wells tested exceeded the Health Risk Limit. However 750 private wells in these townships

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[14] *Estimating the external costs of nitrogen fertilizer in Minnesota*, December 2014, Bonnie Keller and Jesse Gourevitch, University of Minnesota, Institute on the Environment, Prepared for the Minnesota Center for Environmental Advocacy, at 21.
[15] Id.
[16] Id.
[17] Id. at 26.
[18] Id at 17.
[19] Id, at 22.
[20] Data from 2007-2011 show that over 40% of the wells in central Minnesota exceed the Health Risk Limit – this data came mainly from shallow wells installed in uppermost part of the aquifer. *The Condition of MN's Groundwater 2007-2011*, May 2013 MPCA, at 18.
[21] https://www.co.dakota.mn.us/Environment/WaterQuality/WellsDrinkingWater/Pages/targeted-townships-results.aspx

were not tested, but could certainly have been contaminated. Despite well-documented and widespread nitrate groundwater contamination in this area, MDA's proposal will leave extensive groundwater contamination unmitigated.

MDA should revise its proposal to authorize the agency to require compliance with WRPRs in both areas with confirmed groundwater contamination and in areas of the state vulnerable to groundwater contamination.

BMP Adoption Rates Are Not An Appropriate Threshold for Determining the Level of Mitigation Response to Groundwater Contamination.

WRPRs are authorized where implementation of BMPs has proven to be ineffective.[22] Where groundwater contamination exists implementation of BMPs has clearly been ineffective. The Groundwater Protection Act does not, as MDA suggests, require an analysis of BMP adoption rates before WRPRs may be imposed. [23,24] MDA's proposal is contrary to the goals of the act and impermissibly prevents MDA from establishing WRPRs where BMPS are adopted but ineffective. Moreover, it is hardly equitable to require individuals who rely on groundwater to incur the costs of remediation because farmers have failed to voluntarily adopt BMPs or MDA has not required compliance with practices that will mitigate the groundwater contamination.

MDA's Proposed 14-Step Mitigation Implementation Process Is Repetitive, Creates Unnecessary Delay, and Imposes Avoidable Expenses on MDA, Communities and Water Users

Because the U of M nitrogen fertilizer use BMPs are foundational, MCEA urges MDA to immediately adopt these recommendations as WRPRs in all areas of the state that are vulnerable to groundwater contamination, or are currently contaminated. MDA's proposed 14-Step process simply delays the inevitable: where groundwater is contaminated or vulnerable to groundwater contamination, farmers will need to comply with these foundational requirements either voluntarily or as mandated by WRPRs. The only thing the 14-step process does is delay compliance, which in turn creates needless expense for farmers, MDA, well users, and communities.[25]

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[22] Minn. Stat. 103H.275, Subd. 1(b).

[23] Minn. Stat. 103H.275, Subd. 1(b). That MDA intends to restrict application of nitrogen fertilizer in fall and on frozen ground when not recommended by the U of M is evidence that MDA understand its own authority to adopt WRPRs is not limited to areas where BMPS have not been adopted – MDA proposes to adopt a WRPR restricting fall application of nitrogen fertilizer despite the fact that "the vast majority of Minnesota farmers and their crop advisors do not fall apply or apply fertilizer to frozen ground when it is not recommended by the U of M." NFMP at 82.

[24] NFMP at 49.

[25] Dakota County explained that because significant degradation to groundwater has already occurred in the County that MDA should act faster that proposed in the plan, which will take many years to implement. MDA Response to comments at 7.

MDA's Proposed WRPRs do Not Meet the Requirements of the Groundwater Protection Act.

WRPRs are adopted by rule and must be designed to prevent and minimize pollution to the extent practicable and prevent pollution from exceeding the health risk limits. WRPRs may include "design criteria, standards, operation and maintenance procedures, practices to prevent releases, spills, leaks, and incidents, restrictions on use and practices, and treatment requirements."[26]

Notably absent from MDA's proposal are potential WRPRs the agency has identified as most likely to be effective in preventing or mitigating nitrate groundwater contamination in vulnerable areas where crops with high nitrogen demand are grown. Instead MDA proposes to classify these practices as purely voluntary Alternative Management Tools ("AMTs").[27] While MDA will encourage the exploration and use of the AMTs – including utilizing new technologies, improving genetic diversity, increasing continuous cover (including diversifying crop rotation, perennial crops, and cover crops) and retiring crop land – its current proposal excludes the use of these tools as WRPRs.

> *The U of M Fertilizer Use Recommendations, While not Designed to Prevent Nitrate Pollution from Exceeding Health Risk Limits, Are Foundational And Should Be Adopted as Statewide WRPRs.*

The U of M nitrogen fertilizer use BMPs are based only on economics, are not designed to protect groundwater, and even if followed will result in groundwater nitrate contamination in areas of the state susceptible to groundwater contamination.[28] Full adoption of these use recommendations could only reduce nitrate leaching losses by 15-25%.[29] Therefore these practices are not, by themselves, appropriate WRPRs.[30] However, these recommendations are considered "foundational" and if adopted could reduce nitrogen fertilizer application rates in many areas of the state by limiting the application of "insurance nitrogen" that is often recommended by retailers to ensure that "yield-limiting conditions not occur due to insufficient [Nitrogen]."[31]

MDA should immediately adopt as WRPRs for the entire state the U of M nitrogen fertilizer use BMPs and record-keeping requirements that support the use of the right rate for each field the state of Minnesota. See Expert Report of Dr. Gyles Randall, attached.

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[26] Minn. Stat. § 103H.100, Subd. 15.
[27] NFMP at 57-61.
[28] NFMP at 57.
[29] MDA Response to Comments at 6.
[30] See for example Tables 1-4 in attached Expert Report of Dr. Gyles Randall. These nitrogen fertilizer rates may be authorized under the U of M nitrogen fertilizer use BMPS but they result in high rates of nitrate pollution in tile water.
[31] Expert report of Dr. Gyles Randall, at page 3.

MDA should adopt effective WRPRs.

The Groundwater Protection Act defines WRPRs broadly. WRPRs may include nitrogen fertilizer rate restrictions necessary to protect groundwater in vulnerable areas (even if those rates are more restrictive than the yield based U of M nitrogen fertilizer use rates), and production of less nitrogen-demanding crops (including cover crops and perennials).

MDA should adopt the following WRPRs in its menu of practices that could be required by a Commissioner's order:

- Cover crops, where effective, including in areas where they could be planted by September 1 and following sweet corn, peas, small grans and corn removed for silage.[32]
- Alternative cropping systems, including alfalfa and other crops with low nitrate losses.[33]
- Use of low nitrogen input crops such as forage crops and other vegetative cover, and other "AMTs" identified in MDA's NFMP.
- Use of split application of N on coarse-textured soils.[34]
- Incorporate broadcast or inject sidedress application of urea and UAN into moist soil to a minimum depth of three inches.
- Restrict the use of U of M nitrogen fertilizer use BMPS that are "Acceptable , but with risk" if nitrate levels increase or BMPs are not used.[35]
- Use of nitrification inhibitors (NI's) such as N-Serve and urease inhibitors (UI's) such as Agrotain and Limus when appropriate for reducing losses of yield and N.[36]
- The Primary BMP recommendations specific for southern Minnesota identified in Dr. Gyle Randall's expert report at page 3.

MDA Should Perform Research to Identify the Nitrogen Fertilizer Use BMPs that Are Most Effective in Preventing and Mitigating Groundwater Contamination and Adopt those BMPs as WRPRs.

Given the lack of research identifying practices that are most effective at preventing and mitigating groundwater contamination (including nitrogen fertilizer use BMPs, and viable and effective crop rotations and cover crops) MDA should continue to research:

- the impacts of the U of M nitrogen fertilizer use BMPs on groundwater nitrate concentrations, with the goal of establishing the optimal combination of use practices capable of preventing and mitigating groundwater contamination to *the greatest extent*.
- crop rotations with the potential to reduce nitrate losses to groundwater, including rotations including alfalfa or other crops.

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[32] See Expert Report of Dr. Gyles Randall at 2-3
[33] Id.
[34] Id.
[35] Id.
[36] Id.

- cover crops that could be used in corn-soybean rotations to effectively reduce or eliminate nitrate leaching to groundwater.
- potential incentives for agricultural advisers, retailers, consultants, commodity, groups, agricultural interest groups and farmers to adopt fertilizer nitrogen application rates that reduce nitrate groundwater contamination.

See also Expert Report of Dr. Gyles Randall, at 3-4.

MDA should then revise its menu of WRPRs to include those practices most effective at preventing and mitigating groundwater contamination.

MDA's Proposed Restriction on Fall and Winter Application of Nitrogen Fertilizer Should Apply in All Vulnerable Areas of the State

MDA proposes to restrict application of nitrogen fertilizers in fall and on frozen ground in areas where this practice is "not recommended" by the University of Minnesota. However, MDA is proposing to implement this restriction only in townships where at least 50% of the land in the township meets the definition of vulnerable land. MDA's proposal fails to identify any legitimate rational for failing to protect groundwater from fall and winter application in areas where 50% of the land does not meet the definition of vulnerable land. Spring application of nitrogen fertilizers results in higher grain yields and lower nitrate losses.[37] Therefore MDA should restrict application of nitrogen fertilizer in fall and on frozen ground in all areas of the state unless the U of M has identified this practice as "recommended."[38]

Conclusion

For all the above reasons, MDA must revise its proposed Nitrogen Fertilizer Rule and immediately move to adopt rules that 1) require record keeping necessary to determine appropriate rates of nitrogen fertilizer application and other WRPRs; and 2) require compliance with the U of M fertilizer use recommendations statewide. In addition, MDA must revise its rule proposal to 1) eliminate any prohibitions on adopting WRPRs in areas where groundwater is contaminated; and 2) remove the tedious, time consuming, and unnecessary process it proposes must be followed before compliance with WRPRs can be mandated by MDA. Finally, MDA must commit to funding and completing research necessary to develop WRPRs that can be truly effective at preventing and mitigating nitrate groundwater contamination.

Sincerely,

Kris Sigford
Water Quality Director

Betsy Lawton
Water Quality Associate

[37] Expert Report of Dr. Gyles Randall, at 2.

Nitrogen BMP's for Corn in Minnesota

Gyles Randall
Soil Scientist (Retired) and Professor Emeritus
University of Minnesota
grandall@umn.edu

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 to adopt restrictions on the fall and winter application of nitrogen fertilizer and adopt a "menu" of potential water resource protection requirements ("WRPR") that could be required in specific areas of the state via an order of the Commission of the Department of Agriculture, and recommend practices to be included in the menu of WRPRs MDA will adopt.

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 where this practice is listed as "not recommended" by the University of Minnesota's Best Management Practices for Nitrogen use
2) Adopt specific WRPRs that could be applied to local areas through a Commissioner's Order, including
    a. Where the U of M Nitrogen Use BMPS have not been adopted and 10% of private drinking wells exceed 10 mg/L or nitrate levels in public drinking water wells are expected to exceed 10 mg/L in 10 years or less:
        - Collection of irrigation well water samples by MDA or an approved representative
        - Farmers report on their fertilizer management practices to the MDA
        - Irrigation, water management and or nutrient management plans be developed
        - Farmers attend at least one MDA approved education activity.
    b. Where the U of M Nitrogen Fertilizer Use BMPS have not been adopted and 15% of private drinking wells exceed 10 mg/L or nitrate levels in public drinking water wells exceed 9 mg/L
        - Require compliance with region specific U of M Nitrogen Use BMPs.

While MDA's proposal for adoption 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 U of M Recommended Nitrogen Use Fertilizer Recommendations are based on yield optimization and the production economics of corn. Environmental metrics such as nitrate concentration in drainage water or in the soil at the end of the growing season have historically not been measured along-side of the agronomic and production metrics. In the more vulnerable soil areas of the state, this will change in time.

SUMMARY

General Recommendations

- Using the right/correct rate of N is a cornerstone BMP from an economic and water quality perspective. Of all N management practices, rate of application has the greatest potential for reducing nitrate losses to ground and surface waters.
    - include all forms of N added, i.e., starter fertilizer, weed & feed N, ammonium phosphate fertilizers.
    - use N credits from previous crops and manure applications, requiring record-keeping by farmer.
    - Discontinue the application of excess “insurance” N rates generally associated with fall application.

- 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 the farmers and in advocating universal use of the 4Rs.
    - record keeping may be needed 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.

- 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 portion of Minnesota’s corn acres to other non-N demanding crops would likely reduce nitrate losses more than implementing N BMPs.

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).

** = Items marked with an asterisk (*) could be considered as associated with WRPR's.*

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 low vegetative biomass corn planted at lower-than-optimum populations would allow for improved early fall establishment. This would compare the economic risk of reduced corn yields vs. the environmental benefit of reduced nitrate losses to ground water.

- 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”.

Editorial Comment

After preparing this document the question can be asked “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.

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.

	Time of Application[1/]		
Parameter	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.

Method of Application – Placement

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)

Crop Management Practices

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.	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

After preparing this document and reading this current JEQ Technical Report, the question can be asked "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.

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Gyles W. Randall **Southern Research and Outreach Center**
Professor **University of Minnesota**
Soil Fertility and Management

EARNED DEGREES

Ph.D. Soil Science, Univ. of Wisconsin-Madison, 1972
M.S. Soil Science, University of Minnesota, 1968
B.S. Soil Science, University of Minnesota, 1963

EMPLOYMENT HISTORY

Professor and Soil Scientist, Southern Research and Outreach Center and Dept. of Soil, Water and Climate, Univ. of Minnesota, 1980-present
Assoc. Professor and Soil Scientist, Southern Experiment Station, Univ. of Minnesota, 1976-1980
Asst. Professor and Soil Scientist, Southern Experiment Station, Univ. of Minnesota, 1972-1976

TEACHING EXPERIENCE

No formal classroom teaching appointment. Teaching involves approximately 40 “extension” talks each year and invited lectures. Subject matter focuses on N and P management; development of N BMP’s; utilization of land-applied manure; leaching of N, P, and pathogens into subsurface drainage; and conservation tillage.

PROFESSIONAL ACTIVITIES

American Society of Agronomy, member 1964-present
Soil Science Society of America, member 1964-present
- Assoc. Editor, SSSA Journal, 1982-87
- Technical Editor, SSSA Journal, 1988-91

CSRS/NRI Water Quality Grant Review Panels, 1990, 1992, 1993, 1994 & 1996
Farmland/University Fertilizer Advisory Board, 1980-2001

HONORS AND AWARDS

Fellow, American Society of Agronomy, 1988
Fellow, Soil Science Society of American, 1988
Certificate of Excellence Award - Extension Publications, 1997, 2002, 2003
Fluid Fertilizer Researcher of the Year, Fluid Fert. Foundation, 1998
Werner Nelson Award, American Society of Agronomy, 2002
Werner Nelson Award, Fluid Fertilizer Foundation, 2003

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