Overview of accepted nitrification and urease inhibitors for use in drinking water supply management areas with published BMP lists

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There are many nitrification and urease inhibitor products available in Minnesota. Inconsistencies in product efficacy testing and labeling, differences in how products are regulated by state or Federal agencies and recurring changes to product formulations can make selection of effective inhibitors difficult.

The Minnesota Department of Agriculture (MDA) is evaluating active ingredients and products. This is done to assist farmers with selecting inhibitors by providing clarity of products that reasonably can be expected to work when used as directed.

This document provides an overview of common active ingredients and trade names for urease and nitrification inhibitors used in Minnesota. It also provides a list of inhibitors by trade names that are acceptable to be used in drinking water supply management areas with published lists of nitrogen fertilizer best management practices (BMPs).

Active ingredient review

The Minnesota Department of Agriculture is reviewing additional active ingredients and products for inclusion on the list of acceptable products on an ongoing basis.

Please contact Jeppe Kjaersgaard at Jeppe.Kjaersgaard@state.mn.us or 651-201-6149 to suggest additional inhibitor products to be reviewed or for questions.

Nitrogen fertilizer BMPs

Nitrogen fertilizer BMPs for optimizing crop production and environmental protection are developed by the University of Minnesota and adopted by the MDA. The BMPs relate to the source, timing, placement, and rate of nitrogen fertilizer.

Under Minnesota's Groundwater Protection Rule, the commissioner of agriculture publishes a list of nitrogen fertilizer BMPs for drinking water supply management areas (DWSMAs) with elevated nitrate levels in the groundwater. Local farmers and agronomists help select appropriate BMPs for each DWSMA through participation in local advisory teams (mda.state.mn.us/local-advisory-teams). Adoption of the BMPs on cropland within DWSMAs is important for protection of groundwater. Several of the BMPs refer to the use of nitrogen inhibitors, Appendix 1.

Evaluating inhibitors

The primary review criteria used by the MDA for evaluating the inhibitors are:

- **Scientific validation -** The active ingredient(s) is(are) documented, through independent research, to inhibit nitrification or urease activity, and
- **Effective application rate -** The product's application rate stated on the label delivers sufficient active ingredient(s) (when used as directed) to inhibit nitrification or urease activity under typical soil and growing season conditions in Minnesota.

For the evaluation, the MDA prioritizes experimental data from research conducted under or similar to climatic conditions, soil types, and crop management systems in Minnesota. Emphasis is also placed on independent research studies conducted over several growing seasons and with sufficient documentation to evaluate the results.

The MDA recognizes that the efficacy of nitrogen inhibitors depends on several environmental factors, including placement, soil moisture and temperature. The list of acceptable products does not account for all possible factors, but there should be a reasonable expectation they will work in most cases when the label directions are followed. This include using the application rates specified on the label.

Nitrification inhibitors

Ammonium (NH_4^+) and nitrate (NO_3^-) are two forms of nitrogen that plants can uptake from the soil. Ammonium is available from fertilizer or mineralization of organic matter. Bacteria in the soil convert ammonium to nitrate through the nitrification process. Ammonium is a positively charged ion that is retained on soil particles' negative surfaces and is at low risk of leaching through the soil. In contrast, nitrate is very mobile in the soil since it is negatively charged, easily dissolves in soil water and can be lost through leaching or conversion to nitrogen gas forms through denitrification.

The conversion of ammonium into nitrate is called nitrification and occurs in two steps. The first step is the conversion from ammonium to nitrite which is facilitated by ammonia-oxidizing bacteria such as *Nitrosomonas* spp. The second step is the conversion from nitrite to nitrate by nitrite-oxidizing bacteria including *Nitrobactor* spp.

Nitrification inhibitors temporarily delay nitrification by interfering with the metabolism of the *Nitrosomonas* bacteria. By slowing the conversion from ammonium to nitrate, the nitrogen remains in the ammonium form longer thereby reducing the risk of loss. Nitrification inhibitors may provide effective protection for a period of 2 – 8 weeks.

Nitrapyrin

Nitrapyrin, or *2-chloro-6-(trichloromethyl) pyridine* has been used as a nitrification inhibitor since the 1970s. It works by inhibiting the activity of ammonia monooxygenase (AMO), the enzyme in the first step of ammonia oxygenation. Nitrapyrin also exhibits bacteriostatic activity, i.e., it keeps the *Nitrosomonas* in a stationary phase of growth. As nitrapyrin degrades, the inhibition of AMO is reduced and the *Nitrosomonas* population gradually recovers and resumes the nitrification process.

Nitrapyrin can be used with dry and liquid fertilizer, anhydrous ammonia, and liquid manure.

A list of products containing nitrapyrin for nitrification inhibition that can be used as part of the MDA's published nitrogen fertilizer BMPs is shown in Table 1.

Dicyandiamide (DCD)

Dicyandiamide (DCD) has been used as an inhibitor in the US since the 1980s. It is off-patent and is used as the active ingredient in both branded and private label inhibitor products. DCD temporarily inhibits the active site of ammonia monooxygenase to slow the conversion of ammonia to nitrite. DCD is water soluble, is mobile in the soil and can be used with dry or liquid fertilizers and manure.

For dry fertilizer, DCD is available either formulated into the prill during production or as a coating applied onto the fertilizer before field application.

A list of products containing DCD for nitrification inhibition that can be used as part of the MDA's published nitrogen fertilizer BMPs is shown in Table 1.

Pronitridine

Pronitridine was released commercially as a nitrification inhibitor in 2018. Its active ingredient is a mixture of dicyandiamide, reaction products from ammonia, and urea-formaldehyde. Pronitridine temporarily blocks the ammonia monooxygenase which is required to oxidize ammonia to nitrate. Pronitridine is water soluble and can be used with dry or liquid fertilizers containing ammoniacal nitrogen and manure.

A list of products containing pronitridine for nitrification inhibition that can be used as part of the MDA's published nitrogen fertilizer BMPs is shown in Table 1.

Table 1. Nitrification inhibitors that have been evaluated for use in DWSMAs with published nitrogen fertilizer BMPs. There are currently no conditionally acceptable products.

Active Ingredient	Acceptable products	Conditionally acceptable products	Not acceptable products
Nitrapyrin	Instinct Instinct II Instinct NextGen N-Serve		
Dicyandiamide (DCD)	SuperU N-Edge Pro Source DCD 21 Agrotain plus Agrotain plus SC for UAN		Excelis Maxx[1]
Pronitridine	Centuro Nitrain Bullet		

[1]The application rate of DCD is below the established threshold.

Urease inhibitors

Loss of nitrogen through ammonia volatilization can occur when ammonia or an ammonia-forming fertilizer such as urea is surface applied and not incorporated. The nitrogen in urea is hydrolyzed by the urease enzyme and converted first to ammonium carbonate and then to ammonia (NH_3) and carbon dioxide. Ammonia is a gas that volatilizes easily, especially if it is released near the soil surface or in soils with pH greater than 7. Hydrolysis of urea is facilitated by the enzyme urease.

Urease is produced by plants and microorganisms to control the movement of ammonia within their own organisms. The urease enzyme is released to the soil when the plant or bacteria decays and is resistant to degradation in the environment. In situations where incorporation is not appropriate or feasible, a urease inhibitor can be used to delay the conversion of urea to ammonia for 7 – 14 days. The urease inhibitor allows the urea more time to move into the soil with e.g., rain or irrigation, or be incorporated into the soil with tillage.

N-(n-butyl) thiosphophoric acid triamide (NBPT)

A well-studied urease inhibitor is N-(n-butyl) thiosphophoric acid triamide (NBPT). NBPT was originally marketed using the tradename Agrotain but has been available under many other tradenames since it came off patent in the early 2000s. NBPT temporarily deactivates urease to delay hydrolysis and ammonia production.

A list of products containing NBPT for urease inhibition that can be used as part of MDA's published nitrogen fertilizer BMPs lists is shown in Table 2.

Table 2. Urease inhibitors that have been evaluated for use in DWSMAs with published nitrogen fertilizer BMPs

Active Ingredients	Acceptable products	Conditionally acceptable products[1]	Not acceptable products
N-(n-butyl) thiosphophoric acid triamide (NBPT)	Agrotain Advanced ContaiN Max[2] N Edge N Edge 2 Nitrain 2.0 Nitrain 2.0 Express Nitrain 3.0 Nitrain 3.0 Express N-Veil[2] PinnitMax TG	ContaiN Advanced[2,3]	ContaiN[4] ContaiN Duo[5] N Edge Pro[5] N-Fixx[4]
N-(n-butyl) thiosphophoric acid triamide (NBPT) and Duromide	Anvol		

[1]Pending further review. The product is considered meeting the requirements for 2026.

[2]The high rate of the product's application rate must be used (3 qrt/ton).

[3]Per the SDS for ContaiN Advanced, the product contains <20% NBPT. The actual concentration should be confirmed, as the SDS indicates it may vary substantially.

[4]The concentration of NBPT is not provided on the label or SDS, so no application rate of NBPT can be calculated.

[5]The application rate of NBPT is below the established threshold.

Appendix 1

The University of Minnesota (U of M) is using multiple terms for urease and nitrification inhibitors in the nitrogen fertilizer BMPs (mda.mn.us/nitrogenbmps), and in some cases product tradenames are used. Table A-1 aligns terms used in the BMPs with MDA's current interpretations for product use.

Table A-1. Terms used for nitrification and urease inhibitors in the U of M BMPs, and the interpretation used by MDA for DWSMAs with published BMP lists.

Term used by U of M in the BMPs	Interpretation used by MDA	Example of wording used in the BMPs
Nitrification inhibitor	**Any acceptable nitrification inhibitor product (Table 1)**	Spring preplant application with a nitrification inhibitor. Single sidedress application of anhydrous ammonia or urea early in the growing season without a nitrification inhibitor. Use a nitrification inhibitor on labeled crops with early sidedressed N.
N-Serve	**Any acceptable nitrification inhibitor product (Table 1)**	Use of the product N-Serve …
Urease inhibitor	**Any approved urease inhibitor (Table 2)**	
Agrotain	**Any approved urease inhibitor (Table 2)**	Use of the product Agrotain …
Nitrogen stabilizer (N-serve)	**Any acceptable nitrification inhibitor product (Table 1)**[1]	Use a nitrogen stabilizer (N-Serve) on labeled crops when early sidedress is used.

[1]The term *N stabilizer* is commonly used interchangeably for nitrification and urease inhibitors by industry, farmers and others. Examination of the research the U of M used for developing the BMPs makes clear the term in this case refers to nitrification inhibitors.