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PLANT NUTRITION SERIES:

Nitrification Inhibitors

Their Use in Nitrogen Management

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Nitrogen (N) supplied as fertilizer is necessary to obtain maximum economic production for many food and fiber crops. Most nitrogen fertilizers use natural gas or a petroleum base and nitrogen from the air. The need for conservation of these energy sources has increased interest in improving efficiency of nitrogen use by plants.

In the first step of nitrification, ammonium is oxidized (converted) to nitrite (NO_2^-) by *Nitrosomonas* bacteria. The nitrite form of nitrogen is toxic to plants, is not particularly stable in the soil, and is converted by *Nitrobacter* bacteria to nitrate. The rate of nitrification depends on temperature; the rate is slow with soil temperatures less than 50°F and rapid with soil temperatures above 70°F .

Nitrification

Nitrification is a two step bacteriological process of converting ammonium (NH_4^+) forms of nitrogen (i.e., urea, anhydrous ammonia) to a nitrate (NO_3^-) form of nitrogen. This process as part of the nitrogen cycle is illustrated in Figure 1.

Nitrogen Losses

After nitrogen has been converted to nitrate in the soil, it is dissipated through three pathways, namely (1) use by the growing plant, (2) loss through leaching, and (3) loss through

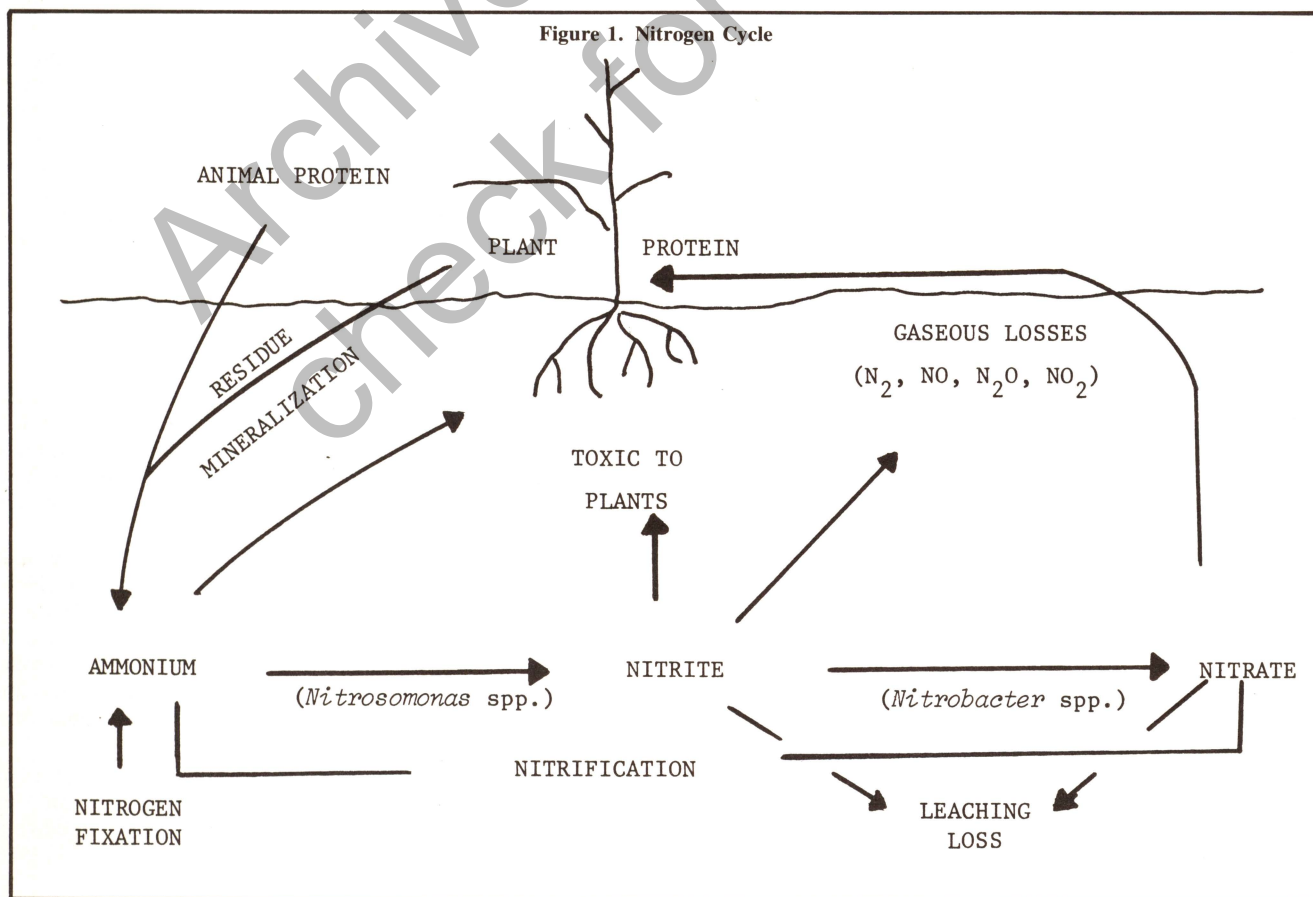
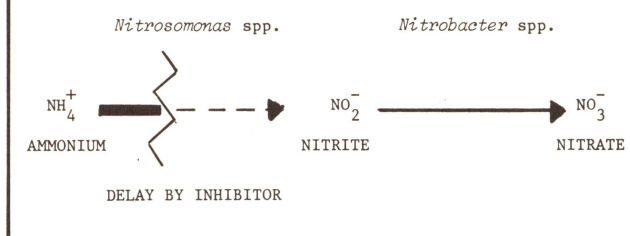


Figure 2. Action of a Nitrification Inhibitor.



biological *denitrification*. Denitrification is the reduction of nitrate nitrogen by anaerobic bacteria (bacteria that do not need free oxygen to function) and by chemical conversion to gaseous forms of nitrogen, principally elemental nitrogen (N_2), which is lost or returned to the atmosphere. Because two of these three paths lead to nitrogen losses, maintaining nitrogen in the ammonium form is desirable because it will attach to the soil and be less subject to loss.

Soil environments and nitrogen management programs where nitrogen losses can be expected are:

- Fall applied nitrogen
- Fields where soil textures vary from sandy to silt loams
- Pre-plant nitrogen on sandy soils
- Pre-plant nitrogen on fine textured soils subject to saturation with water.

The nitrate nitrogen leaching losses occur most readily on the sandy soils, and the denitrification losses will proceed rapidly in fine textured soils, especially after incorporation of fresh organic material and in water saturated, or highly anaerobic, conditions (lack of soil oxygen).

The quantities of fertilizer nitrogen lost from the soil through leaching and primarily by denitrification are estimated from 10 to 100 percent. Some nitrogen balance sheets suggest 45 to 50 percent of the fertilizer nitrogen will be removed by the crop; 25 percent will be retained in the crop residue; and 25 to 30 percent will be lost. This loss has been defined as 5 to 10 percent loss by leaching and 20 to 25 percent loss through denitrification.

How to Reduce Nitrogen Losses

There are ways to improve the plant use efficiency of applied fertilizer nitrogen; for example, (1) spoon feed small quantities of nitrogen to the plant during the growing season; (2) apply nitrogen materials (such as sulfur-coated urea, ureaform, IBDU, etc.) that slowly release their nitrogen to the plant during the growing season; (3) maintain the nitrogen in its most stable state under a wide range of soil conditions. This latter management method includes applying nitrogen in the ammoniacal (NH_4^+) form and maintaining the nitrogen in this form as long as possible or until the plant uses the nitrogen for growth.

Practical ways to help maintain nitrogen in the more stable form include (1) completing fall anhydrous ammonia application after the soil temperature has dropped to less than 50° F, and (2) incorporating a nitrification inhibiting chemical with the ammoniacal fertilizer to delay the bacteriological nitrification process. This latter method has become of great interest during the past few years.

What Are Nitrification Inhibitors?

Nitrification inhibitors, as defined commercially, are compounds that prevent or retard the first step in the process of nitrification of ammoniacal nitrogen by the *Nitrosomonas* bacteria, as shown in Figure 2. Blocking the second step of nitrification by the *Nitrobacter* is undesirable since nitrite

Table 1. Compounds known to inhibit nitrification.

Chemical	Common or Trade Name
2-Chloro-6-(trichloromethyl)-pyridine	Nitrapyrin - N-SERVE
4-amino-1,2,4-triazole	ATC
Sodium azide	--
Potassium azide	--
5-ethoxy-3-trichloromethyl-1,2,4-thiadiazole	TERRAZOLE
2,4-diamino-6-trichloromethyl-S-triazine	CL-1580
Dicyandiamide	--
3-chloroacetanilide	--
1-amidino-2-thiourea	--
2,5 dichloroaniline	--
2,4,6 trichloroaniline	--
Phenylmercuric acetate	--
3-mescapto-1,2,4-triazole	--
2-amino-4-chloro-6-methylpyrimidine	AM
2-sulfanilamidothiazole	ST
Sodium diethyldithiocarbamate	--

buildup in the soil is toxic to plants and pollutes ground waters.

Some Nitrification Inhibiting Compounds

Similar to herbicides, insecticides, and fungicides, most known nitrification inhibiting compounds are organic chemicals, although some inorganic chemicals possess this inhibiting property. At least 100 to 200 compounds are known to possess the capability of inhibiting nitrification, but few have received serious commercial development. Some compounds that possess nitrification inhibiting properties are listed in Table 1. To date, the only product labeled for commercial use as a nitrification inhibitor is 2-chloro-6-(trichloromethyl)-pyridine, sold under the trade name N-SERVE® (Nitrapyrin).

Results Obtained with Nitrification Inhibitors

Numerous experiments have been conducted with nitrification inhibitors, primarily N-SERVE®, to evaluate the full value of this material in crop production. Results show a delay in nitrification of ammonium nitrogen, less stalk rot problem, an increase in yields, and an increase in nitrogen use efficiency.

Delay in Nitrification. Field research results show that more ammonium (NH_4^+) is found in the soil when a nitrification inhibitor is included with anhydrous ammonia. The delay in nitrification can be verified by the results presented in Table 2. Research on Marshall and Mexico soils in Missouri showed that much of the nitrogen applied as anhydrous ammonia with N-SERVE in the fall was still in ammonium form (NH_4^+) at planting time the following spring.

Disease Control. N-SERVE with ammoniacal forms of fertilizer may reduce disease in some crops. Research in Indiana showed that stalk rot was reduced by stabilizing nitrogen in the ammonium form, but work in Missouri in 1976

Table 2. Soil ammonium levels after fall application of anhydrous ammonia.¹

Treatment	pounds ammonium per acre at two-foot depth			
	April 30	June 11	July 31	Sept. 2
180 lbs./acre without inhibitor	78	9	0	0
180 lbs./acre with inhibitor	108	86	22	0

¹Wiese, Nebraska

Table 3. Corn yields with fall application of anhydrous ammonia with and without N-SERVE.¹

Nitrogen, lbs./acre	Yield, bu./acre	
	Without	With
120	100.3	140.5
200	126.1	157.3

¹1974 Purdue University, Sullivan County, Indiana

Table 4. Corn yields with spring application of anhydrous ammonia with and without N-SERVE.¹

Nitrogen, lbs./acre	Yield, bu./acre	
	Without	With
60	132	178
120	150	174
180	150	193

¹1973 Southern Illinois University

did not demonstrate this same effect upon stalk rot. Ammonium sulfate applied with N-SERVE reduced potato scab (*Streptomyces scabies*) and significantly increased yield of U.S. number one potatoes in Michigan. Additional disease control benefits have been reported with other crops.

Yield Results. Most experimental results with N-SERVE and other nitrification inhibitors have been tested using corn and wheat as the experimental crop. Yields obtained in Sullivan County, Indiana from fall applied ammonia are given in Table 3, and yields obtained in southern Illinois from spring applied ammonia are given in Table 4. These results were obtained when spring rainfall was considered excessive and under conditions most conducive to loss of nitrogen by leaching and denitrification; the results clearly show increased yields where N-SERVE® was included.

Results from research in 1975-76 on Mexico silt loam at the UMC Agronomy Research Center with fall applied ammonia and two hybrids are presented in Table 5. These results, obtained during a dry year, show increased yields at only the lower nitrogen levels (60 pounds N per acre), which would suggest that growth factors other than nitrogen—in this situation, the dry weather—were limiting. Conditions causing maximum nitrogen loss and those conducive to high yield did not exist during this dry year.

Effect on Nitrogen Recovery. Increased fertilizer efficiency results have been found when nitrogen was stabilized in the root zone. Three years of research in Indiana consistently showed 65 to 80 percent increase in nitrogen recovery by wheat with N-SERVE. Results from 1976 research at the University of Missouri Research Center with Mexico silt loam are given in Table 6. These results show that, even

Table 5. Two hybrid corn yields with fall application of anhydrous ammonia with and without N-SERVE.¹

Nitrogen, lbs./acre	Yield, bu./acre			
	Hybrid B73 x M017		Hybrid WF9 x 38-11	
	Without	With	Without	With
60	101	111	77	93
120	115	112	100	93
180	131	123	101	97
240	116	121	93	97
check	72	-	63	-

¹(1975-76) Poirot, M.S. Thesis, UMC, 1977

Table 6. Nitrogen recovery in corn grain with fall application of anhydrous ammonia with and without N-SERVE.¹

Nitrogen, lbs./acre	Yield, bu./acre			
	Hybrid B73 x M017		Hybrid WF9 x 38-11	
	Without	With	Without	With
60	46.0	69.3	30.5	62.3
120	39.5	46.8	42.1	35.0
180	42.1	35.5	30.9	25.4
240	26.7	25.3	20.5	22.1

¹(1975-76) Poirot, M.S. Thesis, UMC, 1977

during a dry year, there was an increase in recovery of nitrogen as measured in the corn grain, especially at the lower application rates. This indicates that at higher application rates, lack of moisture or factors other than nitrogen were limiting yields.

Suggested Uses for Nitrification Inhibitors

Two reasons to use methods to improve the efficiency of fertilizer nitrogen use are: (1) to reduce environmental pollution and, (2) to reduce the energy inputs into crop production by conserving the fossil fuels used in nitrogen fertilizer production. To accomplish more efficient plant use of nitrogen, a better understanding of the soil-plant-nitrogen-moisture relationship will be necessary. Research suggests that nitrification inhibitors with nitrogen fertilizers may be beneficial under these conditions:

- Fall applied nitrogen
- Pre-plant nitrogen on sandy soil
- Fields where soil textures vary from sandy to silt loam
- Pre-plant nitrogen on fine textured soil (those where water stands after heavy rains)
- Claypan soils where soils may remain saturated after heavy rains.

These are conditions where nitrogen losses are expected to be the greatest and where improved nitrogen use efficiency could be expected with nitrification inhibitors. Presently, we know that commercially available nitrification inhibitors do perform the function claimed. Increased yields through improved nitrogen use efficiency or reduced nitrogen loss is a function of weather and thus not always obtainable. Using them without knowing future growing conditions is somewhat like purchasing insurance.

Equipment Considerations

Presently N-SERVE is the nitrification inhibitor commercially available. Much concern has been expressed about the effect of this material in anhydrous ammonia upon the ammonia storage and application equipment. The following suggestions are for equipment care and maintenance when

using N-Serve with anhydrous ammonia solutions:

Corrosiveness. Solutions of N-SERVE 24 and anhydrous ammonia are corrosive to aluminum, excepting certain alloys of aluminum. The standard aluminum float gauge is subject to corrosion, especially at the junctions between two different metals when they are immersed in the solution. Replacing these with stainless steel gauges is recommended.

Gaskets. N-SERVE 24 nitrogen stabilizers can cause the Acme fitting gasket (buna-N composition) to swell and become brittle. The brittle or swollen gaskets should be replaced with gaskets of Teflon or Thiokol and cork composition.

Other Components. The other components—fixed liquid level gauge, liquid withdrawal valve, multipurpose valves, liquid fill valve, shut-off valves (hose), safety relief valve, vapor bleeder valve, and 400 p.s.i. ammonia pressure gauge—are not affected by the N-SERVE 24 and anhydrous ammonia solution under normal use situations.

Flow Regulator. The flow regulators on applicators should be routinely checked and cleaned according to manufacturers recommendations before storage.

Whether using or not using N-SERVE, a strict program of inspection, care, and maintenance of nitrogen application equipment should be followed.

References

- Bundy, L. G. and J. M. Bremner. 1973. *Inhibition of Nitrification in Soils*. Soil Sci. Soc. Amer. Proc. 37: 396-400.
- Hanson, Roger Gordon. 1970. *Nitrification Inhibiting Fertilizer Compounds*. United States Patent Office. Patent No. 3,542,537. November 24, 1970.
- Huber, D. M. and H. L. Warren, D. W. Nelson and C. Y. Tsai. 1977. *Nitrification Inhibitors - New Tools for Food Production*. Bio-Science. 37: 523-529.
- Poirot, M. J. 1977. *Effect of Nitrotyrin on Yield, Nutrient Composition, and Diplodia Maydis of Corn*. M. S. Thesis. University of Missouri.
- Potter, H. S., M. G. Norris and C. E. Lyons. 1971. *Potato scab control studies in Michigan using N-Serve nitrogen stabilizer for nitrification inhibition*. Down to Earth. Vol. 27. No. 3. The Dow Chemical Company.
- Scott, D. H., C. D. Spies, D. M. Huber, H. L. Warren, D. W. Nelson and D. R. Griffith. *Potential for Nitrogen Stabilizers*. ID-102. March. Purdue University.
- Wiese, R. A. 1976. *Control Nitrogen, Even After It's Applied*. Nebraska Farmer. April 3, 1976.

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