Managing Nitrogen Fertilizer to Prevent Groundwater Contamination

Extension Bulletin No. 64, April, 1994

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Presence and movement of nitrogen in North Dakota soils

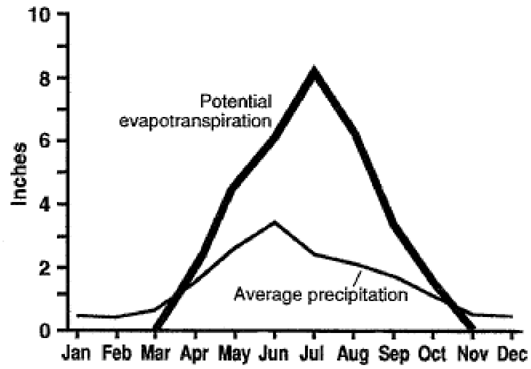
Fertilizers, legumes, manure, crop residue and soil organic matter are all sources of nitrogen needed for plant growth. Although nitrogen exists in many forms, nitrate (NO3) is the most available form to plants. Because nitrate is very soluble in water, it is readily carried to plant roots as the crop uses water. Soil nitrate unused during the growing season is free to move with water that percolates through the soil. This nitrate has potential to contaminate groundwater if water percolates beyond the root zone. The most important factor in nitrate pollution from crop production is leaving excessive amounts of unused nitrate in the soil after the crop has been harvested.

A general assessment of soil nitrate loss

The period when soil in North Dakota is most susceptible to nitrate loss to groundwater is during May and early June. This is at the end of the soil water recharge period when soil water content is at a maximum. However, production experience in North Dakota suggests that fall and spring rain rarely exceeds the storage capacity in the rooting zone of loam and fine-textured soils. Rarely is the rooting zone on these soils fully recharged prior to rapid vegetative growth of the crop.

Generally speaking, little potential for nitrate movement to the groundwater exists under average climatic conditions in North Dakota. Limited rainfall during the growing season reduces the threat of nitrate leaching through most North Dakota soils. Average potential evapotranspiration (PET) exceeds average rainfall during the growing season in North Dakota (Figure 1). Assuming that all of the average non-growing season precipitation soaks into the predominantly medium-textured soils of North Dakota, it should be retained within the rooting zone and subsequently used by the following crop.

Figure 1. Potential evapotranspiration and average rainfall amounts averaged over North Dakota (10).



Variation in soil nitrate loss

In many situations, average conditions do not adequately account for natural variation. As a result, actual potential for nitrate movement to groundwater can be significantly different between a local site and the state as a whole. There are both **natural** and **manmade** factors that must be considered when assessing local potential for nitrogen movement to groundwater.

Locations where surface water percolates through the soil to groundwater are known as recharge sites. The vulnerability of a groundwater aquifer is affected by location and extent of overlaying recharge sites.

Natural Factors

Water storage capacity

Potential for groundwater contamination is high where soils of low water holding capacity occur above a shallow aquifer. These soils are coarse-textured (sands and gravel) and recognized as fragile, low production land that is generally best managed as rangeland or pasture. However, under irrigation, sandy-textured soils can be productive cropland if managed correctly.

Careful management of nitrogen becomes more critical as soil water storage capacity decreases. The amount of water retained in the soil after gravity drainage is controlled by soil pore size. Soils composed of predominately large particles, like sand and gravel, have relatively large pores that hold much less water against gravity compared to fine-textured soils with smaller pores. Therefore, low storage capacity sands and gravel have greater potential for water percolation and nitrate loss.

Two practical aspects of North Dakota agriculture help prevent groundwater contamination by nitrogen:

1. Dryland crop production occurs predominantly on soils with high water storage capacity.
2. Long growing season crops such as sunflower, that are deep rooted, can use water that may escape the root zone of small grains. Rotations that include these crops will scavenge nitrogen that has moved beyond the small grain root zone.

Table 1. Approximate available soil water holding capacity for soil texture groups (3).

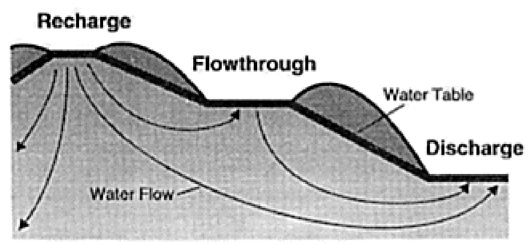
	Available Water Storage Capacity	
Texture	Short Growing Season Crops	Long Growing Season Crops
	(in./4 ft.)	(in./5ft.)
Coarse Sand and Gravel	2.0	2.5
Sand	3.2	4.0
Loamy Sand	4.4	5.5
Sandy Loam	6.0	7.5

Fine Sandy Loam	7.6	9.5
Loam and Silt Loam	9.6	12.0
Clay Loam and Silty Clay Loam	8.4	10.5
Silty Clay and Clay	7.6	9.5

Landform Position

Landform position is an important factor that determines whether groundwater recharge will occur. Generally speaking, low-lying landform positions receive runoff water from higher positions; therefore, the potential for leaching of excess water is increased (Figure 2).

Figure 2. Generalized schematic of recharge-flowthrough-discharge related to a North Dakota landscape (1).



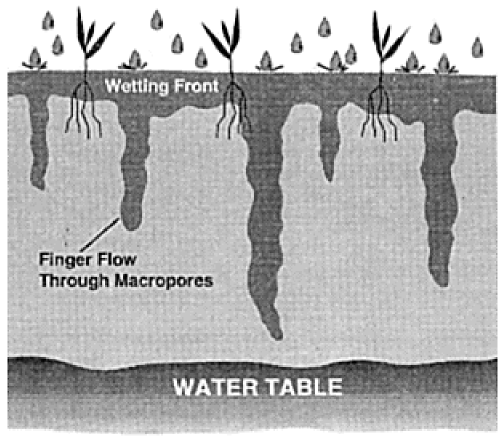
Frozen soils play an important role in water redistribution on North Dakota landscapes. Soils are frozen from early November through late April in North Dakota. During this period, vertical water movement ceases except for limited movement upward to the frost line. Precipitation received as snow or rain has little recharge potential until the entire soil profile is frost free in late April. As a result, spring thaw and subsequent runoff results in significant water redistribution from higher landform positions to lower positions.

Not all depressions and swales are recharge sites. Many are just the opposite and serve as groundwater discharge sites (Figure 2). A soil survey report can be used to identify both leached soils that occur at recharge sites and high lime or saline soils that occur at discharge sites.

Preferential Water Flow

Under some circumstances, significant amounts of water may flow through large soil pores (macro-pores) even though they make up only a small percentage of total pores. This type of water flow is called preferential flow (Figure 3), and may account for water and contaminant movement through finer textured soils once thought to be relatively impermeable. In this respect, fine and medium textured soils with frequent worm holes, cracks, or other vertical channels have the potential to allow nitrate movement deep into the soil beyond the rooting zone.

Figure 3. Illustration of water movement by preferential flow through a soil profile.



Preferential flow through soil depends on a continuous connection between macropores at the soil surface and those that occur much deeper in the soil. If preferential flow is significant in some soils, management techniques such as tillage that break the connection between surficial and deeper macropores would be important to groundwater protection.

Manmade Factors

Summerfallow

Summerfallow has a higher groundwater contamination risk than continuous cropping. Generally, water storage efficiency for the 15-month fallow period ranges from 10 to 25 percent, much less than continuous cropping systems (Table 2). Summerfallow generally reaches field capacity during the first fall or spring after harvest. Precipitation that falls after field capacity is reached runs off or percolates beyond the rooting zone. Because fallow fields remain at or near field capacity for an extended period of time, they have a greater potential to allow percolating water and nitrogen beyond the rooting zone, compared to continuous cropping systems.

Table 2. Excess Water Not Utilized by Crops in Crop-Fallow and Continuous Cropping Systems (4).

	Soil Water Storage (inches)	Average Annual Excess Water (inches)	
		Crop/ Fallow	Continuous Cropping
Vebar	4	2.10	1.20
(fine,	5	1.55	0.80
sandy	6	1.20	0.60
loam)	7	0.90	0.25

Irrigation

Irrigation in North Dakota creates conditions that can carry a higher risk of groundwater contamination compared to dryland farming. Irrigation generally occurs on coarse-textured soils that have good drainage and are prone to leaching. Irrigation often occurs over shallow aquifers. Because irrigation increases yield potential, increased nitrogen levels are required to meet that potential. Excessive inputs of either nitrogen or water, particularly on irrigated coarse-textured soils, substantially increase the potential for nitrogen leaching.

Sprinkler systems, especially center pivots, allow good water control and less leaching risk. Careful scheduling can provide adequate water for daily crop needs at soil water storage levels much less than field capacity (7). Furrow and flood irrigation systems are the poorest in terms of water application efficiency.

Under irrigation, profitable crop production and groundwater protection have been demonstrated when existing guidelines for nitrogen application and water management are followed. Montgomery et al. (1990) found that high corn yields could be produced with carefully managed irrigation and nitrogen fertilizer inputs in North Dakota. Lower irrigation inputs with well managed scheduling resulted in significant reductions in nitrate leaching (Table 3).

Table 3. Nitrogen and irrigation amounts applied to lysimeters and the resulting nitrate-nitrogen losses and final grain yields averaged over three years (8).

Nitrogen Rating	Nitrogen Fertilizer	Relative Irrigation Amount	Irrigation Amount	Nitrate Leaching Losses	Final Grain Yield
	lb/ac		in.	lb/ac	bu/ac
LOW	83	LOW	7.6	17.6	200
LOW	83	HIGH	10.0	30.2	195
HIGH	127	LOW	7.6	19.7	215
HIGH	127	HIGH	10.0	30.1	215

Perspective on nitrogen fertilization

Soil organic matter has been a source of nitrogen for North Dakota crops ever since the first prairie was broken by the plow. Declining soil organic matter content and high yielding crop production have contributed to increased nitrogen fertilizer use (Figure 4). In some soils of North Dakota, soil organic matter has declined to less than one-half of that present prior to cultivation in the early 1900s (Figure 5).

Figure 4. Nitrogen fertilizer use in North Dakota (1940-1990) (9).

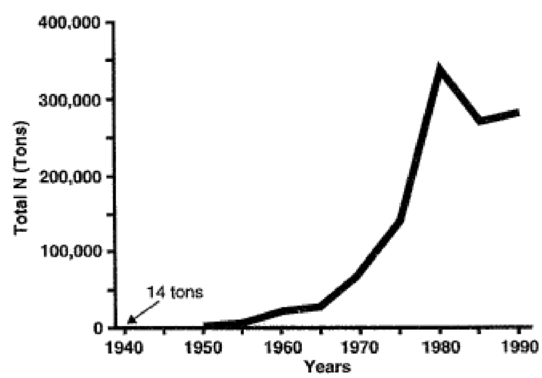
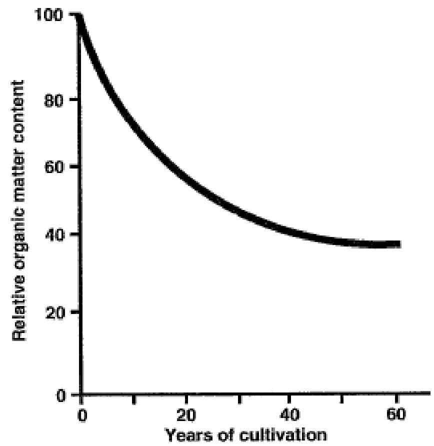


Figure 5. Change in soil organic matter content with cultivation (2).



The need for additional nitrogen fertilizer will continue, due to the high crop needs and an insufficient amount of nitrogen released from soil organic matter. This points out the critical nature of organic matter management. Erosion control and residue management are needed to conserve organic matter. A management plan that conserves organic matter makes good sense from both the water quality and crop productivity standpoint.

Soil Nitrate Testing

As added nitrogen needs became obvious in the late 1950s and early 1960s, research and extensive on-farm testing were used to develop a nitrogen soil test in North Dakota. The soil nitrate testing program is a crop production tool. Its objective is to identify the quantity of nitrogen in the soil after the cropping year. Recommendations for nitrogen fertilization are made by combining the soil test results with knowledge of nitrogen mineralization and crop needs.

The main advantage of using soil testing information is that fertilizer can be applied at rates needed by the crop to produce a maximum yield, avoiding reduced profitability from either under- or over-application of nitrogen. Originally, the need for soil testing was economic; however, we now recognize the additional advantage of water quality protection.

Soil samples in North Dakota's original nitrate testing calibration data extended to 5 feet. Data analysis showed about 80 percent of the precision available in nitrate testing could be obtained from a 2-foot sample. Therefore, as a sampling convenience, a 2-foot sampling procedure was adopted. The only extensive use of deep samples (4 feet) has been with sugarbeets. Concern for groundwater contamination in vulnerable areas may increase the need for nitrogen recommendations based on deep sampling.

The exact amount of nitrogen used, released and tied up depends on a combination of site conditions. Temperature, moisture, soil texture, organic matter and slope are just a few of the important factors that will affect nitrogen mineralization. Fertilizer recommendations can be refined based on the producer's knowledge of specific site conditions. Conscientious nitrogen management will pay dividends in profitability and water quality protection. In general, testing soils for nitrate-nitrogen in North Dakota and following fertilizer recommendations based on testing helps reduce the probability of surplus residual nitrogen after crop harvest.

Best management practices

Managing nitrogen fertilizer to reduce groundwater contamination must strike a balance between nitrogen needs for profitable crop production, seasonal rainfall, and soil water retention characteristics for the field being cropped. Both groundwater quality and production economics are best served when the management program followed does not waste nitrogen fertilizer. Nitrogen fertilizer provided to the crop during peak demand will reduce the potential loss to the groundwater. The following general nitrate management guides for crop production serve equally well as groundwater protection guides.

1. **Soil Test.** Testing identifies the residual soil nitrate from previous applications and nitrate released through organic matter mineralization. Testing to the full crop rooting depth offers opportunity to plan crop rotations for nitrate scavenging. This is an invaluable management tool to identify nutrient additions necessary to meet crop needs and avoid excessive application of nitrogen.
2. **Avoid fall nitrogen applications on coarse- textured soils.** Coarse-textured soils have low water holding capacity and high potential to allow nitrate leaching. These soils often contribute to recharge of groundwater aquifers.
3. **Plan a topdressing program for soils with high nitrate leaching susceptibility.** Nitrogen application on soils with high leaching potential should be split between a preplant application and a topdressing application during early vegetative growth.
4. **Delay fall anhydrous ammonia and urea applications as long as possible.** Studies have shown that delaying fall anhydrous ammonia and urea applications until late October will help maintain the amount of actual nitrogen that remains in the plant root zone (Table 4). If soil temperatures are above 45 degrees Fahrenheit, microbial activity increases, causing the ammonia to be converted to nitrate-nitrogen (NO3). Nitrate-nitrogen is the mobile form of nitrogen and can leach out of the plant root zone.

Table 4. Percent recovery of fall-applied ammonia as ammonium in early April 1991 and 1992, 10 locations, Cass and Barnes counties, ND (5).

Date of Application	April 1991	April 1992	Avg.
	%	%	%
15 September	9	22	16
1 October	16	37	22
15 October	50	66	58
1 November	90	NA	[90]+

NA = no application due to snow on 30 October.
+ = One year's data only.

5. **Know your soils.** County soil surveys have been completed in all counties of North Dakota. The soil survey shows specific soil properties or management predictions for soils on each parcel of land. Information such as soil texture and yield potential are directly related to nitrogen management.
6. **Follow strict irrigation scheduling and fertilizer recommendations for irrigated crops.** Well-timed applications of water and nitrogen fertilizer can effectively eliminate nitrogen leaching on coarse soils for most crops. Strict attention must be paid to water and nitrogen applications so that rates in excess of the crop's needs are avoided. This can be accomplished by scheduling irrigation using a method such as the checkbook method (NDSU Extension Circular AE-792, Irrigation Scheduling by the Checkbook Method) and applying nitrogen in split applications according to crop needs as determined by soil and plant testing.
7. **Use good management judgement.** Management options will vary with crops and seasons. For example, it is technically sound to apply anhydrous ammonia early in the fall under certain conditions. If a fine-textured or heavy soil is dry in the fall, precipitation through May is unlikely to recharge the crop rooting depth or cause nitrate leaching.

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Partial funding for this publication was provided by the USDA Extension Service, under project number 89-EWQI-1-9116 [and the NDSU Extension Service in a contractual agreement with the North Dakota Department of Agriculture.]

Extension Bulletin No. 64, April, 1994.