SOIL

# Soil Nitrogen Movement

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Many nitrogen sources such as sewage effluent, industrial wastes, animal wastes, and commercial fertilizers have been cited by ecologists and other concerned individuals as the principal sources of surface and groundwater pollution.

Nitrogen fertilizer use has aroused special concern because it is known that water containing large amounts of nitrate may present health hazards to people as well as to livestock. Under certain environmental conditions, the presence of large quantities of nitrate in the soil can result in nitrate accumulation in plants at levels toxic to both people and livestock. Aesthetic problems resulting from rapid growth of undesirable aquatic plants, including some algae, in lakes and streams are partly due to increased nitrogen levels in the water.

Nitrogen fertilizer sales in North Dakota have increased from 573 tons of actual nitrogen in 1951 to 64,110 tons during the 1969 calendar year. Use of nitrogen fertilizers is a good investment for most of our soils. North Dakota State University soils specialists estimate that, collectively, the state's farmers could profitably use four to five times as much fertilizer nitrogen as they now use.

Public concern about fertilizer nitrogen's contribution to environmental problems is not entirely without justification. Before condemning fertilizer nitrogen, however, one must understand (1) the contribution of soil organic matter as a nitrogen source, (2) the formation and properties of the various forms of nitrogen found in the soil, (3) the methods whereby nitrogen may be transported from soils to water supplies, and (4) precautions taken by agriculture to prevent loss or improper use of nitrogen.

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**Nitrogen Cycle**

Nitrogen is present in soils mainly in complex organic compounds commonly known as soil humus. Before the nitrogen present in soil humus can be used by plants, it must be broken down by microorganisms. The succession of related reactions involving the breakdown of humus and other processes shown in Fig. 1 is known as the nitrogen cycle.

Nitrogen is lost from the soil by crop removal, erosion, leaching and by volatilization of gases. Nitrogen is added to soil by nitrogen-fixing organisms, manure, crop residues and fertilizers. If losses of nitrogen from the soil are greater than additions, plants eventually become nitrogen deficient. When this occurs, farmers find it advantageous to supply extra nitrogen to the soil in the form of manure or commercial fertilizer. Too much nitrogen added to the soil increases the possibility of some nitrogen getting into water supplies.

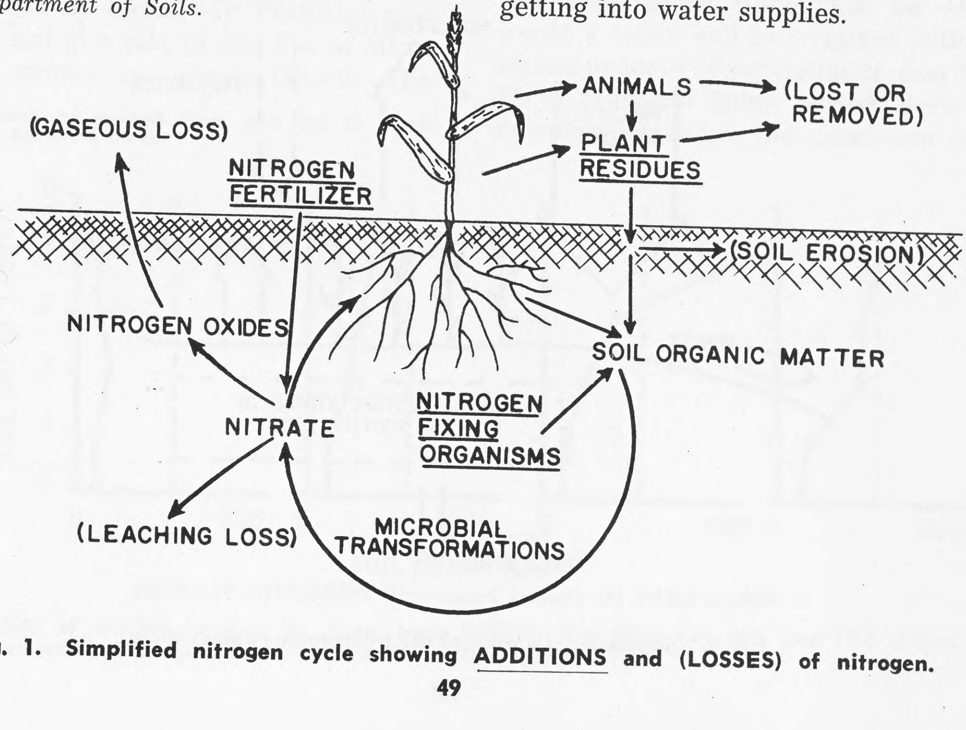


**Fig. 1. Simplified nitrogen cycle showing ADDITIONS and (LOSSES) of nitrogen.**

## Commercial Nitrogen Fertilizers

Ammonium nitrate is the most commonly used nitrogen fertilizer in North Dakota. Upon addition to moist soil, it dissociates into positively and negatively charged particles called ions. Ammonium ions (positively charged) are considered "immoble" because they are adsorbed on (attached to) soil particles and are strongly held in the soil. Anhydrous ammonia, upon application to moist soil, is converted to the ammonium form as are urea and other organic nitrogen fertilizers. Under favorable growing conditions this ammonium is, in turn, transformed to the nitrate form within several weeks. Nitrate ions (negatively charged) are actually repelled by the soil particles and are considered "mobile" and free to move with water in the soil. Therefore nitrate can move downward in soil with water or it can be carried up and deposited at the soil surface by the upward movement of water during evaporation.

## Hydrologic (Water) Cycle

Before examining how nitrogen might get into water supplies, a brief discussion of the hydrologic cycle is in order (Fig. 2).

Annual normal precipitation in North Dakota ranges from less than 13 to more than 20 inches, with the heaviest precipitation occurring during May, June and July. Precipitation (ice, snow, rain) and/or irrigation water may run off, evaporate from soil or plant surfaces, be stored in the soil, be transpired (used) by plants or be lost to deep percolation (movement of water below the root zone).

The quantity of water lost to runoff depends upon the rate, frequency and duration of rainfall. Considerable runoff and associated erosion is visibly evident at various locations throughout the state in any given year as a result of heavy rains. Water not lost to runoff infiltrates the soil or is ponded on the soil surface.

Water infiltrating the soil is either temporarily stored in the soil profile (vertical section of soil) until lost to evapotranspiration (combined processes of evaporation from soil and transpiration from plants) or continues to move downward, resulting in deep percolation. Deep percolation is most likely to occur in the spring when rainfall is high and plant roots generally are not extracting as much water from the plant root zone as that falling as precipitation. The quantity of water lost from soil to deep percolation in North Dakota hinges strongly upon soil texture and soil management practices as discussed below.

## Runoff and Erosion Losses of Nitrogen

Water runoff may result in soil erosion with accompanying loss of ammonium, which is adsorbed to the eroded soil particles. Once in a body of water, some of this ammonium adsorbed to the soil particles may be exchanged for other positively charged ions in the water. The result is a net gain of soluble nitrogen in the water supply. In addition, organic matter and any soluble or insoluble nitro-

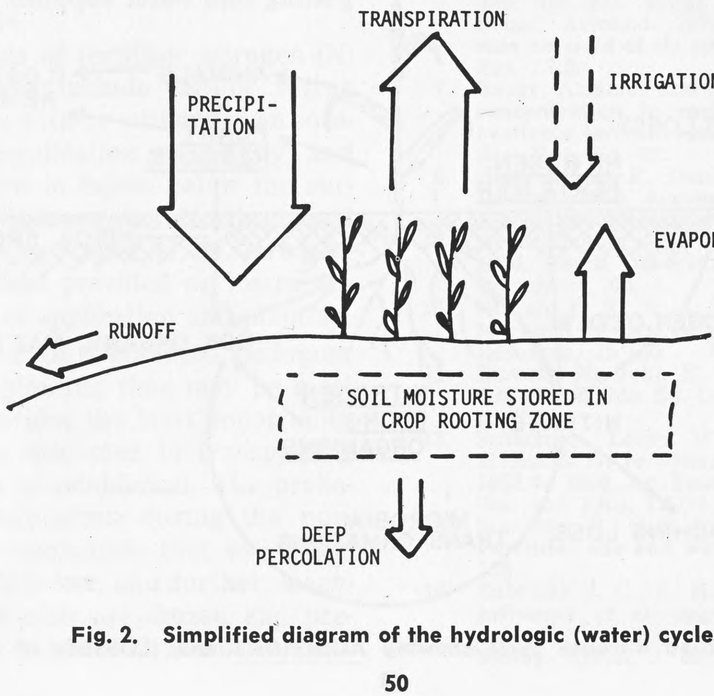


**Fig. 2. Simplified diagram of the hydrologic (water) cycle.**

gen present on or near the soil surface may be eroded.

Timmons, et al., (3) at Morris, Minnesota, found annual nitrogen losses from Barnes loam (6 per cent slope) to be 183, 66, and 31 lbs. per acre for fallow, continuous corn, and corn-oats-hay rotation, respectively. All of the ammonium form of nitrogen lost was associated with soil sediments, but nitrate losses were highest in the water of snowmelt and rainfall runoff.

Runoff from forested and grassland soils contains some nitrogen even though nitrogen fertilizers may not have been applied. The practice of spreading manure on sloping frozen soils results in appreciable loss of manure and nutrients in runoff water during the spring thaw. Soil management practices designed to reduce runoff and erosion also reduce nitrogen loss from soils.

**Nitrate Leaching**

Before nitrogen can be leached from the soil, conditions must be right for deep percolation. Of course, nitrogen must be present in the soil in the nitrate form. Thus nitrogen can be leached from the soil (1) only when deep percolation occurs, and (2) only when it is present in the soil in the nitrate form.[1] Data from the Great Plains Agricultural Research Center, Mandan, North Dakota (2), indicate practically no leaching of nitrate in that area from fertilized grassland or from soils continuously cropped to small grains. On the other hand, loss of nitrate below the rooting zone was observed on coarse-textured soils planted to row crops and also on alternate crop-fallow soils.

Data showing nitrate movement on an irrigated, fallowed, Svea loam soil during the summer of 1969 were reported by Cassel (1). Fertilizer was broadcast on the soil at a rate of 800 lbs. of nitrogen per acre as ammonium nitrate (33-0-0). The soil, kept free of vegetation, was irrigated throughout the summer and soil solution samples were collected at selected times and analyzed for nitrate-nitrogen. Results in Fig. 3 show nitrate-nitrogen distribution in the soil profile after various cumulative amounts of irrigation water were applied to the soil surface.

After 10.5 inches of water were applied, a large increase in nitrate-nitrogen was observed at the 1-foot depth. Each succeeding irrigation continued to move the nitrate-nitrogen deeper into the soil. Additional measurements showed that most of the nitrate-nitrogen detected at the 1-foot depth after 19.5 inches of irrigation water were applied resulted from nitrification of the initially broadcast immobile ammonium-nitrogen. This shows that even though an immobile nitrogen fertilizer was applied to the soil, it was soon transformed to the mobile nitrate form.

The above results would be expected to vary somewhat with soil texture. Less leaching would be expected on fine-textured or clayey soils with more leaching expected on coarse-textured or sandy soils, due in part to different water-holding capacities of the soils involved. In North Dakota, movement of nitrate to groundwater by leaching is most likely to occur on coarse-textured soils with high water tables.

If the Svea loam soil above had been cropped, downward movement of nitrate would not have been as great as shown in Fig. 3 because some of the nitrate would have been intercepted and absorbed by the plant root system. Such large nitrogen applications would not be economical nor would a fallow soil be irrigated, although 20 to 30 inches or more of precipitation may fall during the 20 to 21-month fallow period. Such a study does, however, establish the maximum annual nitrate

[1]Ammonium-nitrogen may be leached from soils but in much smaller amounts than nitrate-nitrogen.

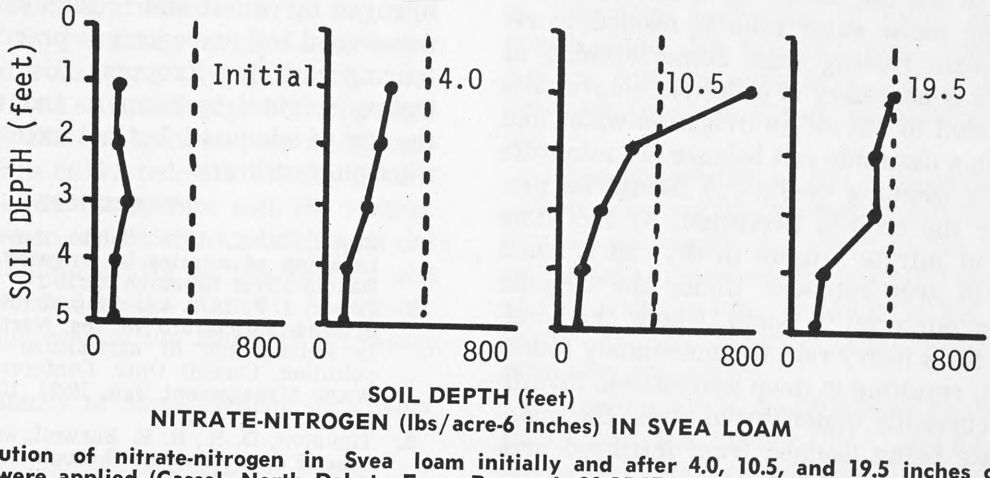


**Fig. 3. Distribution of nitrate-nitrogen in Svea loam initially and after 4.0, 10.5, and 19.5 inches of irrigation water were applied (Cassel, North Dakota Farm Research 28:15-17).**

movement one might ever encounter in a loam soil in North Dakota.

### Cropped Soils

For several weeks following the seeding of a crop, the soil surface is essentially bare and water is lost to the atmosphere from the soil primarily by evaporation. As vegetation becomes established and top growth increases, water is lost through transpiration. Precipitation tends to recharge or replace that water lost from the soil, with very little, if any, water being lost to deep percolation. For this reason, nitrate would tend to be leached from non-irrigated cropped soils primarily during the late fall when precipitation is recharging the soil or in the spring when additional precipitation falls on an already recharged soil profile.

Even if deep percolation does occur, leaching losses from cropped land can presently be minimized by proper fertilization procedures. Current recommendations from North Dakota State University suggest that fall application of nitrogenous fertilizer materials on all except moderately coarse and coarse-textured soils gives results comparable to planting time applications of these materials if the fall-applied fertilizer is incorporated into the soil. This recommendation is based on the likelihood that leaching may occur on the coarse and moderately coarse-textured soils and that incorporation will reduce possible losses due to spring runoff and erosion.

In addition to proper time of application, losses of applied nitrogen are minimized by applying adequate, but not excessive, amounts of nitrogen fertilizer. The best way to insure that the proper amount of nitrogen is applied is to have the soil tested for nitrate-nitrogen each year it is cropped.

### Irrigated Soils

Irrigated soils are susceptible to leaching from early spring to late fall. Leaching of nitrate results from applying more water than is needed to recharge the plant rooting zone. Some leaching of irrigated soils is necessary in order to remove salts which are added to the soil in irrigation water and thus maintain a desirable salt balance. To minimize nitrate losses, leaching operations should be performed after the crop is harvested. At this time the amount of nitrate present in the soil is small as a result of crop removal. Under the climatic conditions encountered in North Dakota, the possibility exists for a heavy rain to immediately follow an irrigation, resulting in deep percolation. Investigations are currently underway to assess the quantity of nitrate being leached from fertilized, irrigated, sandy soils near Oakes.

### Summerfallowing

Of the 20 to 30 inches of water falling on these non-vegetated soils during the 20 to 21-month fallow period, some is lost to runoff and some to evaporation. Appreciable soil erosion may occur on sloping land with the possible loss of substantial amounts of nitrogen. It is not rare for water to infiltrate below the five-foot depth during the fallow period. Since nitrate-nitrogen is released from soil organic matter present near the soil surface, it is susceptible to leaching below the crop rooting zone. Significant movement of nitrate may result.

Investigations are currently in progress to assess the amounts of nitrate-nitrogen being lost in this manner for a variety of soils located throughout North Dakota. Accumulations of up to 800 lbs. of nitrate-nitrogen per acre have been measured to depths of 10 feet in western North Dakota on alternate cropped-fallow soils that have received very little nitrogen fertilizer. Therefore, it is conceivable that most of the nitrogen leached from soils originates from natural decomposition of organic matter during fallow periods rather than from fertilizer nitrogen added at rates based on soil tests.

## SUMMARY

Losses of fertilizer nitrogen may occur from soils. All forms of nitrogen in soils (whether derived from chemical fertilizers, crop residues, manure, etc.) are subject to loss in runoff when accompanied by erosion. Soluble forms of nitrogen may be lost from soils in runoff without erosion; only the nitrate form is subject to leaching. Leaching depends upon many environmental and soil factors, some of which are the rate, duration and intensity of rainfall or irrigation, soil texture, soil water content and the absence or presence of actively growing crops. It is probable that losses of nitrogen accumulated in fallow soils are greater than losses of fertilizer nitrogen from cropped soils. Losses of nitrogen by runoff and erosion can be reduced by using good soil management practices such as contouring and strip cropping. Use of available soil testing services by farmers and ranchers insures the use of adequate, but not excessive, amounts of nitrogen fertilizer.

## REFERENCES

1. Cassel, D. K. 1970. Solute movement in soils: 1. **Leaching of nitrates in irrigated fallow soil.** North Dakota Farm Research 28:15-17.
2. Power, J. F. 1970. **Leaching of nitrate-nitrogen under dryland agriculture in the Northern Great Plains.** In Relationship of agriculture to soil and water pollution. Cornell Univ. Conference on Agricultural Waste Management, Jan. 19-21, 1970. Rochester, New York. pp. 111-122.
3. Timmons, D. R., R. E. Burwell, and R. F. Holt. 1968. **Loss of crop nutrients through runoff.** Minnesota Sci. 24:4.