HOLDING BACK NITRIFICATION

in the dry land wheat area of eastern washington

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The goals of good soil nitrogen management are to:

- obtain maximum profitable return from its use
- hold loss of plant nutrients to surface and ground waters to a minimum
- use efficiently to conserve resources that are used in making nitrogen fertilizers
- use nitrogen fertilizer in such a way that it exerts its maximum benefit with respect to quality of crop.

There are two common natural processes that can result in some loss of nitrogen and interfere with achieving these objectives. These processes are leaching and denitrification. A knowledge of soils, fertilizers and the processes of nature, and an assessment of the field in question can lead to management steps that can minimize these losses. These management steps can be to change time of application of nitrogen fertilizer, change the form of nitrogen applied, or use nitrification inhibitors. All these approaches are attempts to slow or delay conversion of ammonium forms of nitrogen until conditions favoring nitrate loss are past, or until there is rapid uptake of nitrogen by the crop.

Routes by Which Nitrate Nitrogen May be Lost

Of the two types of nitrogen fertilizer—nitrate and ammonium—only the nitrate form is subject to loss by leaching and denitrification.

Nitrate nitrogen is soluble and *mobile* in the soil. It moves readily into the soil profile slightly behind the wetting front. By the time the wetting front has reached six feet, nitrate will be two-thirds to three-fourths of that depth. If sufficient water moves through the soil, the nitrate form of nitrogen may eventually be carried beyond the effective root zone which, in the case of wheat, is generally considered to be six feet. This process is called leaching. Once nitrate has reached this point it may continue to move down into the ground water.

Another process that can lead to loss of nitrate nitrogen is denitrification. This occurs in poorly aerated soil. The most common cause of poorly aerated soil (lack of oxygen) is excessive soil moisture. When excessive soil moisture persists, certain special types of soil microorganisms called denitrifiers can continue to function in the absence of free oxygen they have the capacity to split the nitrate molecule into nitrogen gas and oxygen gas. This leaves elemental nitrogen (a gas) which then escapes to the atmosphere. Nitrate nitrogen is a chemical combination of one atom of nitrogen with three atoms of oxygen (NO_3^-). Nitrogen gas by itself is of no value to wheat or other cereal crops (only chemically combined forms of nitrogen are of value to cereal crops).

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Nature of Ammonium-Type Fertilizers

Most of the manufactured nitrogen fertilizers start out as ammonia (NH_3). Others are products which have been chemically combined with ammonia to form ammonium salts, e.g., ammonium sulfate $(NH_4)_2SO_4$ or ammonium nitrate (NH_4NO_3). One major nitrogen fertilizer is urea $CO(NH_2)_2$. This is still considered an "ammonium type" fertilizer since it quickly converts to ammonium (NH_4^+) after being applied to moist soil. Under some soil conditions, this form of nitrogen can revert to NH_3 (a gas) and can then be lost by volatilization (if left on the surface of moist alkaline soil, for example). Even if the soil is not alkaline, there may be some loss of ammonia by volatilization from urea application if urea is left on moist soil surfaces. The major emphasis in this publication will be on the prevention of nitrate nitrogen loss by leaching and denitrification.

While the ammonium type of nitrogen fertilizers are soluble, they are not *mobile* in the soil. The nitrogen in all ammonium type fertilizers when added to soils, will end up as ammonium ions–NH_4^+. This is true even for urea. The reason the ammonium ion is not mobile (doesn't move in the soil with water) is that the clay particles in the soil (the extremely small soil particles) possess negative electrical charges. These negatively charged clay particles attract the positively charged ammonium ions and hold them very tightly. They will not leach away with the percolating waters.

The nitrate ion (NO_3^-) is negatively charged and since like charges repel each other, the nitrate ion can move on through the soil with the downward movement of soil moisture.

Transformation of Ammonium to Nitrate

The ammonium ion doesn't remain as ammonium forever. Soil microorganisms (nitrifiers) convert the ammonium ion (NH_4^+) to nitrate nitrogen (NO_3^-). The rate of conversion depends on temperature and moisture supply. Whenever soil conditions are favorable for the growth of plants, they are also favorable for the functioning of the soil organisms that change ammonium to nitrate. The rate of transformation is extremely slow at temperatures around 40°F. The rate of transformation progressively increases up to a soil temperature of about 90°F. When the soil moisture level is at the wilting point, there is essentially no conversion of ammonia to nitrate. When the supply is above field capacity, denitrification will likely occur.

The microbial process taking place in the soil which results in conversion of ammonium to nitrate is called *nitrification*. The conversion is carried out in two steps:

(1) $NH_4^+ + O_2 \rightarrow NO_2^-$ (nitrite) — Done by a specific type of organism called nitrosomonas

(2) $NO_2^- + O_2 \rightarrow NO_3^-$ — Brought about by another specific organism called nitrobacter

(The above two steps show only part of the actual chemical reaction involved.)

Determining Form of Nitrogen Fertilizer to Use

For all practical purposes either the nitrate or ammonium form of nitrogen fertilizer is equally effective in bringing about yield increases, as long as the nitrogen remains within reach of the active, functioning plant roots. Plants can utilize either the ammonium or nitrate form of nitrogen, especially the young plant. The major portion of the nitrogen taken up by a plant is, however, in the nitrate form. This is true because under the usual field conditions which are favorable for crop growth, transformation of ammonium proceeds faster than does plant uptake of nitrate nitrogen.

The major consideration in answering the question of which form of nitrogen fertilizer to use is which one can be counted on being located somewhere in the major portion of the root zone during plant growth. In the case of nitrate, will it have leached out of the root zone or will it have denitrified before it can be used by the crop?

Deciding If There Will Be Leaching or Denitrification

In the typical summer fallow portion of the dry land wheat area, there is generally little likelihood of leaching, or denitrification. In the driest portion of this area, two seasons' precipitation will rarely refill the soil profile to or beyond 6 feet. Most often it will not be refilled to more than 5 feet. In such a situation, most of the nitrate will not go beyond the second or third foot, with probably a little in the fourth. Rarely will the surface soil remain saturated sufficiently long for denitrification to occur. Winter wheat can utilize moisture and nitrate to a depth of 6 or more feet if there are no soil conditions restricting root growth. Spring grains will probably not utilize moisture and nitrate beyond 4 feet. However the most desirable location for the nitrate is in the 2- to 4-foot zone where the major portion of the roots function during the early spring growth when the crop's greatest nitrogen demand occurs.

In the annual cropping region (approximately the 16-inch rainfall area and above), only one season's precipitation is available to refill the soil profile. The previous year's crop should have removed the available moisture from the rooting zone. In the lower rainfall portion of this area (14-inch annual rainfall and below), seldom will there be leaching except in the low-lying areas of the field that receive and retain runoff water from adjoining land. In some years in the annual-cropped area, one year's precipitation will more than refill the soil profile to a depth of 6 feet. Leaching of nitrate may result under such situations. A review of past soil moisture and nitrate tests will indicate how frequently this may happen. If no testing history is available, now is a good time to start obtaining this history. A soil test in the spring of the crop year will show whether leaching has occurred. If soil test data are obtained at the time wheat breaks dormancy, it would still be feasible to top dress nitrogen fertilizer if the soil test showed such a need. Soil test data obtained after spring growth is well under way is too late for that year's crop.

Under what conditions will denitrification occur? It occurs without question in those low-lying areas where water stands in the spring well into the growing season—those low lying areas that show yellow (pale green) crops. There may be other areas in a field, too, where it occurs. For example, some areas are underlaid with a dense, slowly permeable subsoil. The soil above these restrictive zones becomes saturated with water, and with frequent spring showers it may remain saturated for extended periods. Denitrification undoubtedly occurs under these conditions.

Avoiding Denitrification or Leaching Losses

Since conditions favoring leaching and

denitrification may develop after applying the nitrogen fertilizer and before the crop needs it, some management system must be adopted to minimize these losses. Once it has been established that leaching or denitrification is a possibility in the field in question, there are some management steps that can be taken:

- Avoid the use of nitrate forms of nitrogen, especially for fall-planted crops.

- Use ammonium types of nitrogen fertilizer and apply them at a time and under such conditions that the fertilizer remains in the ammonium form until the crop can utilize it. For example, if applied sufficiently late in the fall, ammonia fertilizer will not convert (or only slowly) to nitrate until spring growth begins (after late fall, the soil temperatures will be below 40°F most of the time). Even if soil temperatures are in the 50°F range, resulting in a little conversion of nitrate, some nitrate in the 2- to 4-foot depth is desirable.

- Apply in the fall a rate of nitrogen that is adequate for fall growth; then in the spring apply the amount that will meet the remaining needs of the crop. The spring application needs to be made very early–at about the time the wheat breaks dormancy. This may mean aerial applications are necessary.

- Where no cultural practices can satisfactorily assure that the nitrogen fertilizer will remain in the ammonium form until the crop needs the nitrogen, an effective way of managing such a situation is to use a *nitrification* inhibitor with one of the ammonium type nitrogen fertilizers.

Nitrification inhibitors are chemical compounds that are mixed with ammonium fertilizers which temporarily stops the first step in the nitrification process. One of the common nitrification inhibitors is a commercial product known by the trade name N-SERVE (nitrapyrin). This is the only product currently registered as a nitrification inhibitor in the State of Washington. It keeps the nitrogen in the ammonium form 2 to 4 months. To be effective, nitrapyrin-treated fertilizer must be incorporated into the soil.

Experimental Results of Nitrapyrin Use

Field experiments in Washington have shown that nitrapyrin does effectively delay nitrification.[1] Its effect on increasing yields has been variable (its influence on yield is almost totally related to its restriction of nitrogen loss by prevention of leaching or denitrification). Where neither leaching nor denitrification occurs nitrapyrin-treated and non-treated areas will have the same amount of available nitrogen and the yields will be the same.

A definite response to nitrapyrin was obtained in a trial near Pullman in a year when rainfall was 40% above normal. The response was a 23 bushel per acre increase when 120 pounds nitrogen per acre was applied with nitrapyrin.[2]

[1] Cochran, V. L., R. L. Warner and R. I. Papendick, 1978. Effect of N Depth and Application Rate on Yield, Protein Content, and Quality of Winter Wheat. Agronomy Journal 70: 964-968.

[2] Papendick, R. I. and J. C. Engibous. Nitrapyrin for Nitrogen Fertilizer in Eastern Washington. To be published in ASA Special Monograph.

[3] Smiley, Richard W., 1972. Relationship Between Rhizosphere pH Changes Induced by Root Absorption of Ammonium–Versus Nitrate Nitrogen and Root Diseases, With Particular Reference to Take-All of Wheat. Ph.D. Thesis, Washington State University, Pullman, Washington.

The response occurred in the crop year 1973-74 (following a lentil crop), a season of much above-normal precipitation. Fertilizer was applied early in September. Early rains brought about nitrification before cool temperatures slowed and eventually stopped the process.

Nitrapyrin may also be used to influence the protein content of wheat.[3] By heading time, the topsoil will be dry and the wheat roots will be extracting moisture from deep in the root zone. If available nitrogen is also present at these depths, uptake of nitrogen at this stage of growth tends to increase protein content. Where high-protein wheat is desired, nitrogen management should be such that some nitrogen will move deep in the profile. Where low-protein wheat is desired, practices should be followed that will limit the amount of available nitrogen that will be present deep in the profile (where moisture extraction generally occurs at heading time).

The form of nitrogen influences the nature and extent of some plant diseases. Nitrogen in the ammonium form has been shown to be helpful in reducing "take all" disease of wheat. The reason for this is most likely the influence ammonium has on soil pH (it increases the acidity). In those cases where "take all" is a known potential hazard, the ammonium form of nitrogen is preferable. Where there is a potential for rapid conversion of ammonium to nitrate the use of nitrapyrin to slow the conversion process would be helpful. On the other hand, other diseases may be suppressed more by nitrate. At this point, no clear-cut recommendations can be made as to forms of nitrogen for disease management.

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