DYNAMICS OF NITROGEN AVAILABILITY AND UPTAKE

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Nitrate Groundwater Pollution Hazard Index

Doerge et al. (1991) concluded that "The most effective management strategy will be one that recognizes the pattern of nitrogen demand by the crop and the nitrogen release characteristics of all important nitrogen sources to provide adequate, but not excessive levels of soil nitrogen throughout the growing season." Implementation of this strategy requires knowledge of the temporal N demand by the crop and the release characteristics of all important nitrogen sources. The nitrogen sources include: initial soluble mineral N content in the soil; the amount and mineralization rate of soil and applied organic matter; amount and timing of applied readily available N fertilizers; amount, time of application, and rate of release of slow release fertilizers; and N in the irrigation water.

The temporal supply of plant available N must match the temporal N demand by the crop to achieve the goal of "provide adequate, but not excessive levels of soil nitrogen throughout the growing season." Achieving this goal may not always be possible or practical, but one should strive to do so to the extent possible. The complete evaluation of a management strategy also requires understanding N losses by leaching, denitrification, and volatilization as well as plant demand and N supply sources. The expectation is that N losses by these mechanisms will be minimal if the available N at any given time is "not excessive."

Cumulative annual crop N uptake typically follows a sigmoid relation where the uptake curve initially increases gradually followed by a rapid increase and finally a plateau. When the vegetative part of the plant is marketed, the crop is usually harvested before the uptake curve plateaus. The slope of the uptake curve provides the daily rate of N uptake during the growth period.

The rate of N supply must be equal to the rate of uptake or some decrease in plant size will occur. But we will first analyze the case from a quantitative point of view. The effects of applying all the N requirement in a single application at the beginning of the crop season compared with multiple applications during the season is illustrated in figure 1. Clearly the impact of a large precipitation or irrigation event that causes leaching is greater from the large single application than the multiple split applications. One guiding principle, therefore, is that multiple applications, which more closely match the uptake, are better than a single application.

Although evaluating N uptake and supply on a quantitative basis as illustrated in figure 1 is very useful, a comparison of the temporal rates of uptake and rate of supply is a more accurate assessment of whether the crop requirements for maximum growth is being met. Nitrogen moves by two mechanisms from the soil solution to the root surface where it can be taken up by the crop. Water flowing to the root to meet transpiration demand transports soluble N to the root surface. If the rate of N transport to root surface by flowing water exceeds the rate of N uptake, the N concentrates at the root surface and moves away from the root surface by diffusion in response to a concentration gradient. If the N uptake is more rapid than that transported by flowing water, the concentration at the root surface decreases, creating a concentration gradient causing diffusion toward the root. If the combined rate of transport by flowing water and diffusion is less than the potential N uptake rate, plant growth will be less than optimal.

Whether transport of N by flowing water is adequate to meet the plant requirement can be estimated using the following rationale. On a field basis, transpiration rate (TR) has units of $m^3/m^2/d$ and N uptake rate (NUR) has units of $kg/m^2/d$. Nitrogen uptake rate divided by transpiration rate has units of kg/m^3, which are units of concentration. If the N concentration in the soil solution is equal to or higher than NUR/TR, adequate N is transported to the roots by flowing water. If the concentration is less than NUR/TR, water moving to the root will not supply adequate N, and the plant will be impacted unless diffusion is sufficiently rapid to provide the additional required N.

The quantitative analysis of N diffusion to a root system is very difficult, if not impossible, to accomplish. However, some generalizations are possible. Diffusion occurs through root surfaces; therefore, the total amount of N that can be made available to the plant by diffusion is related to the total area of root surface that actively take up N. A plant with a dense root system with many root hairs will be better supplied by diffusion than a plant with a sparse root system.

Information on the rate of N uptake as a function of time is valuable for programming N applications. These curves are presented for field corn and wheat in figure 2. The corn data are from Iowa State University of Science and Technology Cooperative Extension Services (STCES of Iowa State University, 1992) and the wheat data are from Doerge et al. (1991). The total N uptake was 294 kg/ha for corn and 258 kg/ha for wheat. Note that N uptake rate curve for corn is characterized by a much higher peak of shorter duration than wheat. Although the difference in total amount of N taken up between the two crops is not great (36 kg/ha), the N availability as a function of time is very different. Corn requires a very high supply for a relatively short time when compared to wheat.

The curves presented in figures 1 and 2 can be very misleading when one considers the N requirement at the early crop growth stage. Both figures would suggest that very little N is required during crop establishment. However, neither figure addresses the rate of N supply to the plant roots. The NUR/TR ratio identifies the soil solution concentration of N that is required for the transpiration stream to adequately transport N to root surfaces. Although the NUR is initially low (fig. 2), the TR is also small during the seedling stage. Uptake of N is required for the plant to enlarge and uptake must precede growth. Transpiration will increase as the plant becomes larger, but it is a responder to plant size rather than a contributor. Therefore the NUR/TR ratio can be large and indicate the need of a large soil solution concentration of N in the root zone. Diffusion is not expected to be a major contributor of N supply to the roots because of the sparse root system during crop establishment. Therefore, even though the amount of N per land area may not need to be great during the seedling stage, that N must be concentrated in the zone where the plant roots exist.

One fact emerges when one considers the mechanism of N transport to plant roots. It is impossible to extract all the soluble mineral N from soil solution without suffering decreased plant growth. The consequence of this fact is that there will always be some soluble N that can be leached beyond the root zone when "excess" water is applied. The amount and concentration of N leached depends on the several dynamic and temporal factors discussed above.

Thus far, plant N uptake dynamics and mechanisms of transporting N in the soil solution to plant roots have been discussed. Consideration must now be given to the various sources of N supply and matching this information with plant uptake dynamics. The initial soluble mineral N content in the soil represents the amount in the soil that is available for plant uptake or leaching throughout the year. The N in the irrigation water is supplied at the time of irrigation and at the amounts that are related to the concentration of N in the water and the amount of water that is applied. Commercial mineral N fertilizers are available for leaching or plant uptake based on the amount and time of application. These sources can be quantified both by amount and time. In principle, these sources could be managed to match the time and amount of crop N uptake to the extent practicable.

Organic sources and slow release fertilizers require evaluation of the dynamics of the N becoming available for plant uptake or leaching. Organic materials must be mineralized before the N becomes available for plants. Different organic materials have a very high level of variability of mineralization rates, and precise quantitative information is generally not available for a given source. Nevertheless, very important general information is known about mineralization that is significant to the topic under consideration.

The rate of mineralization is highest when the organic material is first incorporated in the soil and tends to decrease exponentially with time after incorporation. The temporal rate of mineralization pattern does not match the temporal rate of plant N uptake. The plant uptake pattern approximates a bell shaped curve (fig. 2) whereas the rate of mineralization is a continuous downward sloping curve. Therefore, it is impossible to program organic material application so that the rate of available N supply coincides with the rate of N uptake. This is particularly true for crops that have a very high rate of N uptake over a relatively short period of time.

Pang and Letey (2000) used the ENVIRO-GRO model to simulate the consequences on plant growth and N leaching of applying two manures with different mineralization rates to corn and wheat that have different temporal N uptake rates. They concluded that crops with high uptake rates for a short time are not well adapted to be fertilized solely by organic matter. Doerge et al. (1991) suggest supplying only a portion of the nitrogen requirement of a crop in organic forms and utilize immediately available nitrogen materials to insure adequate nutrition during periods of peak nitrogen demand.

Slow release commercial fertilizers behave somewhat like organic materials in that the rate of release is highest initially and decreases with time. The big difference is that the rate of release is much greater than the mineralization rate of most organic materials, and essentially all the N is released during the growth period of a crop. Slow release fertilizers have greater utility for crops that have fairly gradual uniform N uptake demand over the production period rather than for a crop with a very high peak demand.

References:

Doerge, Thomas A., Robert L. Rothe, and Bryant R. Gardner. 1991. Nitrogen Fertilizer Management in Arizona. College of Agriculture, University of Arizona. 87 pages.

Pang, X. P. and J. Letey. 2000. Organic farming: challenge of timing nitrogen availability to crop nitrogen requirements. Soil Sci. Soc. Am. J. 64: 247-253.

STCES of Iowa State University. 1992. How a corn plant develops. Special Report No. 48. Iowa State University of Science and Technology Cooperative Extension Service. Ames. IA.

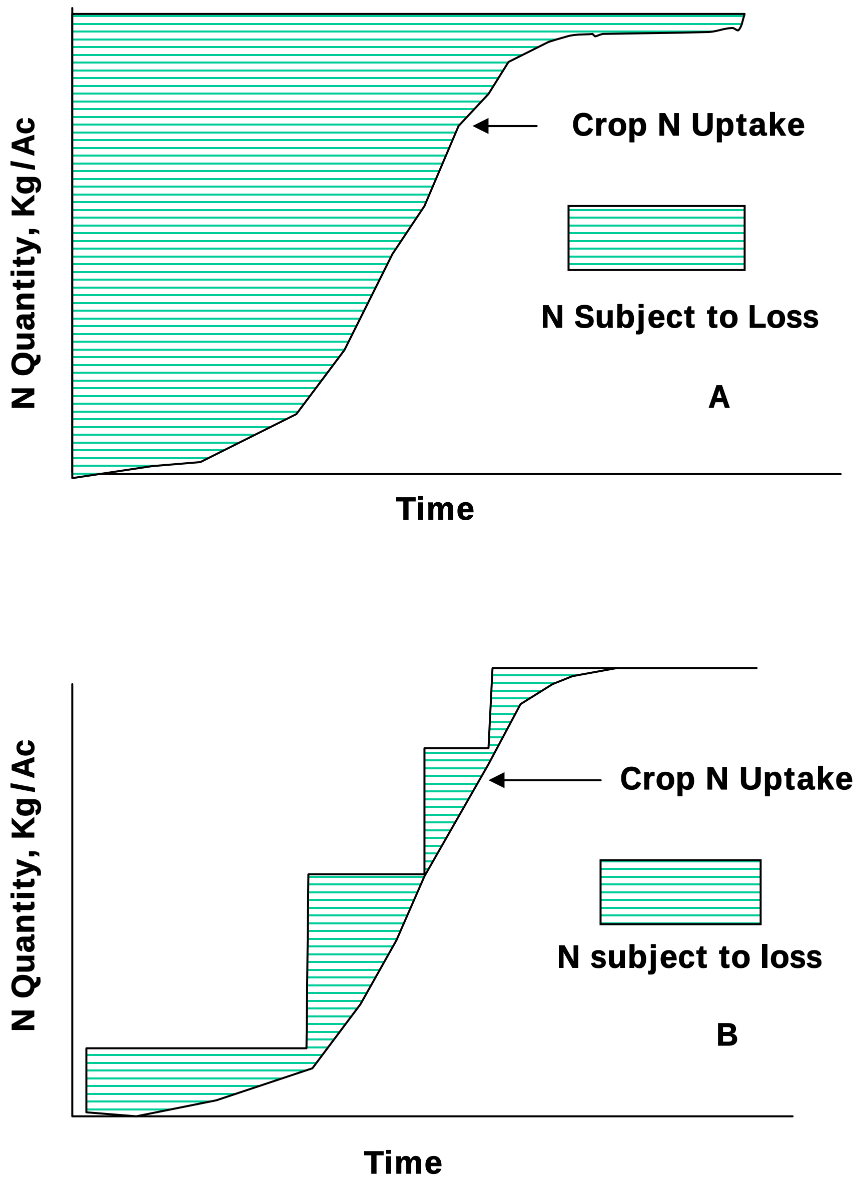

Figure 1. The quantity of N taken up by the crop or subject to loss from a single N application (A) or split N applications (B) (Adapted from Doerge et al., 1991).

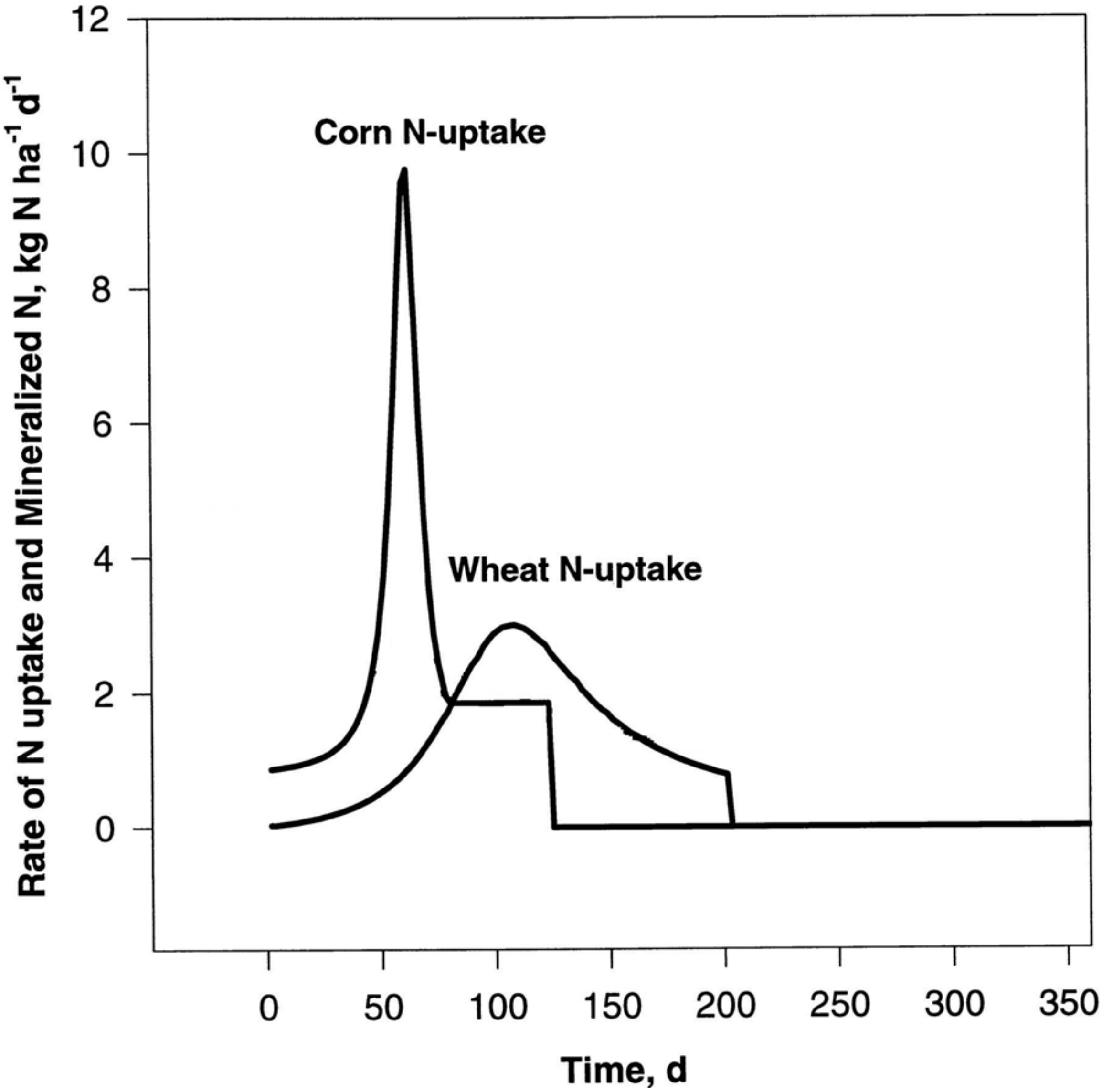

Figure 2. The rate of N uptake for corn and wheat as a function of plant growth over time.