ENVIRONMENTAL NITROGEN FOR PLANT GROWTH

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The availability of nitrogen, its utilization by plants, and its cyclization throughout the environment has been of interest and has consequently been investigated intensely by soil scientists, microbiologists, physiologists, crop production specialists and ecologists, to name a few.

Today, with the increased interest in all the ecological aspects of the mobile components of our environment, it is necessary that we understand the complete dynamics of elements such as nitrogen. To achieve this we must consider their cycling in terms of all the sources of input into the system, the various points at which there may be losses, and the energy levels at which these inputs and losses occur. From this viewpoint, some heretofore seemingly subtle facets have become major factors in altering the natural cycling of nitrogen through our environment. Also, the greater the extent and the longer the time these factors disrupt the natural processes, the less likely it is that the system ever will be able to recover.

The inputs and the withdrawals from the various nitrogenous pools in our environment have been estimated with considerable accuracy by numerous techniques. As a result of these researches, we have a general picture of the major mechanisms by which the different forms of nitrogen are transformed from one to another. We also think we know the major sites of inputs and losses from the system and can explain why some of these inputs do not become accessible to growing plants. There are ways by which nitrogen can be immobilized such as the binding of ionic forms to exchange sites in soils.

The accompanying diagram shows the movements of nitrogen throughout our environment. It also shows the major forms in which nitrogen exists; atmospheric nitrogen (N_2), nitrate ions (NO_3), nitrite ions (NO_2), ammonia (NH_3), etc. These various forms of nitrogen are arranged on a vertical scale representing the electron charge on the nitrogen atom in each respective form. In simplest terms, this is an indication of the state of oxidation of that particular form. A transformation from one form to another represents a change in the charge on the nitrogen atom. The greater the charge difference, the greater the amount of energy required or released in the process. Generally, going up the scale on the left requires an input of energy, while coming down the scale indicates a release of energy. This released energy may be coupled to some

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Note: This article represents the interest of the Agricultural Experiment Station in broad areas that are valuable to the industry of agriculture.

other process and thus may be used within or lost from the system.

Since parental soils contain no endogenous nitrogen, most of the naturally available soil nitrogen has originated from atmospheric nitrogen by a process known as nitrogen fixation.

Nitrogen fixation is the reduction of atmospheric nitrogen into organic combinations. It is accomplished by two different groups of microorganisms. One group works saprophytically; that is, it obtains the energy needed from dead organic matter in the soil. The other group works symbiotically; that is, it lives in the root tissues of certain plants (legumes) where much of the energy is supplied by the living host plant. In such symbiotic relationships, both organisms benefit mutually from the relationship since the microorganism supplies needed nitrogen to the plant. In symbiotic nitrogen fixation, the reduced nitrogen does not have to overcome some of the problems of absorption which other fixed nitrogen and nitrates have to overcome since the reduced nitrogen is already within the flow stream of the plant.

The reduced nitrogen is transported to the growing tissues of the plant where it is used in the synthesis of various complex organic compounds such as protein, a major component of plant tissues. These nitrogenous compounds are returned to the soil directly upon death of the plant as plant residues or indirectly as animal wastes and residues, unless they are exported from the system.

Ammonification is the process by which organic residues are broken down into simpler organic compounds with most of the nitrogen released in the form of ammonia. This process is accomplished by the activity of certain ammonifying bacteria. This ammonia can again be utilized by the plants directly, although it is more common for it to be oxidized by soil microbes to the nitrate ion. The nitrate ion is preferentially taken up by most plants over the ammoniacal form of nitrogen.

Nitrification is the process whereby ammonia formed by ammonification is acted upon by soil microbes and converted to nitrate. This overall

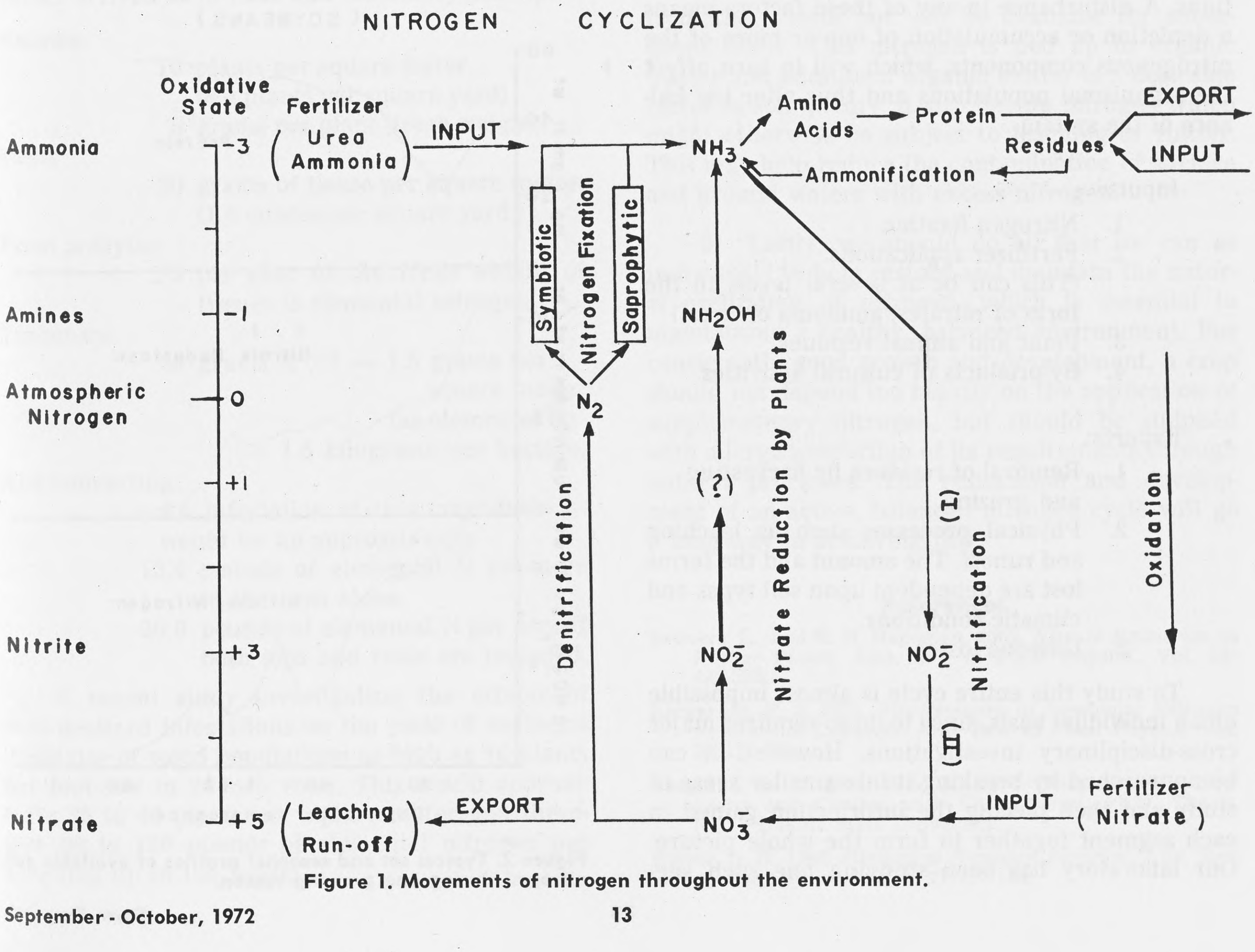

Figure 1. Movements of nitrogen throughout the environment.

oxidation requires at least two steps, each associated with a separate set of organisms. The nitrate so formed is the form most readily used by plants and in the greatest quantities.

Nitrate reduction occurs primarily in the leafy tissue of plants. Soil nitrates are absorbed by the plant roots and translocated to the leaves where a sequence of enzymatic reactions reduces the nitrates to ammonia and thus makes the nitrogen available for assimilation into leafy tissue, seed reserves, etc. The energy to drive this reductive process is supplied indirectly by photosynthetic activity in green tissues.

Denitrification is the process by which some nitrates may also be converted to molecular nitrogen by denitrifying bacteria. This does not occur to any great extent in well cultivated soils since the bacteria only reduce nitrogen in the absence of oxygen.

The maintenance of this system depends upon a number of factors. It requires a balance between the inputs and exports from the system and the existence of adequate plant and microbial populations to perform each of the various transformations. A disturbance in any of these factors means a depletion or accumulation of one or more of the nitrogenous components, which will in turn affect the organismal populations and thus alter the balance of the system.

Inputs:

1. Nitrogen fixation.
2. Fertilizer applications. (This can be at several levels in the form of nitrates, ammonia or urea.)
3. Plant and animal residues.
4. By-products of cultural activities.

Exports:

1. Removal of residues by harvesting and grazing.
2. Physical processes such as leaching and runoff. The amount and the forms lost are dependent upon soil types and climatic conditions.
3. Gaseous losses.

To study this entire cycle is almost impossible on an individual basis, since to do so requires major cross-disciplinary investigations. However, it can be approached by breaking it into smaller areas of study and then piecing the information gained in each segment together to form the whole picture. Our laboratory has been studying one such segment; namely, the reduction of nitrate to ammonia and the subsequent assimilation into the plant tissues.

This can be done in several different ways. One is to study seasonal changes in any of the indicators of nitrogen metabolism. This may include measurements of total nitrogen, soluble protein, nitrate ion concentrations and the activity of certain enzymes. The reduction of nitrate to ammonia involves the change of eight electrons, going from a +5 to a −3 charge. To accomplish this requires a good deal of metabolic energy and therefore it does not occur as a single reaction in the plant. We find that it is accomplished in a sequential set of reactions (involving the addition of pairs of electrons) each representing a small energy change.

It has also been shown, in several different laboratories, that the first reaction is by far the slowest reaction in the sequence. Thus, an assay of this first step, the reduction of nitrate to nitrite, can be used as an indicator of the overall capacity of the plant tissue to reduce nitrate all the way to

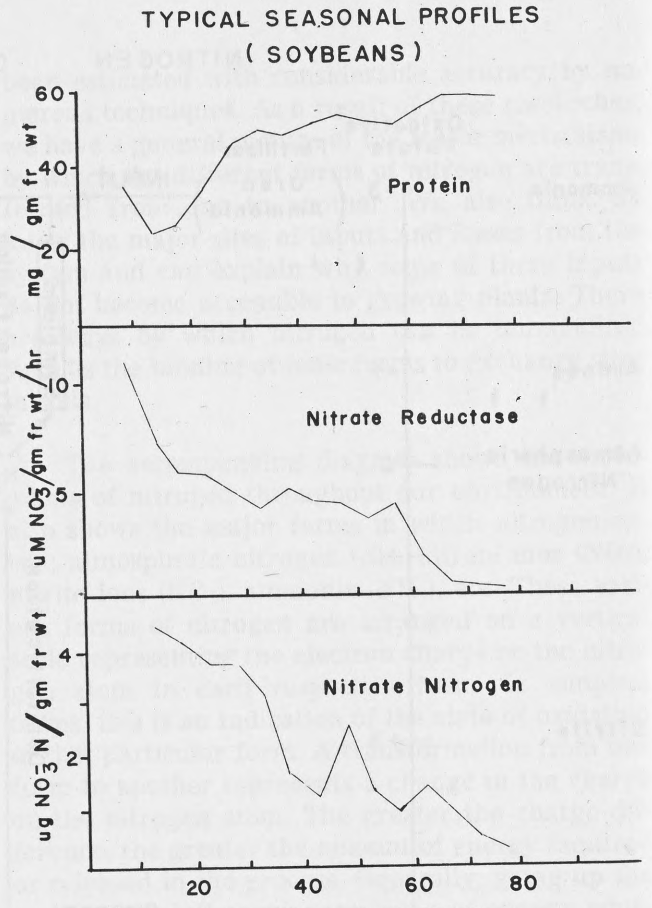

Figure 2. Typical set and seasonal profiles of available soil nitrogen during one growing season.

ammonia. Conducting such studies throughout a growing season gives us valuable data. When correlated to growth it can tell us when nitrogen is required by a plant and in what quantities. Analyzed in relationship to the application of supplemental nitrogen or existing available nitrogen, it can tell us with what efficiency the plant can incorporate nitrogen.

Figure 2 represents a typical set of seasonal profiles obtained during a single growing season. The general pattern shown is that where the major source of nitrogen is soil nitrates. Thus, the rate of protein accumulation depends on nitrate reductase activity, which in turn depends upon availability of nitrate in the tissues. Fluctuations from the general pattern are due to rain, changing availability of soil nitrates, and cloudy weather at the time of sampling.

Such information has many applications. For example, we are concerned with the accuracy of our evaluations of the impact of various factors on our environment. As one specific case we can use the type of data collected to estimate the impact of an infestation of wild mustard on a row crop. Consider the following sample calculation, using values arrived at in field and laboratory studies:

Assume:

10 plants per square meter.
(8.4 plants per square yard)
5 grams per plant (fresh weight).

Then:

50 grams of tissue per square meter.
(1.5 ounces per square yard.)

From analysis:

2-3 per cent of the fresh weight of tissues is elemental nitrogen.

Therefore:

50 grams X .03 = 1.5 grams per square meter.
(as elemental N)
= 1.5 kilograms per hectare.

And converting:

An infestation of this magnitude would tie up approximately
13.4 pounds of elemental N per acre in the tops alone.
26.8 pounds of elemental N per acre if both tops and roots are included.

A recent study investigating the effects of wild mustard infestations on the yield of soybeans made use of weed populations as high as 16 plants per foot-row in 20-inch rows. This would approximate 35 to 40 plants per square meter and therefore 90 to 120 pounds of elemental nitrogen per acre tied up in the weeds.

Ecological Significance

1. Relative to nitrogen metabolism in crops and weeds, the emphasis has been upon increasing the ability of any crop to reduce and assimilate nitrogen. With respect to competitive weeds the emphasis has been upon reduction and or elimination of the weedy species. In this instance the objective would be to decrease or eliminate competition for available nitrogen. Analyses of nitrate reduction and assimilation have been performed on young seedlings of a number of weeds and crops to indicate their overall capacity to reduce and assimilate nitrogen under various field conditions.

2. With respect to decreased nitrogen availability to successive plantings due to weed infestations, there are several considerations. First, under conditions like the example above, the amount of nitrogen removed from the soil is equivalent to an application of fertilizer containing 30 pounds of elemental nitrogen per acre. Secondly, this nitrogen is only temporarily lost for the immediate growth of plants. So long as it does not significantly reduce the current year's yield, seed quality, or contribute to increasing the weed population, it should be kept in mind that it is not nitrogen lost from the system but will be available for subsequent crops. This nitrogen is tied up in organic matter and additional organic matter is a desirable factor in soil quality. It also ties up nitrogen which might otherwise be subject to leaching or runoff. This may help reduce the contamination of surface and ground waters with excess nitrogen.

3. Lastly, we should do all that we can as individuals to help restore and maintain the natural cyclization of nitrogen, which is essential to maintaining a healthy, balanced environment. For consistently good growth and development, a crop should not depend too heavily on the application of supplementary nitrogen, but should be supplied with a large proportion of its requirements through natural processes. The restoration and development of an active, balanced nitrogen cycle will go a long way in achieving this.

References

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