THE HOW AND WHY OF NITROGEN

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Nitrogen is of special significance to the agronomist for two reasons. It is a major constituent of soil organic matter which is required in the soil as a storehouse of plant nutrients, and for its action in altering the physical and physical-chemical reactions of the soil, such as those affecting structure aeration and exchange capacity. The second role of nitrogen is of course that of a major nutrient required for all crop production, and it is this role which receives the greatest attention in research.

An understanding of the role of nitrogen, whether it be as fertilizer-N, or from a naturally occurring source, must take into account the fact that this element occupies a special position because of the many transformations that it undergoes, most of which are enzymatic processes mediated by micro-organisms. A series of cycles, as shown in the accompanying diagram, are always under way. These affect the utilization of nitrogen by plants, its incorporation into soil organic matter and its loss from the soil plant system. We have known of these cycles for a long period of time, however it is only recently the bacteriological and biochemical reactions involved have been uncovered such that we can use this information in the interpretation of field experiments.

One of the most important advances has been the separation of the soil organic matter into two phases; an active phase accounting for 10% to 15% of the soil nitrogen and a passive phase. The passive phase, although of importance from a physical standpoint, contributes only a small amount to the nitrogen nutrition on a yearly basis. Work with tracer elements and our own work in Saskatchewan with carbondating has demonstrated that although this passive phase contains thousands of pounds of nitrogen, the yearly contribution of plant-available nitrogen amounts to only a few pounds per acre.

Nitrogen added as urea in the ammonium form, or as nitrate, usually ends up within a short period as nitrate. It is impossible to obtain 100% utilization of this applied nitrogen and under field or growth chamber conditions some 10% to 40% of the nitrogen is always unaccounted for. An average loss of 30% is a good figure to use, thus for practical conditions, if 100 pounds of nitrogen are added to a soil system it is fairly safe to assume that 70% of this will be utilized. In the presence of plants approximately two thirds of this 70% will be utilized by the living plant and one third will enter the active phase of the soil organic matter, which is constituted of decaying roots, plant root excretions, microbial bodies and recent byproducts of microbial metabolism. Generally, the first year after fertilizer application one can expect 5% of the fertilizer-N that has entered the active phase of organic matter to be released - only 1% being released annually in subsequent years. Thus, the nitrogen and also the carbon in this active phase has a mean residence time of approximately 25 years. It is the cycling of the nitrogen in this phase of soil that makes it possible for the organic matter to be a storehouse of plant nutrients. This is especially so once a soil is in equilibrium such that the nitrogen content stays fairly constant, as is the case with most of the soils of Saskatchewan which have been cultivated for at least 60 years.

It is very important to remember that once the soil nitrogen content is at equilibrium, the soil organic matter acts only as a temporary storehouse of plant nutrients and not as a source of plant nutrients, especially nitrogen.

The only way to increase the nitrogen supplied from this source is by decreasing the content of stable soil organic matter, thus releasing more nitrogen into the active phase. The active phase must be looked upon as a revolving bank account which will release over a 25 year period, the organic material incorporated into it. The much larger amount of organic matter in the passive stage turns over so slowly that it contributes only a very small amount of nitrogen to the soil system on a yearly basis.

A 350 million bushel crop of wheat exported out of Saskatchewan will mean that 520 million pounds of nitrogen have been exported. An estimate of a total export from this province of about 800 million pounds of nitrogen is probably very conservative. Since the efficiency of nitrogen utilization is only approximately 70% this means that 1.2 billion pounds of nitrogen per year must be added to the soil system to maintain our yields. Replacement of this nitrogen solely by commercial fertilizer would increase the costs of agricultural production very greatly. The interesting fact in all this theorizing is that to date we have shown very little need for fertilizer nitrogen under our present cropping systems, with good response being found in specialized cases on stubble and on grasses. The need for additional nitrogen will probably rise as we increase our yields above the present level. However, at present there is no indication that natural processes are not supplying enough nitrogen.

A possible source of plant-available nitrogen which has not been recognized until recently is the non-exchangeable or fixed ammonia. This is the ammonium ion (NH_4^+) which is held within the clay lattice of the soil minerals. This type of nitrogen makes up at least 5% of the nitrogen of surface soils and the fixed ammonia actually increases with depth. In a glacial till soil such as the Haverhill or Weyburn, the fixed ammonia content is about .02%.

This is 200 parts per million and amounts to 3200 pounds of N per acre in the top four feet. To date we however know very little about this nitrogen fraction.

The fixed ammonia, especially in the lower depths of the soil profile, is probably geological in origin. Thus, the concept that all of the nitrogen in the soil profile comes from the atmosphere is probably erroneous. The extent to which this nitrogen plays a role in the nitrogen equilibrium in the soil and as a plant nutrient is not known. The fixed ammonia content can be altered by cultivation, fertilization and by plant growth. Further research in the future may make it possible for us to tap this fairly large reservoir of nitrogen.

Recent studies in various parts of the world have corroberated the previously published figure that rainfall brings down about 5 pounds of nitrogen per acre per year. This depends to some extent on the occurrence of lightning and the extent of combustion of fuels such as coal and to the proximity of volcanoes, but the figure is remarkably uniform throughout the world. Since the soil humus, when in an equilibrium condition acts only as a temporary storehouse with no net contribution of nitrogen and since to date the fixed ammonia fraction of the soil does not appear to have been tapped by the plants, the only alternative source of nitrogen other than fertilization is that of nitrogen fixation.

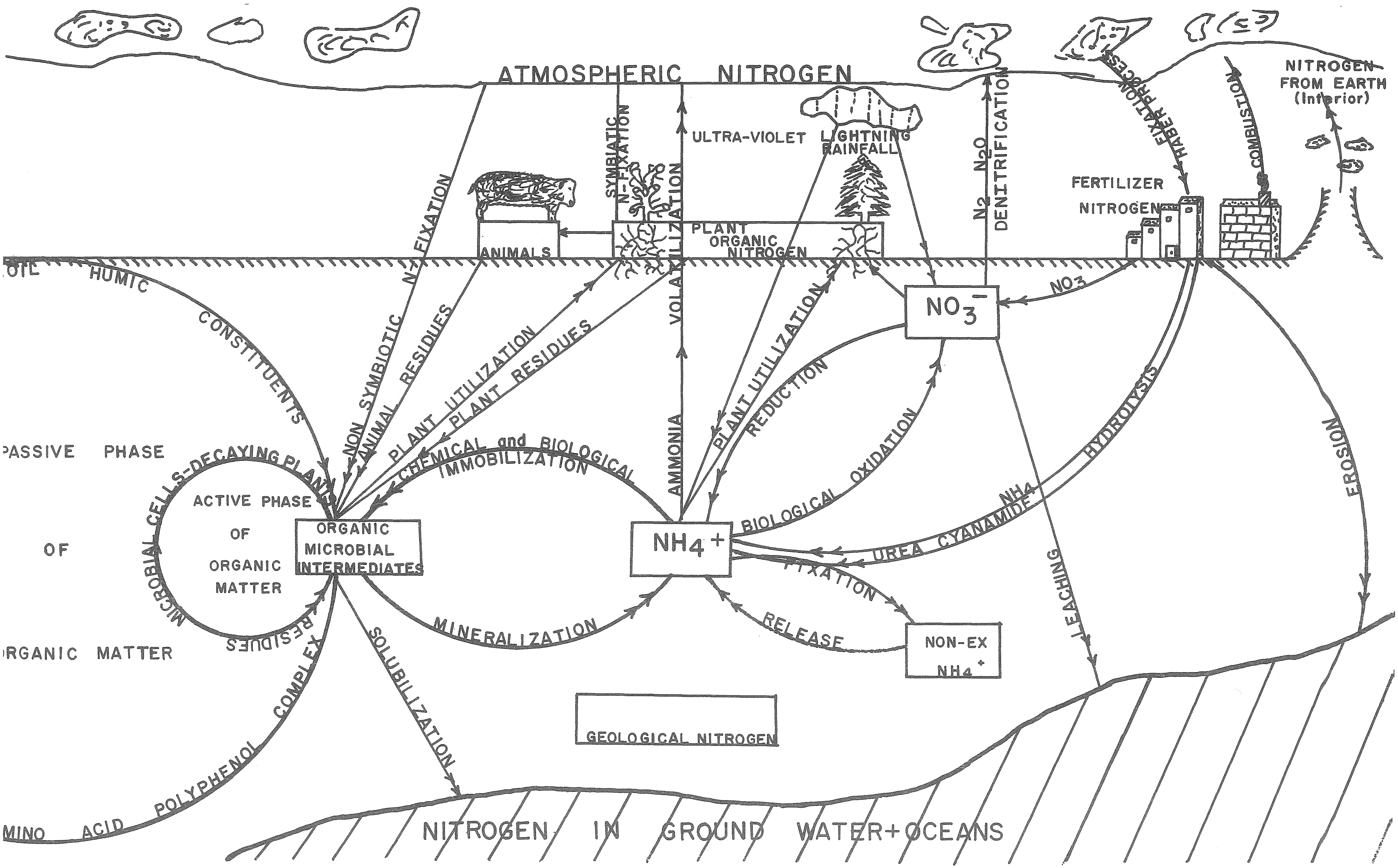
The processes involved in nitrogen fixation both symbiotic and non-symbiotic have been well characterized. We know much of the biochemistry of the reaction and many of the factors controlling it. Symbiotic nitrogen fixation has a phenomenal potential, with the New Zealanders claiming up to 700 pounds per acre of nitrogen fixation and a figure for us to strive for would be 200 pounds in our northern areas. A number of shrub species, such as alder, have been shown to fix significant amounts of nitrogen in association with some micro-organism and this could contribute to the nitrogen economy of a forest system.

Out on the bald prairie where much of our agriculture is established, symbiotic fixation will however continue to play a minor role. The intriguing question of the extent of the non-symbiotic fixation has still not been answered. We know much of the organisms involved, and there are at least 10 commonly occurring soil organisms which can carry out fixation under our conditions. Non-symbiotic nitrogen fixation is carried out to a much greater extent under reduced than under oxidized conditions, and many of our common root and soil inhabiting microorganisms fix nitrogen under anaerobic conditions.

The answer to the question concerning the amount of non-symbiotic fixation still has eluded scientists. We can only make estimates of the amount fixed under our conditions. Even where phosphate has been used to increase crop growth for a fairly long number of years, there does not appear to be any deficiency of nitrogen except in wet, cool years, and even this is sporadic. Thus, it would appear that non-symbiotic fixation plays a fairly substantial role in our nitrogen economy.

In conclusion, a few statements should be made about the utilization of both plant and soil nitrogen by the growing crop. This question has received a fair amount of attention in our own laboratory here in Saskatchewan during the last nine or ten years, with special attention being paid to growth chamber studies. Under growth chamber conditions there is a close inverse relationship between yield and nitrogen content of the grain. In a normal field there is a certain amount of nitrogen and increased yields will not necessarily mean an increased yield of nitrogen for very often the carbohydrate to protein ratio is widened. The introduction of high yielding wheat for growth under our conditions has been greatly hampered by the fact that the protein content must always be maintained at a high level. Thus if for a normal year Thatcher wheat has utilized all the available nitrogen to produce a 30 bushel crop of wheat, if a new variety is produced that produces 40 bushels, the protein content must go down. This means that the high protein content of our wheats can only be maintained at higher yield levels if the available nitrogen in the soil is raised. This of course is best and most easily done by nitrogen fertilization. The wheat breeder may therefore, in the future, breed for high yield and rely on fertilization to maintain his protein level.

Fertilization with nitrogen, especially at high levels introduces the problem of nitrogen toxicity, especially if some factor such as hail, drought or frost suddenly inhibits the growth of the crop. Feeding of this material to livestock often results in death due to high nitrates which have been accumulated in the leaves and have not been utilized for grain production. This problem will become more acute if we start utilizing nitrogen to increase the protein level of the seed grain and then get a very dry year, which greatly inhibits growth. Since it is impossible to forecast climate in the spring and thus forecast nitrogen requirements, the best alternative in the future will probably be application of nitrogen to the standing crop when it shows signs of requiring it.


ATMOSPHERIC NITROGEN
SYMBIATIC N-FIXATION
ULTRA-VIOLET
LIGHTNING RAINFALL
N2 N2O DENITRIFICATION
HABER PROCESS FIXATION
COMBUSTION
NITROGEN FROM EARTH (Interior)
FERTILIZER NITROGEN
ANIMALS
PLANT ORGANIC NITROGEN
VOLATILIZATION
SOIL HUMIC CONSTITUENTS
NON SYMBIOTIC N2 FIXATION
ANIMAL RESIDUES
PLANT UTILIZATION
PLANT RESIDUES
AMMONIA
PLANT UTILIZATION
REDUCTION
NO3
NO3−
HYDROLYSIS
EROSION
PASSIVE PHASE OF ORGANIC MATTER
MICROBIAL CELLS-DECAYING PLANTS
ACTIVE PHASE OF ORGANIC MATTER
ORGANIC MICROBIAL INTERMEDIATES
CHEMICAL and BIOLOGICAL IMMOBILIZATION
NH4+
BIOLOGICAL OXIDATION
NH4 UREA CYANAMIDE
FIXATION
RELEASE
NON-EX NH4+
LEACHING
RESIDUES
MINERALIZATION
SOLUBILIZATION
GEOLOGICAL NITROGEN
AMINO ACID POLYPHENOL COMPLEX
NITROGEN IN GROUND WATER+OCEANS