# FEEDING THE EARTH

# OPTIMIZING REACTIVE NITROGEN USE FOR SUSTAINABLE AGRICULTURE

**The dietary needs and changing preferences of a growing population are increasing demands on global agriculture. Because the area for agriculture is limited, yields must rise on land that is already cultivated. This will require both greater amounts of crop nutrients and more efficient use of them, including nitrogen fertilizers. In the short term, wider dissemination of best management practices is needed in order to achieve greater output without increasing unwanted environmental impacts related to nitrogen lost from agriculture. In the longer term, additional research is needed to develop innovative means to meet conflicting demands for ever greater agricultural outputs and ever fewer unwanted impacts. Because of its role as the primary supplier of nitrogen and other crop nutrients, the fertilizer industry is at the centre of these efforts.**

## Providing enough food, fibre and bioenergy is a daunting challenge for the agriculture sector

The world population is expected to grow from 6.2 billion in 2000 to around 8.2 billion in 2030. Over this same period, the number of calories consumed daily by each person is expected to increase on average by around 9%. These changes will occur largely in developing countries where food and nutrition security have not yet been achieved. As incomes improve, the proportion of animal products in diets will increase, in turn requiring more forage and grain as feed. Agriculture will also need to meet growing demands for fibre and bioenergy from crops while compensating for losses of agricultural land area due to urbanization and desertification.

Photo: BASF

Nitrogen deficiency symptoms in oats

Nearly all of the additional food, feed, fibre and bioenergy will need to be produced on the existing or shrinking agricultural land. This means crop yields must increase. To meet the requirements of higher crop yields and prevent soil depletion, the amounts of nutirents removed by crops will have to be replaced through the combined use of mineral fertilizer and the improved recycling of organic nutrient sources.

## Reactive nitrogen is essential for life

Nitrogen is vital for life, being an essential component of all proteins and of DNA. The atmosphere is 78% nitrogen, and about 99% of all nitrogen on Earth is atmospheric dinitrogen gas ($N_2$). Dinitrogen is an ideal gas to make up most of an atmosphere that supports life. This molecule is nearly chemically inert (dampening potentially damaging reactions such as combustion) and is not a greenhouse gas. However, it is not available to plants because it does not react with other molecules under normal conditions. Under certain circumstances, the extremely strong chemical bonds in diatomic nitrogen can be broken, and the nitrogen can be 'fixed' into compounds, with elements such as hydrogen, oxygen and carbon, that plants can use. This conversion requires large amounts of energy such as that provided by lightning. **About 1% of all nitrogen on Earth is in a fixed or 'reactive' form**. Without reactive nitrogen, life as we know it could not exist.

### What is reactive nitrogen?

Reactive nitrogen includes a wide range of molecules such as ammonia ($NH_3$), ammonium ($NH_4^+$), nitrate ($NO_3^-$), nitrite ($NO_2^-$), nitrous oxide ($N_2O$), nitrogen oxides (NO and $NO_2$), urea, amino acids (the building blocks of proteins) and nucleic acids (the building blocks of DNA).

Some bacteria are capable of fixing dinitrogen and, in a process known as biological nitrogen fixation, a few of these form symbiotic relationships with plants. For example, leguminous crops (e.g. soybean, alfalfa) live in symbiosis with bacteria that often provide their full nitrogen requirement.

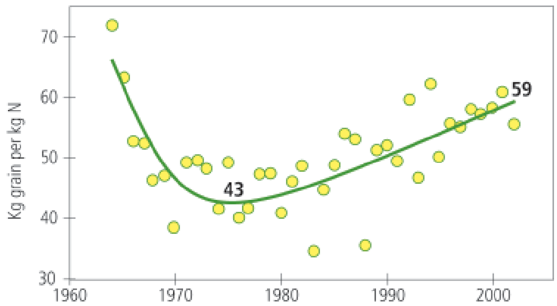

Field trial with maize in Kenya

Nitrogen is also fixed industrially through the Haber-Bosch process, which is the basis for the production of nitrogen fertilizers.

**In addition to influencing yield, nitrogen inputs can improve crop composition and thus the nutritional quality of food.** The most direct effect is to increase protein content, but correcting nitrogen deficiency also fosters the uptake of other nutritionally important elements. **Effective use of nitrogen fertilizers therefore improves both food security (quantity of food produced) and nutrition security (e.g. food protein content).**

## Sustainable agriculture requires more efficient use of reactive nitrogen

Nitrogen use efficiency tends to decline as the supply of plant-available nitrogen increases. This presents a challenge: to meet the growing demands on agriculture in a sustainable way. Nevertheless, **there are examples where both yield and nitrogen use efficiency have increased steadily over a period of years**, even on a national scale. This is the case for maize production in the USA since the mid 1970s, as well as for rice production in Japan and grain production in the European Union over the past two decades.




Fertilizer nitrogen use efficiency trends for maize in the USA (Adapted from Fixen and West, 2002)

Meeting the challenge of increasing nitrogen use efficiency and crop yields simultaneously is difficult but not impossible. The key to success on a global scale is establishing a commercial, technical and regulatory environment that encourages site-specific agronomic improvements on farms, particularly in developing countries.

Nitrogen use efficiency is measured in various ways, for example the average yield produced per unit of nitrogen applied, the quantity of extra nitrogen contained in the crop per unit of nitrogen applied or the extra yield produced per unit of nitrogen taken up by the crop. All of these ratios can be used as measures of the efficiency with which nitrogen is used. **Accurate application in terms of the right product, rate, timing and placement for local conditions helps optimize nitrogen use efficiency. This in turn reduces nitrogen losses, thus benefiting the farmer, society and the environment.**

Some of the fertilizer nitrogen applied in one year becomes combined in soil organic matter and will be released by mineralization in later years. Measures that do not take these latter contributions into account underestimate nitrogen use efficiency.

Nitrogen use efficiency can be applied to any nitrogen source but is usually used to assess fertilizer application. It is easier to measure and control the nitrogen use efficiency of fertilizers than of manures, because the precise composition of fertilizers is known, facilitating accurate application.

Crop yields increase with the supply of available nitrogen until a maximum point beyond which adding further nitrogen has no effect on yield, or may even reduce it. There is a point on this curve where the cost of a small addition of nitrogen is just equal to the value of the extra yield generated. At this point, the economic return from the application of nitrogen to the crop is greatest. A great deal of effort is expended by farmers, farm advisers and scientists to identify the economically optimum amount of fertilizer nitrogen needed for individual crops under site specific conditions. The overarching objective is to simultaneously increase the economic return and nitrogen use efficiency.


Providing agronomic advice to farmers:
The «Hariyali Kisan Bazaar» initiative in India

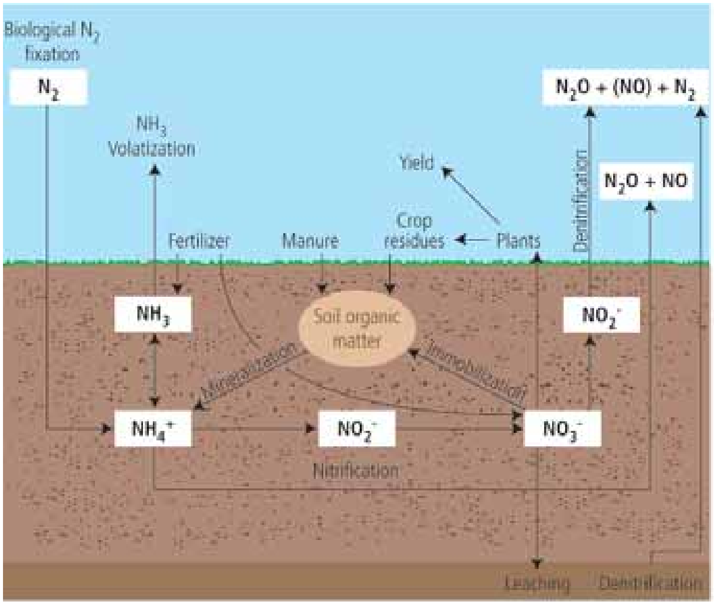
## All forms of nitrogen used in agriculture exist in the natural nitrogen cycle

Once nitrogen has been fixed into a ‘reactive’ state, it can become involved in various chemical and biochemical processes. There are many forms of reactive nitrogen in living organisms, soil, water and the atmosphere.

Nitrogen follows chemical and spatial pathways through the soil, water and atmosphere. Collectively, these pathways form the nitrogen cycle. In a natural ecosystem, a small amount of nitrogen is fixed from the atmosphere by bacteria. This nitrogen is incorporated into organic compounds in the bacteria or in the bacteria’s host plant. When these bacteria and plants die, the nitrogen is released into the soil in the inorganic, ammonium form through the decomposition of organic matter (this is known as mineralization). Some plants are eaten by animals and the nitrogen is excreted in organic forms or as ammonium or urea. Ammonium-N may be taken up by plants or by soil microorganisms or may be converted by certain bacteria into nitrate (nitrification). Under certain conditions, soil ammonium-N may be released to the atmosphere as ammonia (volatilization). A small amount of nitrate reaches the soil through deposition after lightning oxidizes atmospheric dinitrogen. Nitrate may be taken up by plants or may be leached from the soil when there is excess rainfall. Nitrate that is leached may enter water sources. Soil nitrate may also be converted to gaseous dinitrogen and nitrous oxide by specific bacteria (denitrification), completing the nitrogen cycle by returning nitrogen to the atmosphere.

Human activities modify the nitrogen cycle in various ways. Where crops are grown without nitrogen replenishment, soils lose organic matter and fertility. In the past, new land could be brought into cultivation and depleted land could be left fallow to compensate for the degradation of cultivated fields, but this is no longer viable because of the increasing pressure on agro-ecosystems. Fortunately, we now have the means to increase the amounts of reactive nitrogen and other essential plant nutrients at various points in the agricultural cycle so that soil depletion can be avoided.

Application of fertilizers, animal manure and human wastes adds ammonium and nitrate to the soil. Expansion of soybean cropping has increased biological nitrogen fixation and the breakdown of soil organic nitrogen. Emissions of ammonia and nitrogen oxides have increased largely due to increased livestock production and fuel combustion. Some of these emissions return to the soil through atmospheric deposition.



The soil nitrogen cycle

### How does the fertilizer industry contribute to sustainable agriculture?

The primary and most direct contribution of the fertilizer industry to meeting the challenges facing agriculture is ensuring that adequate fertilizer supplies are available. To provide this service in the most sustainable manner possible, the industry is committed to improving product properties, to ensuring suitable fertilizers are available to meet farmers’ specific needs and to developing methods for better matching nitrogen supply to crop requirements.

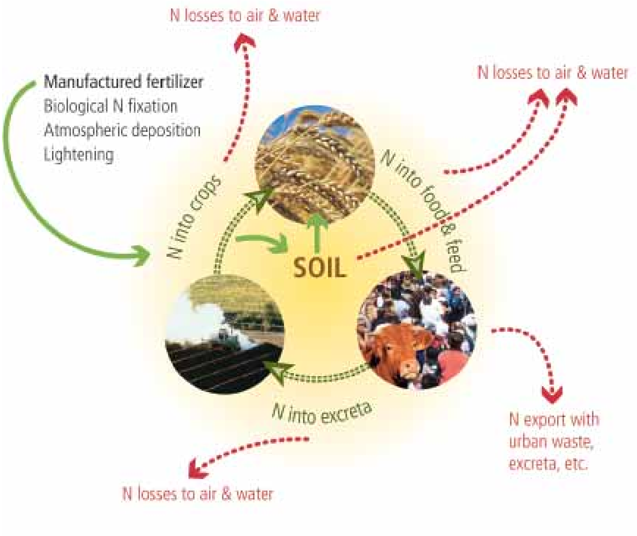
A wide range of multi-nutrient fertilizers is produced to help ensure balanced crop nutrition for particular crops and local conditions. Nitrogen use efficiency can be improved substantially by meeting a crop’s needs for all essential nutrients.

The industry plays a central role in developing nutrient best management practices to help farmers use fertilizers most effectively. **The objective of best management practices is to match total nitrogen supply to a crop’s requirement for optimum economic yields and for minimal losses of nitrogen into water and the atmosphere.** The aim is to optimize nitrogen use efficiency whilst achieving full economic yields. Farmers must have the means to identify and, so far as practically possible, to quantify all sources of nitrogen available to an individual crop. Applications of fertilizer nitrogen can then be targeted more accurately, with benefits for both the farmer and the wider environment.The fertilizer industry supports the implementation of best management practices through research into techniques for predicting or diagnosing nitrogen requirements accurately and involvement in advisory and educational initiatives directed at farmers.

## Fertilizers are essential to meet crop nitrogen requirements

In the natural nitrogen cycle, ammonium and nitrate – the forms of nitrogen that most crops take up readily – are released into the soil through the mineralization of organic matter, biological nitrogen fixation and atmospheric deposition. But these naturally occurring amounts are rarely sufficient to meet the needs of an economic crop today. Livestock manures are valuable sources of nitrogen in some places but, even taking these into account, **the amount of organic nitrogen available globally is much less than global crop requirements.** Nitrogen fertilizers supplement these natural or indigenous sources so that the crop can achieve a full economic yield.

**Applying fertilizer replenishes soil nitrogen and maintains or increases the soil organic matter content, thus supporting high yields over the long term.** This makes it possible to exploit existing agricultural land in a sustainable way that would not be possible otherwise.




The actual agricultural nitrogen cycle: an open system with inevitable losses

## Maximizing environmental benefits and minimizing unwanted effects

Fertilizer nitrogen brings environmental benefits by supporting sustainable yields, maintaining economic crop yields on existing agricultural land and improving water use efficiency (the amount of crop that can be produced with a given amount of water). It also helps reduce atmospheric carbon, immobilizing carbon that could otherwise contribute to global warming as carbon dioxide.

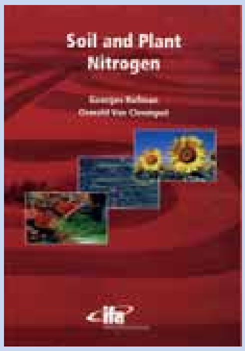
On the other hand, unwanted impacts on the wider environment can occur when nitrogen is lost from agricultural land to water or to the atmosphere. This can be a particular problem when livestock manures are used inefficiently or when nutrient best management practices are not in place. Losses occur naturally, and manure or fertilizer use does not introduce any new pathways to the nitrogen cycle. However, **increasing the amounts of nitrogen flowing through the cycle increases the risk of loss from agricultural land**. The main environmental issues associated with nitrogen use in agriculture are leaching of nitrate to water and losses of ammonia and nitrous oxide to the atmosphere.

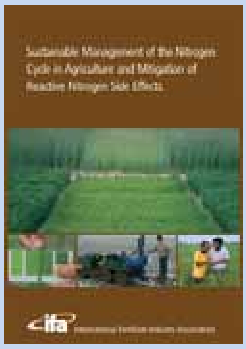
Together with phosphorus, nitrate can contribute to excessive algal growth in surface waters and consequent adverse effects on fish and other organisms (eutrophication).

Ammonia lost to the atmosphere contributes to acid rain and dust formation. **Agriculture is responsible for around 75% of global ammonia emissions. Half of this is associated with livestock manures. About 16% of global ammonia emissions are associated directly with fertilizer production and use.**

Nitrous oxide contributes to the greenhouse effect and may damage stratospheric ozone. Globally, it has been estimated that agriculture accounts for around 38% of total and 86% of anthropogenic nitrous oxide emissions. Of the agricultural emission, 44% is related to the management and application of animal manures while 14% is associated directly with the use of manufactured fertilizer. Significant uncertainties remain with regard to estimates of global nitrous oxide emissions. These should be reduced as improved methodologies are introduced.

For more information on nitrogen in agriculture, you may order the following IFA publications:



*Feeding the Earth* represents a series of issue briefs produced by the International Fertilizer Industry Association to provide current information on the role of fertilizers in sustainable agriculture and food production.



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