Nitrogen recycling for sustainable agriculture

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Summary

The innovation of synthetic ammonia by the Harber-Bosch process has contributed greatly to an increase in food production and an unprecedented expansion of the world population. It has come to supply 1/3 of the amount of protein now assumed to be necessary for the world population of 6 billion people. That is, only a population of 4 billion people could be supported by organic farming which uses effluents and green manure. However, serious environmental pollution has been caused by the unrestricted use of synthetic fertilizers. Once a stable-pair of nitrogen atoms in the atmosphere change into reactive nitrogen, they take on various forms. Therefore, such reactive nitrogen becomes a serious environmental pollution factor – causing such nitrate pollution problems as soil and hydrosphere contamination and greenhouse effect, depletion of the ozone layer, acid rain, and photochemical smog attributed to the nitrous oxide in the atmosphere. How can a method of sustainable animal agriculture which supports a world population of 6 billion people and preserves the environment be developed? With this in mind, the following case studies are discussed:

1. A dairy farming model of small holders and modern mega-farms in Qinghai Province, China
2. "Biomass Japan" - a national policy of Japan and model with new ideas

Keywords: synthetic ammonia, Harber-Bosch, nitrogen recycling, nitrate, biomass

Introduction

The human population quadrupled during the 100 years of the 20th century. The main reason was the innovation of the synthesis of ammonia by the Harber-Bosch process; although many other factors have contributed to this unprecedented expansion. The ready availability of nitrogen fertilizers has effectively boosted food production. The world population now has enough to eat, on average, because of numerous advances in modern agricultural practices.

Figure 1 shows that the sudden growth in global consumption of nitrogen fertilizer during the last century has been matched by a parallel increase in the world population. Whereas human beings obtained a method to freely produce synthetic nitrogen from unlimited atmospheric paired nitrogen using the Harber-Bosch process like legume plants, the amount of nitrogen drawn from the atmosphere into the global environment has become inscrutable.

The present paper deals with nitrogen recycling as a significant environmental issue to establish sustainable agriculture.

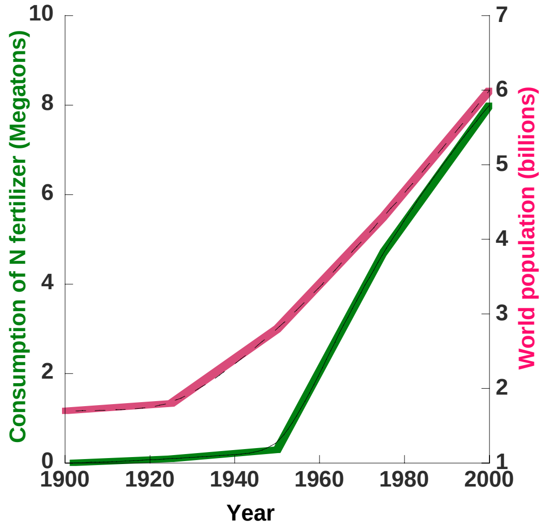


Figure 1 Sudden growth in the global consumption of nitrogen fertilizer during the 20th century has been matched by a parallel increase in world population

Merits and demerits of nitrogen

Why is nitrogen so important? Compared with carbon, hydrogen, and oxygen, nitrogen is only a minor constituent of living matter. But whereas the three major elements - carbon, hydrogen and oxygen - can move readily from their huge natural reservoirs through the food and water people consume to become a part of their tissues, nitrogen remains largely locked in the atmosphere. Only a tiny fraction of this resource exists in a form that can be absorbed by growing plants, animals and, ultimately, human beings. Yet nitrogen is of decisive importance. Nitrogen is needed for DNA and RNA - the molecules that store and transfer genetic information. It is also required for making proteins - those indispensable messengers, receptors, catalysts and structural components of all plant and animal cells (Figure 2).

Humans, like other higher animals, cannot synthesize these molecules using nitrogen in the atmosphere and have to acquire nitrogen compounds from food. There is no substitute for this intake, because a minimum quantity is needed for proper nutrition. However, getting nitrogen from the atmosphere to crops is not an easy matter. Paired nitrogen atoms make up 78 percent of the atmosphere, but they are too stable to transform easily into a reactive form that plants can take up. Lightning can cleave these strongly bonded molecules; however, most natural nitrogen "fixation" is done by certain bacteria. The most nitrogen fixing bacteria are of the genus *Rhizobium symbiont* that creates nodules on the roots of leguminous plants such as soybeans. To a lesser extent, cyanobacteria also fix nitrogen. In some cases legumes have been grown without harvesting food from them at all. These crops are plowed into the soil as so-called green manures. In Japan, Chinese milk vetch has traditionally been used as a green manure for rice fields.

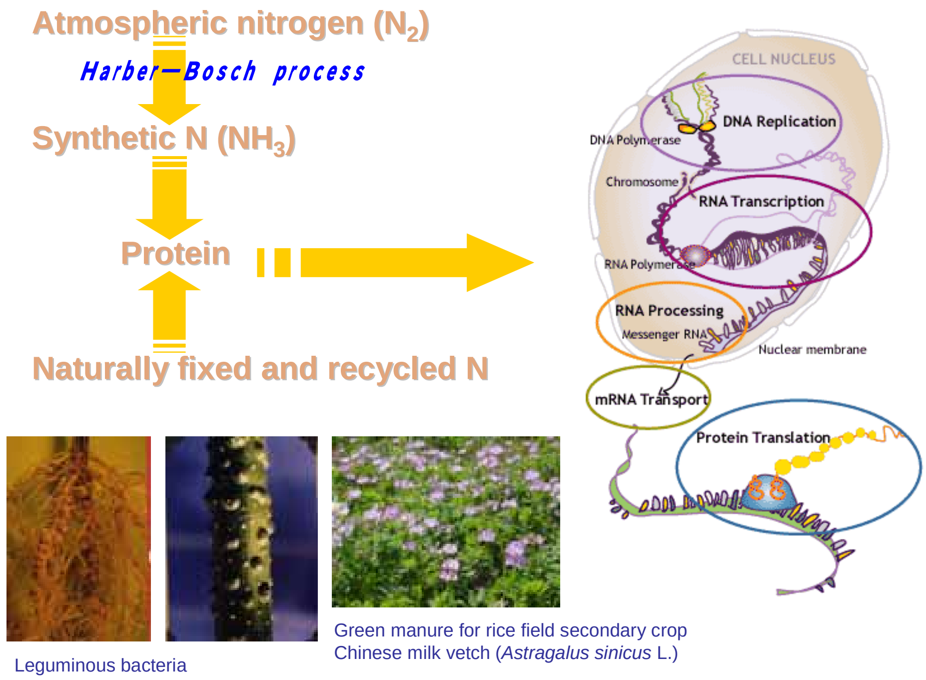


Figure 2 Acquisition of nitrogen and its importance

Recent rapid expansion of the world population and global requirements of energy and protein.

More than 214,800 tons of protein is now required everyday to support the world population. This value is obtained from a simple calculation of multiplying 35.8g daily protein requirement for an adult human by 6 billion world population. The amount of nitrogen incorporated into this protein requirement equals 34,368 tons per day.

How is the supply of nitrogen able to meet this demand? The combination of recycling human and animal waste along with planting green manure can provide annually up to around 200 kg of nitrogen per hectare of arable land, also resulting in 200 to 250 kg of plant protein. If the farmland has good soil, adequate moisture and a mild climate and allows continuous cultivation throughout the year, a hectare should be able to support as many as 15 people.

In practice, however, population density may be limited to about 5 people per hectare with organic farming due to many reasons including environmental stress without synthetic nitrogen fertilizer.

Just how dependent has humanity become on the production of synthetic nitrogen fertilizer?

Figure 3 shows human dependency on synthetic nitrogen. Around 175 million tons of nitrogen flows into the world croplands every year, and about half of this total nitrogen is incorporated into cultivated plants. Synthetic fertilizers provide about 40 percent of all the nitrogen taken up by these crops. Because they furnish about 75 percent of all nitrogen in consumed proteins, about one-third of the protein in the human diet depends on synthetic nitrogen fertilizer. In other words, about 2 billion of the world population is currently nourished by synthetic fertilizer. During the early 1960s, affluent well-developed countries accounted for 90 percent of all fertilizer consumption, but by 1980 their share had fallen below 70 percent. Developed and developing world demand was the same in 1988. At present, developing countries use more than 60 percent of the global output of synthetic nitrogen fertilizer. Organic farming can only support 4 billion people. The remaining two billion people – most likely people in low-income countries - would perish from the earth from lack of food if the use of chemical fertilizers was eliminated. However, the massive introduction of reactive nitrogen into the soil and water has many deleterious consequences for the environment. Once reactive nitrogen is withdrawn from atmospheric nitrogen, it undergoes multiple transfigurations (transformations). Problems range from deep underground to above the stratosphere. Fertilizer nitrogen that escapes to ponds, lakes or ocean bays often causes eutrophication.

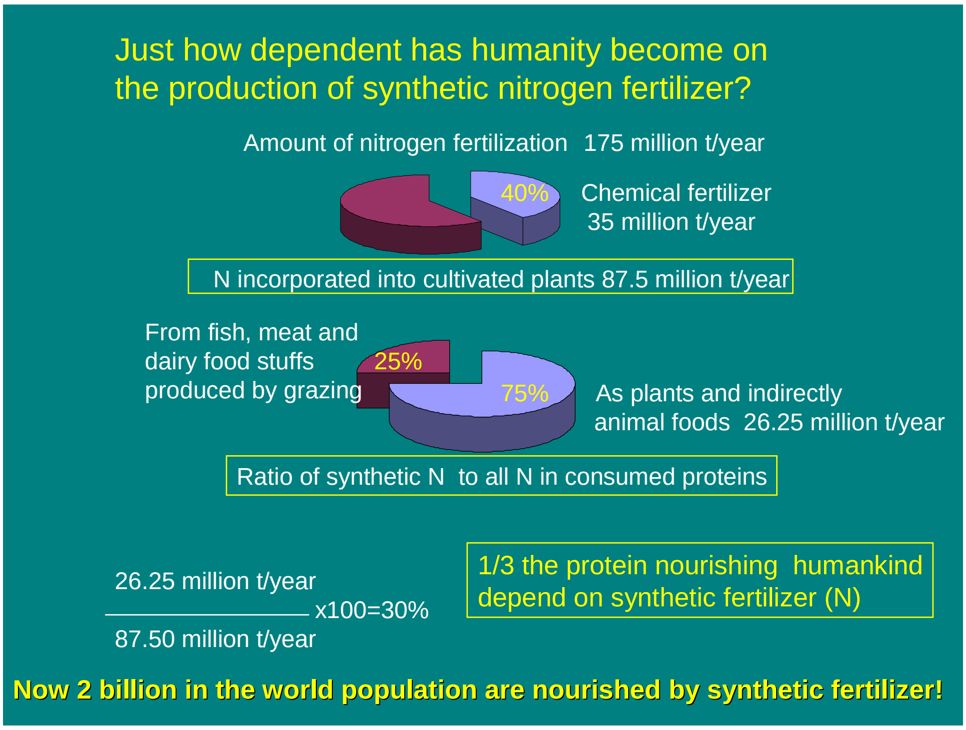


Figure 3. Dependency of humanity to synthetic fertilizer

Appearance of nitrate poisoning in ruminant animals such as cattle.

Mismanagement of animal effluents has resulted in severe contamination of an excess level of nitrate underground and pathogens such as cryptosporidium in surface water. Excess nitrate can cause toxic nitrite accumulation and consequent methaemoglobinemia in cattle, and even in human infants (Figure 4).

Nitrogen compounds in fertilizer can be oxidized to nitrate by soil bacteria. Nitrate is a precursor of plant protein synthesis. However, plants accumulate a high level of nitrate when excess nitrogen in effluents is used as fertilizer, and photosynthesis can be disturbed by some unusual environmental conditions. When ruminant animals consume high nitrate plants as feed, the nitrate can be reduced to nitrite and then to ammonia in the rumen. Unfortunately, as nitrate to nitrite reduction is more dominant than nitrite to ammonia, a toxic level of nitrite will accumulate in the rumen when an excess amount of nitrate is consumed. Nitrite absorbed into the blood stream can oxidize oxyhemoglobin to methaemoglobin (Takahashi and Young, 1991). Consequently, the animal will suffer methaemoglobinemia. Severe methaemoglobinemia will cause sudden death due to anoxia.

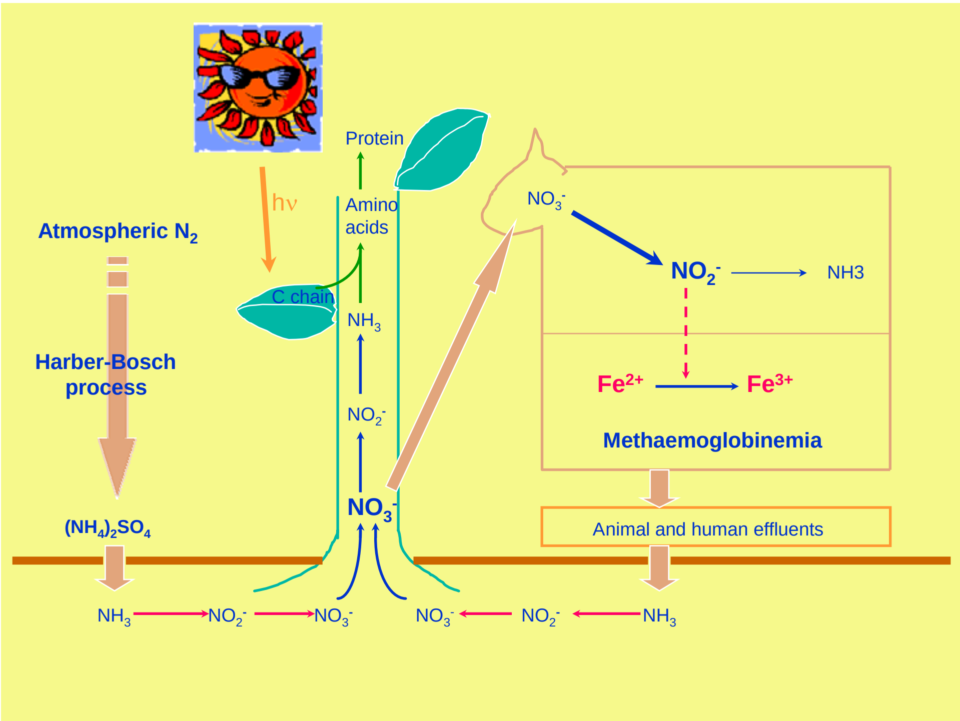


Figure 4 Excess nitrogen fertilization and nitrate poisoning

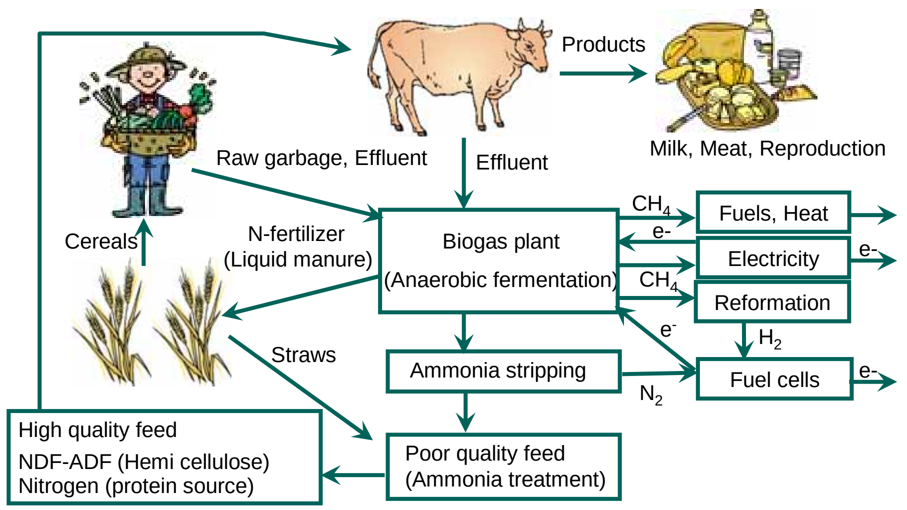
Leaching of highly soluble nitrates, which can seriously contaminate both underground and surface water in areas undergoing heavy fertilization, has been disturbing farming regions. A dangerous accumulation of nitrate is commonly found in wells in the American Corn Belt and in groundwater in many parts of Western Europe. Concentrations of nitrate that exceed widely-accepted legal limits occur not only in the many smaller streams that drain farm areas, but also in such major rivers as the Mississippi and Rhine. The increasing use of nitrogen fertilizers has also sent more nitrous oxide into the atmosphere. Reaction of nitrous oxide with excited oxygen contributes to the destruction of ozone in the stratosphere. Below the stratosphere, in the troposphere, nitrous oxide promotes an excessive greenhouse effect (Houghton, 1994). The atmospheric lifespan of nitrous oxide (N_2O) is about 120 years ((IPCC, 1994), and every one of its molecules absorbs roughly 200 times more outgoing radiation than does a single carbon dioxide molecule.

Furthermore, the nitric oxide (NO) related to microbes that act on fertilized nitrogen cause another atmospheric problem. The nitric oxide which is produced in even greater quantities by combustion reacts in the presence of sunlight with other pollutants to produce photochemical smog. The deposition of nitrogen compounds into the atmosphere may overload a sensitive ecosystem producing acid rain.

Unequally distributed nitrogen

On the other hand, there are many nitrogen deficient areas in the developing world. In the case of Qinghai Province, China, cow manure has been used for fuel by small-scale dairy farmers. As trees are not available for fuel in this area, livestock manure is a valuable fuel material rather than fertilizer, as is the case in other central Asian countries. A floor heating system using cow manure as fuel is common in this area. Combustion of livestock manure, however, means no return of nitrogen and organic matter to the soil. Though these small dairy farmers are supported by the Qinghai Provincial Government, there are many problems involved in breeding and feeding the cows. Extremely low milk production, especially, is a common problem due to malnutrition. Wheat straw which has a low nutritional value is fed to the cows as their main feed. Qinghai Province consists mostly of a plateau at an altitude 3000 meters or more above sea level. Both the Hwang Ho and Yangtze Rivers originate in the province. Environmental destruction, including desertification, is spreading rapidly in this area destroying the natural, abundant prairies. Although there are natural factors, as well as anthropogenic factors, contributing to this desertification, over-pasturing and over-harvesting of shrub trees as fuel are the major causes. In fact, the desertification occurring in most parts of the world can be attributed to factors related to human activity such as over-pasturing, over-cultivation using irrigation agriculture, and the excessive intake of fuel materials, causing serious social and economical problems in the respective countries. In contrast to rural areas, intensive dairy farming is being introduced in newly developed urban areas, corresponding to the expanding demand for dairy products. Modern mega-farms are currently under construction in Xining, the capital city of Qinghai Province. In China, where economic development has been carried out quickly, wealthy large-scale farm managers now exist. However, concerning these farms, adequate measures for processing and effluent treatment of the large amounts of cow manure generated is not fully taken into consideration.

Accordingly, the following scheme for sustainable dairy production was proposed to the Qinghai Provincial Government. Firstly, a low-cost biogas plant should be constructed adjoining the mega-farm using local materials. Biogas generated in the plant can use various energy sources. Digested liquid would be available for crop production as nitrogen fertilizer. Alternatively, ammonia stripped from digested liquid can be used for ammonia treatment of agricultural byproducts. Low-quality feeds such as wheat straw, bean hulls etc. can be improved by ammonia treatment. In consequence, milk production can be improved by feeding ammonia-treated feeds. Environmental preservation and the improvement of animal production can then be assured in this way. Figure 5 shows a schematic explanation of a biogas plant with ammonia stripping system.



Heat and the electric power are obtained from animal and human effluent, raw garbage, etc. with the biogas plant. The digested liquid is used for the grain production as liquid manure. Moreover, the ammonia treatment is given to a low quality agricultural by-products such as wheat straw by using the ammonia extracted from the digested liquid. In consequence, the feed value is improved.

Figure 5 Diagram of an advanced recycling system for low-quality agriculture by-products such as wheat straw

Nitrogen is unevenly distributed over the earth. In a word, to establish sustainable agriculture, excessive nitrogen generated from intensive animal production must be incorporated into the recycling system. Then, we will be able to reduce the demand for synthetic nitrogen as fertilizer (Suzuki, 2002).

Figure 6 illustrates sustainable agriculture based on energy crop production as biomass energy. As part of the Japanese government policy, "Biomass Japan", cropping the energy crops in fallow areas is examined for producing ethanol in Tokachi Prefecture, Hokkaido. More efficient energy and nitrogen recycling in this agriculture and animal agriculture system become possible by introducing new technologies such as catalytic conversion of hydrocarbons from energy crops to hydrogen for fuel cells, bone char production from waste of animal bodies for soil improvement (Takahashi et al., 2003), improvement of the poor quality of agriculture byproducts such as wheat straw, and ammonia stripping from effluents.

An additional technology is converting ammonia to hydrogen for fuel cells. The residue nitrogen can be returned to the atmosphere as stable paired nitrogen.

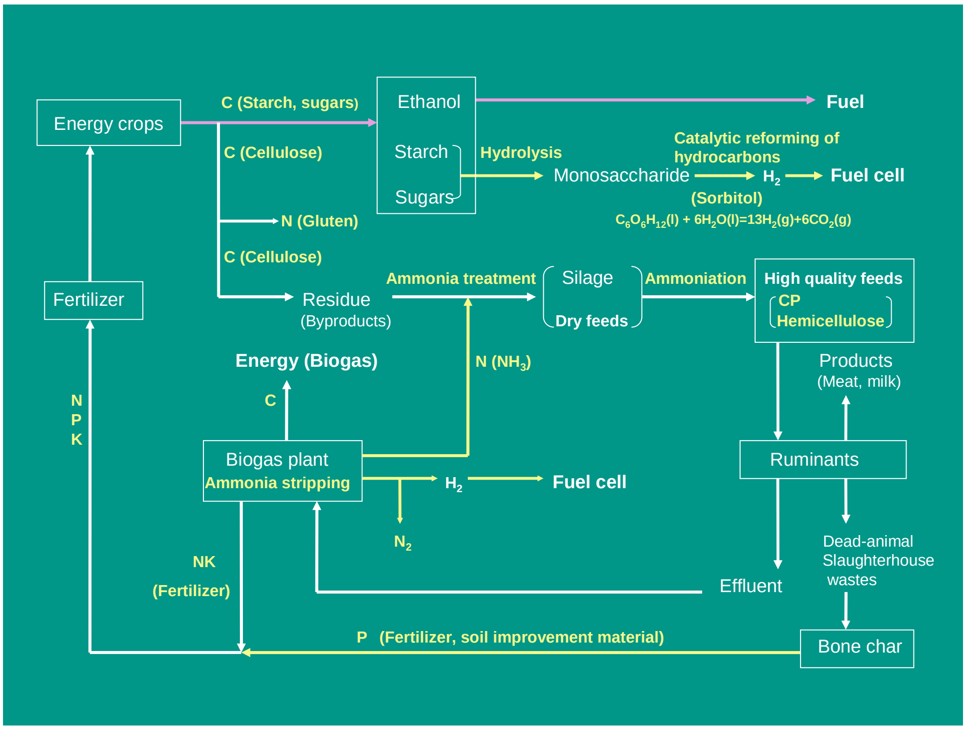


Figure 6 Sustainable agriculture based on energy crop production as biomass energy

These technological advances will greatly contribute to the establishment of true and safe sustainable agriculture without environmental pollution. .

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