# Nitrogen From Fertilizers

## Too Much of a Good Thing

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**By Beth Nolte**

Fertilizers are chemicals used to make the soil produce more plants. They contain reused plant and animal waste—such as manure—or a mixture of chemicals made by humans. Unfortunately, many farmers and gardeners use too much fertilizer, and the excess pollutes the environment, sometimes causing health problems for humans and animals.

Among the many chemicals present in fertilizers, three are critical for plant growth: nitrogen, phosphorus, and potassium. Of those three, nitrogen has caused the most damage to the environment. When released into the environment, nitrogen from fertilizers forms compounds that can contribute to our changing climate and create conditions that kill fish and other marine life.

What can we do about it? Decreasing fertilizer waste is a large part of the solution, and this means taking a closer look at how we grow our food. Some scientists advocate growing food on small local farms instead of large industrial farms. This way, it is easier to control the amount of nitrogen used by plants. Other scientists are growing new crops that live for 3 or more years instead of the more common crops that live only 1 year.

## Fertilizers and the nitrogen cycle

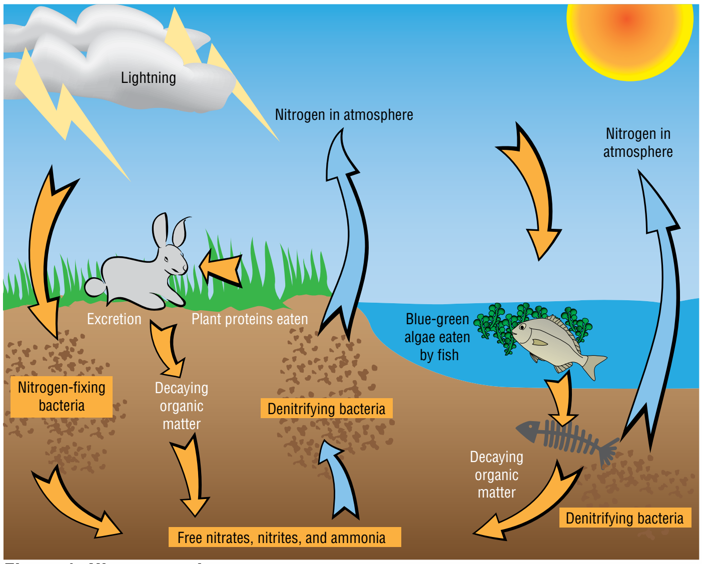
It is perhaps surprising that plants would need an additional source of nitrogen, since almost 80% of the air consists of nitrogen. But the nitrogen in the air is in the form of $N_2$ molecules, which react very little and cannot be used by plants to grow. Instead, fertilizers provide a form of nitrogen that plants can use, called "fixed" nitrogen.

There are exceptions, though. Some plants, such as soybeans, peas, and clover, can use nitrogen from the air. That's because they have symbiotic bacteria growing in their roots. These bacteria have the unusual ability to convert atmospheric nitrogen ($N_2$) into a chemically usable form.

What happens when we spread fertilizer on soil? The nitrogen from the fertilizer is taken up by plants to help them grow. But if too much nitrogen is present—which is what happens when too much fertilizer is used—some of this nitrogen does not return to the atmosphere and contributes to environmental pollution instead.

The way nitrogen is used by plants and returned to the environment is part of a natural cycle called the nitrogen cycle (Fig. 1). To understand how it works, let's look at how nitrogen is absorbed by plants.

In soil or in a fertilizer, nitrogen is in the form of either ammonia ($NH_3$) or the ammonium ion ($NH_4^+$). Bacteria and fungi present in the soil convert ammonia into ammonium ions. Then, soil bacteria of the *Nitrosomonas* species convert the ammonium ions into nitrite ions ($NO_2^-$), which are further con-




ANTHONY FERNANDEZ

**Figure 1. Nitrogen cycle**

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verted into nitrate ions ( $NO_3^-$) by bacteria of the *Nitrobacter* species.

For some plants, such as soybeans, peas, and clover, bacteria that live on the roots of these plants convert nitrogen gas ($N_2$) from the air into ammonium ions, which are then incorporated by the plant. The conversion of nitrogen gas into a form of nitrogen that plants can use is called nitrogen fixation.

Nitrogen fixation can also occur when lightning strikes (Fig. 1, upper left). Because lightning carries a large amount of energy, it can break nitrogen molecules apart. Then, the nitrogen atoms combine with the oxygen present in the air to form nitrogen oxides. These oxides dissolve in rain, forming nitrates, which are then carried to the soil. This type of nitrogen fixation contributes 5%–8% of the total nitrogen fixed.

Animals then feed on plants, and other animals feed on these animals. When these plants and animals die, bacteria, molds, and mushrooms take the nitrogen present in the dead material and convert it into ammonia and ammonium ions. Other bacteria convert these compounds into nitrogen gas, which goes into the atmosphere. This completes the nitrogen cycle.

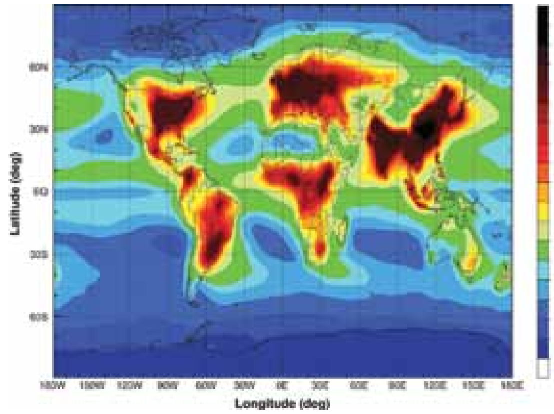


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**Figure 2. Estimated nitrogen deposition from the atmosphere to the Earth's surface. The unit scale is in kilograms of nitrogen per hectare per year.**

## Excess fertilizer = Damage to the Environment

When too much fertilizer is applied to the soil, the excess leaches into groundwater and runs off into rivers and lakes, and ultimately into oceans, where it can cause trouble for marine life. First, nitrates from the fertilizer help algae grow more than usual. Then, when these algae die, they fall to the bottom of the ocean and are decomposed by bacteria. To do so, the bacteria use oxygen dissolved in the water. When the number of dead algae is larger than normal, the bacteria can use up all of the oxygen present in water and, as a result, fish and other marine life cannot breathe, and they die.

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Nitrates from fertilizers can also be converted into nitrous oxide ($N_2O$), which is released into the air. This gas contributes to global climate change and reduces the amount of ozone ($O_3$) present in the stratosphere. Ozone is a chemical that absorbs much of the harmful ultraviolet radiation that comes from the sun. The stratosphere is a layer of the atmosphere located at altitudes between 6 miles and 30 miles above the Earth's surface.

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## Organic Farming

ADAM BARR

**Adam Barr holding Daikon radishes.**

To reduce pollution from nitrogen compounds that come from fertilizers, some farmers advocate using only naturally occurring fertilizers—animal manure, decomposed plant and animal material called compost, and a type of vegetation called green manure. These farmers don't use fertilizers that contain synthetic chemicals or minerals because these fertilizers release more nitrogen in the environment than naturally occurring fertilizers.

Organic farming has grown over the years. In 2007, it was a $46 billion industry, with about 32 million hectares (80 million acres) farmed organically worldwide.

Adam Barr is an organic farmer who owns a seventh generation family farm in Meade County, Ky., about an hour outside of Louisville. Barr and his family don't use synthetic fertilizers to raise vegetables, beef, and chicken.

Wearing a wide-brimmed hat, Barr leans against the back of his truck that serves as a farm stand at a local market. He sells onions, carrots, and meat. He also distributes boxes of fresh vegetables to customers who subscribe to a program called Community-Supported Agriculture. Through this program, people sign up at the beginning of the season and pay an upfront fee. Then, each week during the growing season, they pick up their week's worth of produce. Barr's customers buy fresh vegetables at better than retail price, while experiencing the ups and downs of the growing season.

Organic farmers ensure that nitrogen is present in the soil for plant growth and does not leach out. In the chicken house at Barr Farms, sawdust is spread over the floor to trap and stabilize nitrogen from the chicken waste. The carbon-based layer of sawdust traps the ammonia and prevents it from leaking in the air. A fine layer of sawdust is spread on the fields in the spring to provide a nitrogen boost.

For Barr, growing food means understanding the cycles of plant and animal life. "Life and death are two ends of the same loop," he says. "You see what's naturally happening with livestock and plants and it is about getting them to work in concert."

*—Beth Nolte*

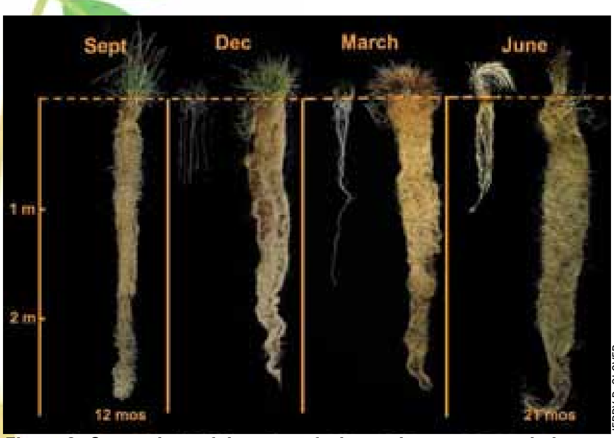
How bad is the situation? James Galloway, environmental science professor at the University of Virginia in Charlottesville says that because plants and animals do not use nitrogen efficiently, only 10%–15% of the nitrogen actually ends up in the food we consume. The rest is washed away into rivers and lakes.

Worldwide, the amount of nitrogen wasted in the environment is even larger. In 1990, fertilizers provided 110 billion kilograms of nitrogen for the production of food. The human body requires only about 2 kilograms per year of nitrogen in food, so with a world population of 5.3 billion people in 1990, only about 10 billion kilograms was needed.

Not only is nitrogen from fertilizers released in lakes and rivers or in the air, but it can also deposit from the air to the Earth's surface, where it can further pollute the environment. The amount of nitrogen deposited annually from the air to the Earth's surface worldwide is shown in Fig. 2.

## Small farms versus big farms

Do large industrial farms cause more nitrogen pollution than small farms? Studies by the U.S. Environmental Protection Agency have shown that this is indeed the case.

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JERRY D. GLOVER

**Figure 3. Comparison of the roots of winter wheat, an annual plant (at left in each panel) and those of intermediate wheatgrass, a perennial plant (at right in each panel). Perennial plants have more developed roots than annual plants and have access to more nutrients and water than annual plants.**

The main source for this pollution comes from the storage and disposal of animal waste, which is often sprayed as fertilizer in fields. This animal waste is stored in gigantic tanks that can hold millions of gallons of manure and urine. These tanks often leak and can either rupture or overflow, causing devastating damage to the environment.

The other problem is that in an effort to get rid of the waste, too much is applied to agricultural fields. The overload gets washed into aquatic systems. Some scientists note that these problems don't happen on small farms, where the amount of animal waste is easier to manage.

## Long-living crops

Every year, farmers sow seeds, wait for crops to grow, and then harvest them. But in the future, all this may change. Scientists at the Land Institute in Salina, Kan., are breeding new crops that would live for many years. This way, farmers would not have to grow them again every year and, as a result, would use less fertilizer.

Plants that can live for years on end are called perennials. Most crops, however, live only for one growing season and are thus called annuals. By breeding annual crops with their perennial relatives, the scientists at the Land Institute have created plants that have the best of both—the high productivity of an annual in a long-living perennial. The hope is to create perennial wheat, corn, sorghum, and sunflower.

If that happens, it would be a huge achievement! It would change the process of farming as we know it. New hybrid perennial plants would have more developed roots than annual crops, creating a niche for microorganisms to live and create healthy soil.

Jerry Glover, an agroecologist at the Land Institute, and colleagues predict that it will be possible to grow perennial crops within the next 25–50 years. While this is far into the future, it offers a good option to reduce fertilizer waste and to increase crop yields.


**SELECTED REFERENCES**

Altieri, M. A. Small Farms as a Planetary Ecological Asset: Five Key Reasons Why We Should Support the Revitalization of Small Farms in the Global South: http://www.foodfirst.org/en/node/2115 [Dec 2009]

Galloway, J. N. et al. Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. *Science*, May 16, 2008, *320*, pp 889–892.

Glover, J. D. et al. Future Farming: A Return to Roots? *Scientific American*, Aug 2007, pp 82–89: http://www.landinstitute.org/pages/Glover-et-al-2007-Sci-Am.pdf [Dec 2009]



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# Haber-Bosch Process

## Chemistry that Changed the Way We Farm

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Nitrogen fixation is a process by which very stable bonds between nitrogen atoms in a molecule of nitrogen ($N_2$) are broken down, so that nitrogen compounds that plants can use are formed. In nature, nitrogen fixation is performed by bacteria that bind to the roots of certain types of plants called legumes, which include peas, beans, lentils, and peanuts.

At the beginning of the 20th century, German chemists **Fritz Haber** *(top photo)* and **Carl Bosch** *(bottom photo)* developed a process that put the power of nitrogen fixation into human hands. The process takes nitrogen from the air ($N_2$) and combines it with hydrogen ($H_2$) to create ammonia ($NH_3$):

$$N_2 + 3H_2 \rightarrow 2\ NH_3$$

The reaction requires metallic iron as a catalyst and is carried out at high pressure (between 150 and 250 times the atmospheric pressure) and high temperatures (300–550 °C).

Ammonia was first produced on an industrial scale in a German factory in 1913. By the 1930s, American scientists figured out how to apply ammonia to the ground as fertilizer. The nitrogen in ammonia helped farmers increase their crop yields. The availability and use of fertilizers eventually changed the scale of agriculture into the industrial model that we have today.

Haber and Bosch were awarded Nobel Prizes in Chemistry in 1918 and 1931, respectively.

*—Beth Nolte*