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NITROGEN

It's colorless, odorless and gets no respect, but it's vital to the cycle of life--and we may be using too much

It's all around you, but you can't see it. You breathe it in with every breath, but your body doesn't use it; you just breathe it back out again. It is one of the most common and important elements in living things, yet few people pay any attention to it. Overworked and underappreciated, nitrogen carries a large part of the load of maintaining the biosphere--and indeed may now be in the process of overloading it. Nitrogen seems to live in the shadow of its more flashy relative, carbon, but now it may be time for us to start paying more attention to it.

Nitrogen is essential to life; it is found in every cell of every living thing. An odorless, colorless gas, it makes up almost 80 percent of the air we breathe. Yet the molecules of nitrogen--each composed of two nitrogen atoms, written as N2--in the air are of no use to living things. The two nitrogen atoms in those molecules are so tightly bound that the molecules do not react easily with anything else. For use by living organisms, nitrogen must first be "fixed." This means splitting the nitrogen atoms apart and then attaching other atoms, such as oxygen, to each nitrogen atom so the two cannot recombine. In nature, this is being done constantly, mostly by bacteria, a little by lightning.

The system has worked nicely for a very long time. Before World War I, Germany developed a process to synthesize ammonia, a form of fixed nitrogen. Nitrogen is integral to gunpowder and explosives, and the country could have been cut off from its supply of Chilean nitrate, its chief source of fixed nitrogen. The Haber process involves combining, under high pressure and heat, molecular nitrogen as found in the air with hydrogen, using a catalyst to speed the reaction. This produces ammonia, which consists of one nitrogen atom and three hydrogen atoms. Factory-fixed nitrogen became important, and even indispensable, as a fertilizer as well. After World War II, agricultural use boomed. Now we have contaminated groundwater in some farming areas, and streams and estuaries that are becoming oxygen-deficient because of nutrient--including nitrogen--overload. Learning to fix nitrogen has cut both ways.

In the natural nitrogen cycle, the element is constantly being made into compounds, which are constantly being broken apart again. The world consists of a huge reservoir of molecular nitrogen coupled to a bottleneck: the capacity of bacteria to fix it and thus make it available to living things. When a plant or animal dies, some of the nitrogen compounds remain, fertilizing the ground. Eventually, denitrifying bacteria restore the nitrogen to its two-atom molecular form--along with producing some N2O, a greenhouse gas that also destroys ozone--and return it to the atmosphere. This is the classic nitrogen cycle, long familiar to ecologists. Although I've described it in simple terms, the actual operation of the cycle is rather complex, with lots of loops, extra steps and shortcuts a given nitrogen atom can take from the time it leaves the atmosphere until the time it returns.

The atmospheric reservoir contains nearly 4 quadrillion tons of nitrogen. Otherwise there are about 20 trillion tons dissolved in the world's oceans and about 100 billion tons of fixed nitrogen on land. Of the fixed nitrogen on land (excluding rocks, sediments and coal), only about 4 billion tons is locked up in living plants and animals; the rest is stored in dead and decomposing plants and animals, eventually to be returned to the atmosphere as molecular nitrogen, as well as in other forms.

Bacteria are by far the most important natural source of fixed nitrogen on land. Estimates vary, but most experts put the total production at 90 to 140 million tons per year. Most nitrogen-fixing bacteria live independently, but many live in nodules on the roots of a family of plants (trees, shrubs, and herbaceous or nonwoody plants) known as legumes.

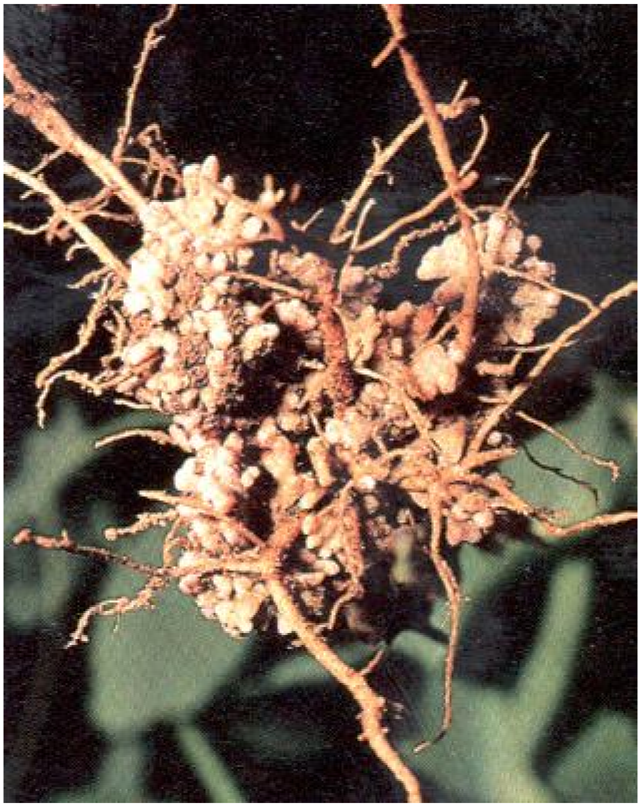
A small fraction of naturally fixed nitrogen enters the biosphere in a surprising way: as a by-product of lightning bolts. Each second an average of 100 lightning flashes occur somewhere on earth--as many as 500 since you began reading this paragraph. Each stroke heats the surrounding atmosphere to a temperature at which nitrogen "burns" and becomes a nitrogen oxide (one nitrogen atom with one or two oxygen atoms attached). By the time some of this nitrogen reaches the ground in the form of acid rain, it has become a nitrate, one of the forms living things can use. Lightning fixes less than 10 million tons of nitrogen a year.

Since the agricultural revolution 10,000 years ago, and particularly since the industrial revolution 200 years ago, humans have been increasing the supply of fixed nitrogen in three major ways. In order of increasing importance, these are burning fossil fuels, growing legumes and producing industrially fixed nitrogen for use as fertilizer.

Since the middle of the 19th century, humans have been burning fossil fuels, such as coal and oil, to produce steam and electricity and to power vehicles. Just as lightning does, the burning of these fuels converts nitrogen in the air to compounds of nitrogen and oxygen. (It also releases fixed nitrogen in the fuel itself.) Some of this is nitric oxide (NO), a precursor of both smog and acid rain. The burning of fossil fuels adds more than 20 million tons of fixed nitrogen to the cycle yearly.

Rows of soybeans, which add nitrogen to the soil, flank aswath of corn on this Iowa farm. The crops' places are switched yearly.

Farmers have known for millennia that the way to rejuvenate worn-out fields is to plant legumes, thereby returning nitrogen to the soil. Plowing the plants under at the end of the season adds to the restoration. Today leguminous crops add about 40 million tons of fixed nitrogen to the global ecosystem each year.



Nodules on the roots of peas contain bacteria that convert molecular nitrogen to ammonia.

The supply of fixed nitrogen is often the limiting factor in the growing of crops. Farmers have been spreading nitrogen-rich manure on fields for thousands of years. But the commercial fixing of nitrogen opened up a whole new world. The production of such fertilizers has grown from a few million tons to about 80 million tons today. Not all of that goes to farms. Homeowners use bagged fertilizer that is often a mixture of fixed nitrogen, potassium and phosphate.

Once fixed nitrogen is laid down, some will be absorbed by plants and whoever or whatever eats the plants. Some will simply return to the atmosphere. (Nitrogen compounds that add to the overfertilization of the Chesapeake Bay, for example, are transported through the air from as far as Detroit and Toronto.) Some will be carried away in water on the surface or in the ground. Thus, no matter where or why we apply it, we are adding fixed nitrogen to the global ecosystem.

If we total what is being added by way of fossil-fuel burning, legume growing and commercial fixation, we come up with 140 million tons per year--as much as or more than the contribution of all natural sources on land. Human activity has come to dominate one of the most basic cycles in nature.

Our activity has always influenced the environment, of course. Think of forests being cleared in Europe and North America, and the use of dikes to take land from the sea in the Netherlands. These kinds of changes were slow and incremental, however. Clearing the forests took centuries. Yet in only 50 years we have come to dominate the nitrogen cycle. In some parts of the world, notably Western Europe, there is the potential for "nitrogen saturation," in which the ecosystem is storing all the nitrogen it can, and any more that is added may be transported into the air or water.

The yellowish-brownish band that obscures this city is photochemical smog, caused in part by the action of sunlight on nitrogen compounds emitted by cars.

Fixed-nitrogen fertilizers are essential if we hope to feed the world's growing population. So far, we have not only kept up but improved. The calories available per person per day in developing countries rose from 2,140 between 1969 and 1971, when the world's population was 3.7 billion, to 2,520 between 1990 and 1992, when the population had grown to 5.3 billion. This success would not have been possible without the nitrogen.

Two basic questions would seem to be: 1) What would a world with "too much" fixed nitrogen look like? and 2) What can human beings do to make that world less likely?

One answer to the first question comes from a long-term study conducted by David Tilman, of the University of Minnesota, in four grassy fields at the Cedar Creek Natural History Area, 30 miles north of Minneapolis. Parts of the fields were divided into 207 plots, most 13 feet on a side. Some, the controls, received no treatment at all. Others were given essential nutrients, such as phosphorus and potassium, but no nitrogen. The rest were also given nitrogen, at one of seven dosage levels. The plots that received nitrogen produced more biomass, and those that received the most nitrogen produced the most of all.

While the biomass went up, however, the number of species on a given plot went down. Some plants (mainly nonnative grasses) grew more quickly, shading out other plants that were not as efficient in using light. On average, the number of species on a heavily fertilized plot was about half that on unfertilized plots. The plots that received the most nitrogen often supported only one species. In Tilman's words, a nitrogen-rich world would be "green and weedy."

"A nitrogen-rich world won't be brown and shriveled," adds Peter Vitousek, a biologist at Stanford University, "but it will have lower biodiversity, more hazy days and more green scum in lakes and estuaries. It's not a world I would particularly like to live in, but it's important to distinguish between disaster and degradation." He points out that Europe is much farther along the road to nitrogen saturation, but most people do not see it as a bad place to live. The extra haze (coming from nitrogen compounds in the air) and the loss of a few ecosystems (such as heaths in the Netherlands, which are being replaced by grasslands) are probably not noticeable to most people, although scientists and public officials are concerned.

Most experts agree that the farm, and specifically the more efficient use of fertilizer there, is the place to start looking for ways to decrease our nitrogen use. On some farms, fertilizer is applied long before plants can use it, so that most of what the farmer buys and puts on the field is gone before it's actually needed. Vitousek used the term "precision agriculture" to describe techniques now being developed to cut nitrogen use without cutting productivity. It might, for example, be better to apply nitrogen more often but in smaller, carefully timed doses than to dump it on a field all at once.

The test patch at left received some nitrogen and has a dozenplant species. Lots of nitrogen was added to the plot at right, leaving only quack grass.

An example of precision agriculture comes from Pamela Matson (now at Stanford University). On a 37,000-acre sugarcane plantation on Maui, her team from the University of California at Berkeley looked at losses of nitrogen gases from sites where fertilizer was fed to plants through underground irrigation lines in carefully timed doses. Result: the plantation used less nitrogen than other sugarcane plantations in Hawaii, with a large reduction in nitrogen compounds entering the air. "We can reduce the consequences of activity we're not going to stop," Matson says.

A second line of attack involves dealing with fixed nitrogen once it's already in the system. Vitousek points out the possibility of using natural and artificial wetlands as places where nitrogen can be held and returned to the atmosphere as molecular ("un-fixed") nitrogen. "All we have to do is provide a place where the denitrifying bacteria can do their work," he says.

For the first time in history, scientists are confronting a situation in which human beings dominate one of the great natural cycles of our planet. "For better or for worse," Vitousek says, "the world is in our hands." Given that, we surely need to have a clearer picture of where we're taking it.

DIAGRAM: Even a simplified version of the nitrogen cycle is complex. Thenearly inert molecule found in the air (solid lines) is "fixed" (dotted lines) and thus made available to plants by microbes in the soil and legume roots (below barn), lightning and especially fertilizer factories (behind tractor). On the negative side, it is fixed and also released by the burning of fossil fuels in vehicles and factories, leading to smog and acid rain. Some fixed nitrogen stays in the ground, some washes into streams and estuaries and some is put back together as molecular nitrogen by denitrifying bacteria and returned to the air.

PHOTO (COLOR): A rotary spreader drops a rain of nitrogen fertilizer pellets onyoung corn plants, which appear to be thriving.

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