ENVIRONMENTAL POLICY

The Other Global Pollutant: Nitrogen Proves Tough to Curb

Experts call for international cooperation to slash nitrogen pollution, which they say ranks with greenhouse gases as an environmental threat

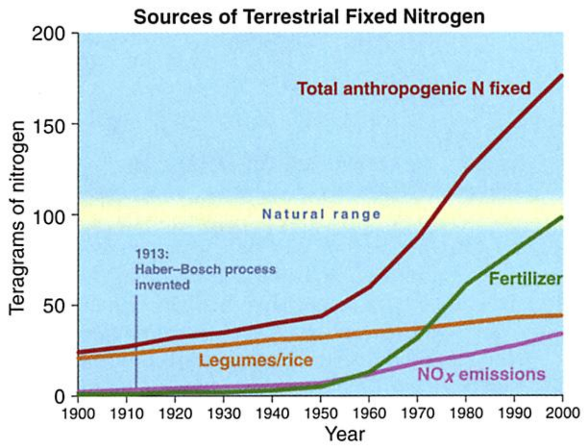
POTOMAC, MARYLAND—To get a handle on one of the world's biggest environmental headaches, think about dinner. Say that tonight you eat 100-gram helpings of both rice and chicken. Producing those foods in rice paddies and chicken farms required 40 grams of nitrogen in fertilizer, 90% of which was wasted, leaking into the soil, water, and air. Add the 4 grams of nitrogen from the meal that you'll leave in the toilet, and that's part of your daily contribution to nitrogen-related problems such as algal blooms and smog, says biogeochemist Jim Galloway of the University of Virginia in Charlottesville. "Once [nitrogen] is out there, it just keeps circulating"—and polluting.

Nitrogen is an essential element for the crops that feed the world's 6 billion people. But a surfeit of nitrogen, from fertilizers and the burning of fossil fuels, is harming ecosystems and threatening public health. Although the disruption of the nitrogen cycle has largely failed to attract the sweeping public attention accorded to other global pollutants, such as chlorofluorcarbons that fray the Antarctic ozone layer and carbon dioxide that spurs global warming, ecologists say that nitrogen's impacts are at least as great. "In terms of effects, [nitrogen] is way up there," says Stanford ecologist Peter Vitousek.

Yet control efforts are lagging, according to some 400 experts who met here last month to ponder how to plug nitrogen leaks while still feeding and powering the world.[*] "I think people haven't recognized the global nature of nitrogen and that human activity is altering the nitrogen cycle," says Galloway, a meeting co-chair. One problem is that leaks stem from diverse sources, and the effects are many and varied, including ozone and soot air pollution, harm to forests from acid rain, oxygen-depleted coastal waters, and the loss of biodiversity.

To help stem the flood, attendees—who ranged from agronomists to economists to energy analysts—called for more integrated policies that address the entire nitrogen cycle, including the creation of an international scientific body for nitrogen. A similar body, the Intergovernmental Panel on Climate Change, eventually led to the Kyoto global warming treaty. Participants also swapped ideas for more targeted, technological fixes, including solutions for developing countries, where producing food often takes priority over cleaning up the environment.

The current nitrogen glut stems largely from one of the greatest achievements of modern science: synthetic fertilizer. The 1913 discovery of the Haber-Bosch process, still used today to convert inert N_2 gas and hydrogen to ammonia (a reactive form of nitrogen that plants can use), spurred a leap in global crop yields. But even by 1970, a few researchers foresaw a potential downside, as the amount of reactive, or fixed, nitrogen released from fertilizer alone approached the amount fixed naturally on land, with unknown environmental consequences.



Overdose. Output of anthropogenic fixed nitrogen is still soaring and now far outstrips the natural terrestrial amount, leading to a host of environmental problems.

Today humans produce about 150 teragrams of fixed nitrogen per year—1.5 times the natural terrestrial amount (see graph). Fertilizers are the chief culprit, although nitrogen oxides (NO_x) from fossil fuel combustion constitute roughly 25% of total sources. All this reactive nitrogen then cycles from one polluting form to another: nitric acid, which causes acid rain; nitrates and other compounds in waterways, blamed for oxygen-depleted coastal waters; urban ozone and soot particles, which endanger respiratory health; and N_2O, a potent greenhouse gas. Extra nitrogen is also likely lowering biodiversity by shifting the composition of plant ecosystems. "Once you break that triple bond [in inert N_2], that N atom stays reactive for a very long time and then cascades through the environment" before microbes finally convert the nitrogen back to N_2, says Galloway.

Unfortunately, existing regulations have largely zeroed in on one pollutant or another rather than tackling the entire nitrogen cycle, notes forest pathologist Ellis Cowling of North Carolina State University in Raleigh, a conference co-chair. Even strict policies in nitrogen-choked countries such as the Netherlands have failed to work as well as hoped, because nitrogen pollution easily crosses national borders, and curbing one source can cause it to pop up elsewhere.

Yet on the NO_x front, at least, speakers at the meeting sounded a cautiously optimistic note. The U.S. Congress took aim at NO_x with 1990 amendments to the Clean Air Act, and levels have stabilized. More reductions should come as requirements for cleaner burning diesel engines and sport utility vehicles kick in over the next few years. In Europe, a multipollutant treaty called the 1999 Gothenburg Protocol is expected to cut NO_x levels more than 40% by 2010. And the Bush Administration has said it expects to propose a plan that caps NO_x and other pollutants and allows power plants to trade pollution "permits" in a market system, as they now do with sulfur.

But far less progress has been made in curbing the nitrate and ammonia leaking from farmers' fields and animal waste. About 60% of sampled streams in the United States have total nitrogen levels above the background level of 1 mg per liter, and in Europe groundwater has even worse contamination, speakers noted. The problem is particularly acute in Asia, where growing crops to feed the population is a top priority. Synthetic fertilizer use there took off in the 1970s, and Asia now contributes 35% of the world's total synthetic nitrogen; its output is expected to double by 2030 to 100 teragrams of nitrogen per year, noted Congbin Fu of the Chinese Academy of Sciences. But specific measures could help minimize fertilizer use in Asia, suggested Rabindra Roy of the United Nations Food and Agriculture Organization, such as developing a simple machine to implant cakes of fertilizer deep in the soil and avoid runoff. Meanwhile U.S. officials are working on new policies, including a proposed rule to crack down on runoff from

CREDIT: J. GALLOWAY/UNIV. OF VIRGINIA

[*] N2001, Second International Nitrogen Conference, 14 to 18 October (education.esa.org/n2001).

farms into rivers.

Crop plants aren't the only culprits: 40% of the world's grain goes to feed livestock, which produces mountains of nitrogen-rich manure. The Netherlands illustrates the challenges: There, strict rules since 1986 have required steps such as keeping manure covered or plowing it into fields. But nitrogen still escapes, wafting off the fields as ammonia or washing into streams, says Jan Willem Erisman of the Netherlands Energy Research Foundation: "You can put it in the soil, but it comes out anyway."

The best way to address that problem—other than decreasing meat consumption—would be to reduce the amount of nitrogen animals release in the first place by feeding them a precise amino acid ratio, said Henry Tyrrell, an animal scientist at the U.S. Department of Agriculture; it's unneeded proteins that wind up as the nitrogen-rich urea in an animal's urine. But such precision feeding would be expensive.

Indeed, cost is a factor in many of the technological fixes suggested at the meeting, such as capturing NO_x produced by power plants for fertilizer. As long as energy prices stay low, making synthetic fertilizer will always be less costly, researchers said. "It's much too cheap," Erisman says. Confronting the unyielding economics of the Haber-Bosch process may be policy-makers' biggest challenge. –JOCELYN KAISER

OLFACTION

Smell's Course Is Predetermined

New studies suggest a high level of hardwiring in the olfactory system, perhaps explaining instinctual reactions to some scents

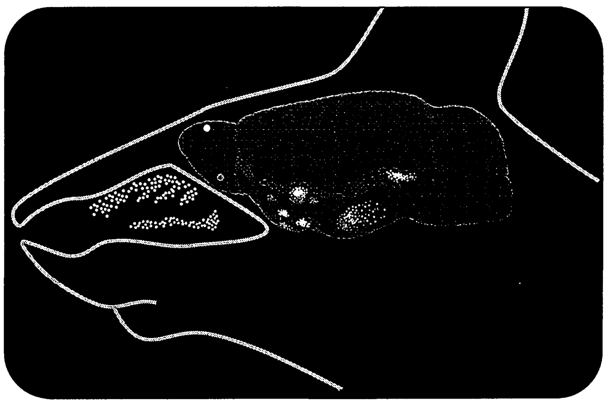
From the aroma of coffee enticing us to rise and shine to the alarm we feel at the acrid smell of smoke, our brains are constantly responding to odors. The brain can differentiate the smells of thousands of chemicals, should they happen to waft into our noses and tickle sensory neurons located there. But how those neurons pass information to the brain, and how the brain processes it to discern, say, the scent of an orange from that of a tangerine, has remained a mystery.

Two papers in the 8 November issue of *Nature* provide new insights into how the brain is structured for sorting out smells. In one study, Linda Buck and her colleagues at Harvard Medical School in Boston traced the connections of odor-responsive neurons in the brains of mice, providing the first glimpse of how the olfactory cortex, the part of the brain that processes odors, organizes incoming signals. In separate work, Liqun Luo's team at Stanford University revealed how links form between odor-responsive neurons and the brain.

Both papers suggest that the olfactory system is highly genetically programmed, or hardwired, perhaps more so than vision and other sensory systems, says olfaction researcher Leslie Vosshall of Rockefeller University in New York City. And that may help smells to directly trigger instinctual behavior, some researchers speculate.

The sensation of a smell begins when odor molecules bind to receptor proteins on sensory neurons in the nose. Mice have millions of sensory neurons, each bearing one of about 1000 different types of receptors on its surface. Those neurons send extensions called axons to a brain area called the olfactory bulb. Whereas neurons that bear the same receptor type are scattered rather randomly inside the nose, their axons sort out neatly, converging in each half of the bulb onto one or two structures called glomeruli, each of which receives input from only one receptor type. Most smells consist of multiple odor chemicals; the receptors they trigger send signals to a small subset of the 2000 or so glomeruli in the olfactory bulb.

But what happens to the signals at the next step—the olfactory cortex—has been unclear. "The olfactory cortex has been terra incognita," says neuroscientist Lawrence Katz of Duke University Medical Center in Durham, North Carolina. Some researchers have speculated that the connections linking the olfactory bulb to the cortex may be random and that the brain may learn to recognize the pattern each odor produces. Others suspected that there must be some predetermined order in the olfactory cortex; now Buck's team has found that to be true.



Connect the dots. Buck's team traced the connections of sensory neurons bearing two different olfactory receptors (yellow and pink) from sites in the nose (left), to one glomerulus on each side of the olfactory bulb (near the nose), to multiple spots in the olfactory cortex.

CREDIT: Z. ZOU AND L. BUCK

The team discovered the organization of connections by marking the pathway of neurons that receive signals from an individual type of odor receptor. Zhihua Zou and Lisa Horowitz in Buck's lab inserted the gene for a marker protein called barley lectin next to the gene for an olfactory receptor protein in mice. Neurons bearing that receptor made barley lectin and transferred the marker to connecting neurons, enabling the team to trace the olfactory neurons' connections through the olfactory bulb to the olfactory cortex.

The researchers did this with two odor receptor genes. In each case, they found one or two stained glomeruli on each side of the olfactory bulb, as expected, and multiple clusters of stained neurons in the olfactory cortex. And the pattern of staining was clearly not random: For each receptor type the pattern was the same in all the mice. That shows for the first time "that there is order in the projection from the bulb to the cortex," Katz says.

What's more, the data suggest that pathways from different receptors converge in the cortex, an important feature if their signals are to be compared and processed. Buck's group deduced this because in the olfactory bulb, each receptor is represented in 1 out of 1000 glomeruli in each half of the bulb, or 0.1% of the bulb's area. But when a receptor's projections reach the cortex, they occupy about 5% of the area, suggesting that individual olfactory cortex neurons receive input from up to 50 different olfactory receptors. "Those signals have to be brought together," says Harvard olfaction researcher Catherine Dulac, to enable the brain to analyze and distinguish among the patterns triggered by different smells.

Luo's team, meanwhile, has filled in information about how neurons form the links that carry olfactory signals. In fruit flies, so-called "projection neurons" pick up the signal in the glomeruli and carry it to the fly's equivalent of the olfactory cortex. But what determines which connections those neurons make? The neurons might have no special instructions but wait for sensory