**The dark side of nitrogen**

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The amount of food a farmer could grow was once limited by his or her ability to supplement soil nitrogen, either by planting cover crops, applying manure, or moving on to a new, more fertile field. Then, about 100 years ago, a technical innovation enabled us to produce a cheap synthetic form of nitrogen, and voila! Agriculture’s nitrogen limitation problem was solved.  The age of industrial nitrogen fertilizers had begun.

The breakthrough, by German chemists Fritz Haber and Carl Bosch (rhymes with posh), made it possible to grow many, many, many more crops per acre. For the last 50 years, farmers around the world have used synthetic nitrogen fertilizers to boost their crop yields and drive the 20th century’s rapid agricultural intensification.

But in their fervor to increase yields, farmers often dose their crops with more nitrogen than the plants can absorb. The excess is now causing serious air and water pollution and threatening human health. Ironically, all that fertilizer may even be ruining the very soil it was meant to enrich.

Nitrogen, it seems, has a dark side, and it has created serious problems that we are only now beginning to reckon with.

**Nitrogen kills a bay**

To see nitrogen’s ill effects up close head to the mid-Atlantic coast and visit the Chesapeake Bay, the nation’s largest estuary. Once the site of a highly productive fishery and renowned for its oysters, crabs, and clams, today the bay is most famous for its ecological ruin.

On Dec. 9, 2008, the Environmental Protection Agency’s restoration program for the Chesapeake Bay marked its 25th anniversary. Other than the passing of the years, there wasn’t much to celebrate. The [Chesapeake Bay Program’](http://www.chesapeakebay.net/)s goal is rehabilitation of the vastly polluted estuary, yet its 2008 [“Bay Barometer”](http://www.chesapeakebay.net/indicatorshome.aspx?menuitem=14871)assessment found that “despite small successes in certain parts of the ecosystem and specific geographic areas, the overall health of the Chesapeake Bay did not improve in 2008.” (The fight to save the Chesapeake continues; in 2009, President Obama ordered the federal EPA to lead the ongoing cleanup efforts, but groups involved are still arguing over the details.)

A significant portion of the Chesapeake Bay pollution comes from agricultural operations whose nutrient-rich runoff — in the form of excess nitrogen and phosphorus — fills the Bay’s waters, leading to algal blooms, fish kills, habitat degradation, and [bacteria proliferations that endanger human health](http://www.cbf.org/Page.aspx?pid=521).

The nitrogen runoff comes from the synthetic fertilizer applied to farm fields, as well as the manure generated from the intensive chicken farming on the east bay. Of course, the nitrogen in that chicken manure — some 650 million pounds per year, [according to *The New York Times*](http://www.nytimes.com/2008/11/29/us/29poultry.html)*—* can largely be traced to synthetic nitrogen; the chickens are merely recycling the synthetic fertilizer that was originally applied to feed crops.

This type of reactive nutrient pollution is now so common that the dead zones, acidified lakes, and major habitat degradation it can cause are occurring with greater frequency, not just in the Chesapeake Bay, but in other parts of the United States and [around the world](http://www.time.com/time/health/article/0%2C8599%2C1832905%2C00.html).

**Bombs away: Synthetic nitrogen comes of age**

Nitrogen is ubiquitous. It makes up 78 percent of the earth’s atmosphere. But atmospheric nitrogen is inert. It exists in a stable, gaseous form (N2), which plants cannot use. Unless nitrogen is made available to plants, either by nitrogen-fixing bacteria in the soil or by the application of fertilizer, crops won’t grow as productively.

The German chemists Haber and Bosch found a way around this availability problem. Originally conceived as a way to make explosives for war, their technique turned inert nitrogen gas into highly reactive ammonia (NH3), a form of nitrogen that can be applied to soil and absorbed by plants. With their discovery, nitrogen ceased to be a limiting factor in agriculture.

The widespread use of synthetic fertilizer took off after World War II when innovations allowed nitrogen fertilizer to be produced inexpensively and on a grand scale. When Norman Borlaug, a leader of the Green Revolution, and other plant breeders began developing and exporting dwarf, high-yielding, fertilizer-loving varieties of corn and wheat, the new chemical fertilizer addiction went global. In 1960, farmers in developed and developing countries applied about 10 million metric tons of nitrogen fertilizer to their fields. In 2005, they applied 100 million metric tons.

This order of magnitude increase coincided with the Green Revolution. Indeed, nitrogen fertilizer is largely responsible for the phenomenal crop yield increases of the past 45 years. Without the additional food production fueled by nitrogen fertilizer, researchers estimate that two billion fewer people would be alive today.

**Shifting shapes, getting around**

Modern agriculture — and, consequently, present-day human society — depends on the widespread availability of cheap nitrogen fertilizer, the ingredient that makes our high-yielding food system possible. But the industrialization of this synthetic nitrogen fertilizer has come with costs.

The high temperatures and very high pressures needed to transform N2 to NH3 are energy intensive. About one percent of the world’s annual energy consumption is used to produce ammonia, most of which becomes nitrogen fertilizer. That’s about 80 million metric tons (or roughly one percent) of annual global CO2 emissions — a significant carbon footprint.

Nearly half that fertilizer is used to grow feed for livestock. Herds then return the nitrogen to the landscape, where it contributes to several different kinds of pollution — the second cost of synthetic nitrogen.

Synthetic fertilizer is made with reactive nitrogen — that’s what makes the fertilizer easy for plants to use. As it turns out, though, reactive nitrogen doesn’t always stay where you put it. Farmers may apply this synthetic fertilizer to their cornfields, but the nitrogen in it will happily engage with the soil carbon, oxygen, and water in its environment. This is the essential problem with reactive nitrogen — its ability to morph and move around, often to unhealthy ends (see illustration).



Estimates vary on just how much nitrogen escapes from fields and remains reactive and potentially harmful, but it’s not unreasonable to assume that plants absorb 30 to 50 percent of the nitrogen in the soil. So if a farmer applies 125 pounds of nitrogen fertilizer to an acre of corn, 30-50 percent of it will end up in the corn; as much as 70 percent — or 87 pounds per acre — could end up somewhere else.

**‘N’ stands for ‘Needs to improve’**

There is an obvious way around this nitrogen problem: use less fertilizer more efficiently. But there’s not much incentive to cut back.

Farmers get paid by the ton, which makes yields the driving force of modern agriculture. Most agronomists agree that farmers can get the same yields without applying as much fertilizer and manure as they now do. But few farmers are willing to take that chance. Many farmers use fertilizer as a form of insurance; better to apply a little too much and get high yields than apply too little and risk yield (and profit) declines.

The challenge then is to find a way to provide plants with enough nutrients to maintain high yields while also minimizing nitrogen leakages. This may sound straightforward, but it’s tough to find mainstream farmers who are using nitrogen efficiently and safely. There simply aren’t incentives to do so. Fertilizer is cheap, and polluters don’t pay.

The situation might change if nitrous oxide becomes regulated under climate legislation. But in the climate bills currently making their way through Congress, agricultural emissions are explicitly exempted from any cap. Even if ag-related nitrous oxide emissions did get capped, policies would have to address efficiency directly. Otherwise, a climate-focused policy risks encouraging farmers to adopt practices that simply force the reactive nitrogen in another direction — into ground and surface water, for example.

Farmers don’t over-apply nitrogen on purpose. Nor do they want to contribute to estuary pollution and dead zones. But for 40 years, we’ve invested in a type of agriculture that rewards high yields over all other considerations.

U.S. grain farmers operate under pressure to generate volume, and have little or no incentive to conserve synthetic nitrogen along the way. Under the Farm Bill, commodity farmers get subsidies based on how many bushels they churn out, not how efficiently they use nitrogen. Even when fertilizer prices spiked in 2008, synthetic nitrogen remained a remarkably cheap resource — and corn farmers had every economic reason to lay it on liberally.

In their 2009 paper in the Annual Review of Environment and Resources, researchers G. Philip Robertson from the University of Michigan and Peter M. Vitousek from Stanford noted that the cost of applying a little additional nitrogen to a cornfield is more than paid for by the marginal gains in yield. In other words, corn is really cheap — but nitrogen is even cheaper.

Scientists now know that this arrangement can’t last forever — agricultural intensification has come with enormous costs. They also know there are other ways to manage crops and reward farmers. [The Rodale Institute’s research](http://www.rodaleinstitute.org/) on high yield production using cover crops to build soil organic matter and biologically fix nitrogen provides one example of a potential alternative to current practices. But the incentive structure around farming must change.

No longer can farm-support policy blindly push maximum yield. Farmers should be rewarded at least as much for conserving nitrogen and building the organic matter in soil. Rodale’s research suggests that those goals can be achieved without sacrificing much in the way of long-term yield.

Twenty-five years ago, the Commonwealths of Pennsylvania and Virginia, the state of Maryland, and the District of Columbia formally agreed to cooperate with the United States Environmental Protection Agency, in order “to fully address the extent, complexity, and sources of pollutants entering the [Chesapeake] Bay.” As it turns out, the Bay and other nitrogen-threatened ecosystems need more than[cooperation](http://www.chesbay.state.va.us/) to get healthy. They need the kind of [political will](http://www.washingtonpost.com/wp-dyn/content/article/2009/11/09/AR2009110901903.html) that will take nitrogen efficiency and impacts seriously — and force actual changes to agricultural practices. And endangered ecosystems need for those changes to happen soon. We don’t have another quarter century to spare.