



## A Mixed Blessing

If we don't watch out, agriculture could destroy our planet. Here's how to grow all the food we need with fewer chemicals.

By Dan Charles

Photograph by Peter Essick

**N. Nitrogen. Atomic number seven.** Unnoticed, untasted, it nevertheless fills our stomachs. It is the engine of agriculture, the key to plenty in our crowded, hungry world.

Without this independent-minded element, disinclined to associate with other gases, the machinery of photosynthesis cannot function—no protein can form, and no plant can grow. Corn, wheat, and rice, the fast-growing crops on which humanity depends for survival, are among the most nitrogen hungry of all plants. They demand more, in fact, than nature alone can provide.

Enter modern chemistry. Giant factories capture inert nitrogen gas from the vast stores in our atmosphere and force it into a chemical union with the hydrogen in natural gas, creating the reactive compounds that plants crave. That nitrogen fertilizer—more than a hundred million tons applied worldwide every year—fuels bountiful harvests. Without it, human civilization in its current form could not exist. Our planet's soil simply could not grow enough food to provide all seven billion of us our accustomed diet. In fact, almost half of the nitrogen found in our bodies' muscle and organ tissue started out in a fertilizer factory.

Yet this modern miracle exacts a price. Runaway nitrogen is suffocating wildlife in lakes and estuaries, contaminating groundwater, and even warming the globe's climate. As a hungry world looks ahead to billions more mouths needing nitrogen-rich protein, how much clean water and air will survive our demand for fertile fields?

The nitrogen dilemma is most starkly visible in China, a country that loves its food and worries that supplies might run out. To the casual visitor, that anxiety seems misplaced. There's a feast, it seems, on every street. In a restaurant called San Geng Bi Feng Gang, on the outskirts of Nanjing, I watch with wonder as dishes parade by: steamed fish, fried mutton chops, chrysanthemum-leaf-and-egg soup, a noodle dish made from sweet potatoes, fried broccoli, Chinese yams, steaming bowls of rice.

"Did you always eat this well?" I ask Liu Tianlong, an agricultural scientist who's introducing me to farmers nearby. His boyish smile fades, and for a second he looks grim. "No," he says. "When I was young, you were lucky to get three bowls of rice."

Liu grew up in the aftermath of China's great famine, which lasted from 1959 to 1961 and killed an estimated 30 million people. Drought played a part, but the catastrophe was inflicted mainly by the whims of Chairman Mao. The Chinese leader's Great Leap Forward collectivized farming and forced peasants to turn their harvests over to a centralized bureaucracy.

The famine passed, but scarcity continued until the late 1970s, when farmers regained control of their own harvests. "Within two years, almost overnight, food was in surplus," recalls Deli Chen, who witnessed those reforms as a boy in a small rice-growing village in Jiangsu Province. Chen is now a soil scientist at the University of Melbourne in Australia. Yet China's newly entrepreneurial farmers ran into another barrier: the limits of their land. As the country's population grew by an astounding 300 million people between 1970 and 1990, China's traditional agriculture struggled to keep up. Song Linyuan, an elderly but spry farmer in a village northwest of Nanjing, recalls how he once kept his 1.3 acres of cropland as fertile as possible, composting household waste and spreading manure from his pigs and chickens. In all, his efforts added perhaps a hundred pounds of nitrogen per acre of land each year. He harvested 2,600 to 3,300 pounds of rice per acre.

That's a respectable harvest, a better yield than in many parts of the world. But now he gets more than twice that: 7,200 pounds per acre. It's a harvest many farmers can only dream of.

The difference? "Better fertilizer," he says. We're sitting in a shop surrounded by farmers. Song's answer provokes a loud discussion. Some agree that fertilizer was key; others say better seeds were more important. In reality the two technologies are intertwined. The high-yielding varieties of rice and wheat that breeders created in the 1950s and 1960s could reach their full potential only if they got more nitrogen.

The Chinese government made sure those crops were well fed. Between 1975 and 1995 it built hundreds of nitrogen factories, quadrupling the country's manufacture of fertilizer and turning China into the world's biggest producer. Song now spreads about five times as much nitrogen as before, saturating his fields with urea—a dry form of nitrogen—by casting handfuls of the snow-white granules across green shoots. This adds up to 530 pounds of nitrogen per acre. Farmers who grow vegetables use even more; some spread a ton of nitrogen, or even two, on each hectare (2.47 acres). Few of them think they're doing anything harmful. "No, no pollution," says Song, when asked about the environmental effects of fertilizer.

Scientists tell a different story. "Nitrogen fertilizer is overused by 30 to 60 percent" in intensively managed fields, says Xiaotang Ju, of the China Agricultural University in Beijing. "It's misuse!" Once spread on fields, nitrogen compounds cascade through the environment, altering our world, often in unwelcome ways. Some of the nitrogen washes directly from fields into streams or escapes into the air. Some is eaten, in the form of grain, by either humans or farm animals, but is then released back into the environment as sewage or manure from the world's growing number of pig and chicken farms.

Deli Chen recalls catching fish as a boy. “The river was so clean. You could see right through it,” he says. By 1980 “you couldn’t see the fish anymore.” The cloudiness came in part from proliferating phytoplankton, a symptom of water that’s eutrophic, or overloaded with nutrients. A recent national survey of 40 lakes in China found that more than half of them suffered from too much nitrogen or phosphorus. (Fertilizer containing phosphorus is often to blame for algal growth in lakes.) The best known case is Lake Tai, China’s third largest freshwater lake, which regularly experiences huge blooms of toxic cyanobacteria. A spreading bloom in 2007 contaminated water supplies for two million people in the nearby city of Wuxi. Excess nutrients are damaging fisheries in China’s coastal areas in the same way that fertilizer runoff flowing down the Mississippi has destroyed fisheries in the Gulf of Mexico: by creating dead zones in which algae and phytoplankton bloom, die, and decompose, using up oxygen and suffocating fish.

Our demand for food, to be sure, isn’t solely to blame. The combustion that drives cars and electric generators releases nitrogen oxides into the atmosphere, and when those compounds return to Earth in drops of rain, they also act as fertilizer. (This accounts for about a quarter of the nitrogen load in Lake Tai.) But worldwide, commercial fertilizer adds up to 70 percent of the nitrogen that human activity produces every year.

Nitrate-eating bacteria in the soil can convert these disruptive forms of nitrogen back to the original, environmentally benign source that makes up nearly 80 percent of our atmosphere. But even this process is a mixed blessing, as the bacteria also release small amounts of nitrous oxide, a powerful greenhouse gas. “To solve this nutrient-overload problem, it is my dream,” says Xiaotang Ju, who is part of China’s “nitrogen family,” a loose network of scientists devoted to this herculean task. The patriarch of the cause, Zhu Zhaoliang, startled a conference of China’s ruling party in 1998 with a lecture about the dangers of agricultural pollution. China’s president at the time, Jiang Zemin, responded that he didn’t realize agriculture could pollute so seriously.

These scientists have begun working with small groups of farmers, showing them that less fertilizer doesn’t shrink their harvests and can actually fatten their wallets. They’re promoting the use of compost and teaching farmers to apply synthetic fertilizer when and where the plants actually need it. But they admit they’ve made little progress. The biggest obstacle is that most Chinese farmers are part-time. They aren’t interested in saving a few yuan by cutting back on fertilizer. It’s more important to save time and keep their city jobs, so they apply fertilizer quickly but inefficiently. And fear of food scarcity still haunts the Chinese imagination, outweighing concerns about the environment. Huang Jikun, director of the Center for Chinese Agricultural Policy, frequently tries to convince government officials that their worries are misplaced. “I tell them, China is more food secure than it has been for 5,000 years!” he says. But for officials and farmers alike, applying less fertilizer seems like tempting fate, risking a disastrous shortfall.

It’s likely that China—and the rest of the world—will use more nitrogen in the years to come, not less. Populations continue to expand, and meat is growing more popular. Feeding pigs or cattle demands several times more agricultural production than does using that grain to directly nourish people. “If Chinese change their diet to be like yours [in the West], the environmental pressure will be very high,” says Xiaotang Ju somberly. “We have to tend to this problem. Otherwise it will be really big.”

**There’s a glimpse** of a solution on a farm just outside the small town of Harlan in western Iowa. Here 90 cattle graze on green pasture, and a few hundred pigs root about in beds of straw, surrounded by fields of alfalfa, corn, soybeans, oats, and barley.

Ron and Maria Rosmann spread no nitrogen fertilizer on these fields, at least not the kind that comes from factories. Instead, it’s added biologically, by nitrogen-fixing bacteria that live in nodules on the roots of legume crops like soybeans, alfalfa, and a cover crop of clover that Ron Rosmann plants in the fall, only to till it back into the soil before he plants corn

in the spring. Some of that nitrogen is captured in the corn, which he feeds to the pigs. Most of that ends up in manure, which goes back onto his fields, and the cycle starts all over again. Rosmann, unlike many other organic farmers, doesn't buy manure from neighbors.

"One of our goals has been to maintain a closed system," he says. "We are a model for what organic farming should be like."

We wade into one cornfield. The stalks tower over our heads. "Look at this corn," Rosmann exults. "We could have 200-bushel corn right here. A lot of naysayers will say, You organic guys can't feed the world. I say, That's not true. Look at this crop!"

Yet Rosmann's methods carry their own cost. Farming this way takes more work, for one thing. And biology works more slowly than a nitrogen factory. The crops that build up the soil's store of nitrogen, like alfalfa, don't bring in as much money, or feed as many people, as nitrogen-hungry corn.

That's not necessarily a problem for North America. The United States, with six times as much arable land per person as China, has the luxury of planting less-productive crops that protect the environment, if people are willing to pay for them. That setup works for Rosmann; he gets a small payment from the government, part of an environmental subsidy program, and sells his organic crops for premium prices.

But will everyone pay those prices? Could his methods feed the world's most populous country? Zhu Zhaoliang, in his office at the Institute of Soil Science in Nanjing, laughs out loud at the question. "Organic farming is not a solution for China," he says flatly.

Yet there may be a middle ground—excellent harvests with reduced nitrogen pollution—and some of the world's most intensely studied fields are pointing the way toward it. Those fields, each exactly a hectare in size, are part of Michigan State University's Kellogg Biological Station, near Kalamazoo. For 20 years these fields have been growing corn, soybeans, and wheat in exactly the same rhythm, providing a side-by-side comparison of four different ways to farm, ranging from mainstream to organic. Everything that enters or leaves the fields is carefully measured: rainfall, fertilizer, nitrous oxide emitted from the soil, water that leaches into groundwater, and finally the harvest.

Michigan State's Phil Robertson, who helped set up this long-running experiment, takes me on a tour of the fields. He's itching to reveal some new and "quite amazing" data. Each field planted according to standard plowing and fertilizer recommendations released 610 pounds of nitrogen per acre into Michigan's shallow groundwater over the past 11 years. "So about half of the fertilizer that's added we lose," Robertson says. This loss is much less than what's common in China. Yet when multiplied by tens of millions of acres of American cropland, it's enough to produce polluted groundwater, a nutrient-loaded Mississippi River, and an enormous dead zone in the Gulf of Mexico.

The organic fields in Robertson's experiment, which received no commercial fertilizer or manure, lost only a third as much—but those fields also produced 20 percent less grain. Intriguingly, the "low input" fields, which received small amounts of fertilizer but were also planted with winter cover crops, offered the best of both worlds: Average yields were about as high as those from the conventional fields, but nitrogen leaching was much reduced, almost to the level of the organic fields. If America's farmers could cut their nitrogen losses to something close to this level, Robertson thinks, restored wetlands and revived small streams could clean up the rest. As in China, though, many farmers find it hard to change. When a family's livelihood is at stake, it may seem safer to apply too much fertilizer rather than too little. "Being a good steward currently has economic consequences that are unfair," says Robertson.

**Viewed from Africa**, the problem of overusing commercial fertilizer seems like a luxury. African farmers use meager quantities of the stuff—just seven pounds per acre on average. Alternative sources, such as manure or legume crops, are scarce as well.

Many in Africa's rural villages have fallen into a set of vicious circles. Fearing hunger, they concentrate on crops like rice or corn that deliver maximum calories but that tend to strip nutrients from the soil. Depleted land delivers increasingly poor harvests, leaving farmers too financially strapped to afford fertilizer, from whatever source. And since there is little demand for commercial fertilizer, no one makes it locally, so it's imported and expensive.

According to many experts, African soils are being mined. The natural reservoirs of fertility—nutrients stored in the organic matter of decomposing roots and leaves from previous centuries—are shrinking as farming extracts more nitrogen, phosphorus, and potassium every year than it replaces. This leaves the land progressively less able to feed the people who depend on it—"a scenario for disaster over the long run," according to the World Bank.

The average grain yield in sub-Saharan Africa is about 900 pounds per acre, just one-fifth the average in China. Nearly everyone who's looked at the situation agrees: African farmers need more nitrogen to improve their harvests and their lives. But there's a raging, bitter debate over where they should get it.

Some, like Jeffrey Sachs at Columbia University's Earth Institute, believe that increasing agricultural production demands more commercial fertilizer, and if poor African farmers can't afford it, then wealthier nations should provide it. In 80 villages across ten different African countries, Sachs's Millennium Villages Project passes out bags of improved seeds and fertilizer. And the project's having a big impact, according to its own data. In the millennium villages of Tanzania, Kenya, and Malawi, grain production doubled almost immediately.

In 2006 the government of Malawi started providing cheap fertilizer to about half the nation's farmers. Production of corn doubled—although good rains get much of the credit. These programs, however, are haunted by doubts about the future. Fertilizer subsidies were tried in many African countries during the 1970s and 1980s but fell out of favor because they were expensive and plagued by corruption. Malawi's current subsidy program is already in trouble: The government is running out of money to pay for it.

"Africa cannot afford massive amounts of fertilizer," says Sieglinde Snapp, a crop scientist at Michigan State University. A more sustainable approach, she says, is greater reliance on nitrogen-fixing plants. Thousands of farm families in Malawi have begun growing nitrogen-adding pigeon peas and peanuts on their land, replacing some of their corn. It's part of a ten-year-old experiment begun by local hospitals, farmers, and agricultural researchers.

Because peas made the soil more fertile, the next season's corn harvest was larger—more than making up for the fact that less land was being planted with corn. "Less corn is more corn," says Snapp. Plus that bonus crop of pigeon peas provided more nutritious, protein-rich meals. "But it didn't happen overnight," says Snapp. "It took education on how to use the legumes. It was 20 years of work, with a hospital involved. People changed their recipes."

Snapp's observation—that acquiring and conserving nitrogen in the future will take considerable know-how and patience—is echoed by many people engaged in this worldwide quest. Asked what Chinese agriculture needs most, soil scientist Zhu Zhaoliang responds quickly, "More scale"—meaning larger, more skillfully managed farms. Ron Rosmann, in Iowa, explains that farming without added nitrogen "takes more management, more labor, more attention to detail. We're kind of fanatics."

A century ago, when chemist Fritz Haber first learned how to capture nitrogen from the air, synthetic fertilizer seemed like an easy shortcut out of scarcity, delivering a limitless supply of agriculture's most important nutrient. Yet new limits on

nitrogen are appearing. This time the innovations that save us—and our planet—may not be invented in a chemistry laboratory. Instead they may come from farmers and fields in every corner of the world.