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## Nitrogen Fertilizer: Agricultural Breakthrough--And Environmental Bane

A new report citing drawbacks of the corn ethanol craze casts a pall over the centennial of a Nobel Prize-winning discovery that transformed global food production

Mar 20, 2009 | By Sarah Simpson

One hundred years ago this month, a laboratory experiment at the University of Karlsruhe in Germany set the stage for the Green Revolution. Chemist Fritz Haber placed a sheet of osmium in a steel chamber, pumped in a mix of nitrogen and hydrogen gases, and cranked up the heat and pressure. Then, out flowed ammonia, the elusive raw material for producing synthetic fertilizer. It was the eureka moment scientists had been pursuing for a decade: Haber managed to create the necessary conditions to transform **nitrogen gas**, abundant in the atmosphere but useless for life, into a digestible form. The work would earn Haber the **1918 Nobel Prize in Chemistry**. (Many protested the award because Haber had been instrumental in developing and deploying **chlorine gas** for Germany during World War I.)



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Once implemented on an industrial scale, ammonia synthesis enabled the widespread fertilization of croplands for decades hence. As a direct result, the world's population skyrocketed from 1.6 billion to six billion during the 20th century. But Haber's nourishing discovery has a dark side he probably never imagined. The boom of

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fertilizer, long injudiciously applied, has come at a high price for the environment.

And now, according to a new report to be released later this month by the [Scientific Committee on Problems of the Environment \(SCOPE\)](#) of the International Council for Science, society's aspiration to use biofuels to kick its oil addiction could backfire. By intensifying nitrogen pollution, a business-as-usual approach to biofuels production could exacerbate global warming, food security threats and human respiratory ailments in addition to familiar ecological problems. Scientists have long known that the reactive nitrogen in fertilizers leaching from agricultural fields (as well as those smaller amounts exiting tailpipes and smokestacks) wreak havoc as they cascade through the air and rivers. Rogue nutrients often spur harmful algal blooms as they flow into the ocean, and hundreds of estuaries around the world suffer from so-called seasonal dead zones as a result. "We're getting to the point where dead zones will be continuous bands around the continents," warns marine ecologist Jeremy Jackson of Scripps Institution of Oceanography in La Jolla, Calif.

Fixing the nitrogen problem is at the heart of Jackson's call to make the Green Revolution truly green, a sentiment echoed by scientists around the world. A primary culprit: so-called first-generation fuels, which are based largely on fermentation of cane and corn sugars.

"The production of ethanol from corn in the U.S. is a disaster in terms of fertilizer flowing down the [Mississippi River](#)," says Cornell University environmental biologist Robert Howarth, chair of the International SCOPE Biofuels Project. The U.S. Energy Independence and Security Act of 2007, passed with strong bipartisan support, set a goal of producing 54 billion liters (14.3 billion gallons) of ethanol from corn by 2022. But new research outlined in the SCOPE report indicates that, without a change of practice, meeting that goal could increase the nitrogen flux in the Mississippi by 37 percent. That pits ethanol production overwhelmingly against another national goal: reducing nitrogen flux in the same river by at least 40 percent to reduce the size of the dead zone in northern Gulf of Mexico.

Corn is a troublesome biofuel source, particularly from a nitrogen standpoint, Howarth says. Typical corn-growing practice is to apply high doses of fertilizer, with substantial losses to the surrounding environment. Corn has very shallow roots compared to most crops and so can use nitrogen only in the top one to two inches (0.4 to 0.8 centimeters) of the soil. Moreover, it only takes up nitrogen and other nutrients for 60 days out of the year. Other crops such as soybean and wheat have deeper roots that are active longer. But the rising price of corn has encouraged farmers to grow more of this "nitrogen leaky" grain. Land set aside for conservation purposes as well as some active soybean and wheat fields are being converted back to active corn cultivation.

Still, this growth in corn production cannot hope to enable the world to reach its ethanol production goals, the report says. The U.S., for example, put 24 percent of its 2007 corn harvest into ethanol, yet that generous contribution amounted to only 1.3 percent of the nation's use of liquid fuels. Based on this and other early findings, the

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SCOPE report projects that substituting 10 percent of the liquid fossil fuels used for transportation with biofuels could require a third of the world's arable land, causing trouble not only with nitrogen pollution but also food security.

Current biofuel targets impart other major problems for global warming and human health that Howarth says scientists have "long underestimated." Fertilizers release significant quantities of nitrous oxide, a greenhouse gas with 300 times the heat-trapping capacity of carbon dioxide (CO<sub>2</sub>). A 2007 analysis by Nobel laureate Paul Crutzen of the Max Planck Institute for Chemistry in Mainz, Germany, and his colleagues suggests that for most current biofuel crops, corn included, any CO<sub>2</sub> savings will be wiped out by higher emissions of nitrous oxide and nitrogen oxide. The latter destroys so-called "good" ozone, which shelters life from damaging ultraviolet radiation; it also fuels production of ground level ozone, the main constituent in smog that is widely known to exacerbate human respiratory ailments. According to the U.S. Environmental Protection Agency, millions of Americans live in areas that exceed the national standards for ozone exposure.

Even as researchers sound the alarm on biofuels, they suggest promising solutions. On the horizon is [cellulosic ethanol, sometimes dubbed "grassoline"](#). The wood or woody grasses that are the feedstocks for these so-called second-generation biofuels can be grown on marginal lands (thereby not competing for space with food crops) and need much less fertilizer, according to chemical engineer George Huber of the University of Massachusetts Amherst. A mature cellulosic biofuel industry will be able to compete with oil at around \$50 per barrel and deliver fuel to the pump at about \$2 per gallon, say Huber and his Michigan State University colleague Bruce Dale.

But that vision is still several years off, Howarth points out. Meanwhile, the SCOPE report suggests that even grassoline may not be the best use of biomass: "The world would be better off using the cellulose directly for combustion," Howarth says. "If you try to use biomass in a stationary way, it's much more efficient." Direct combustion of switchgrass for heat and electricity can provide 2.6-fold more energy than converting the same source to ethanol—and 9-fold more energy than producing ethanol from corn. The proof is out there: 35 percent of homes and commercial buildings in Sweden are heated by combustion of biomass, mostly willows grown on nearby plantations.

Biofuels are a hot topic right now, but the litany of issues surrounding fertilizers and nitrogen pollution are far more complex. Foremost among the challenges is the need to use more fertilizer to combat hunger in many parts of the world, points out ecologist Alan Townsend of the University of Colorado at Boulder. Townsend, like Howarth, has spent much of the past 15 years analyzing the human perturbations to the global nitrogen cycle. More fertilizer is badly needed to help feed burgeoning populations in much of the developing world, and yet mistakes of the West are being repeated elsewhere. A study published in February suggests that China could cut its fertilizer use by a third without reducing crop yield. Pursuit of meat-intensive diets, which requires massive production of fertilized crops to feed animals, is another problem Townsend and Howarth point out.

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Despite their dire warnings, neither scientist is a pessimist. Haber's discovery has been a miracle for a century, Howarth says. We just need to be smarter about how we apply it.

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**albertsonrich**

March 20, 2009, 1:33 PM

supporting the increased availability of biofuels is among the lesser problems caused by Fritz Haber's "gift" to humanity. If I remember correctly he was also the father of Germany's WWI use of poison gas.

The overarching problem with these chemicals is they need to be "water soluble." The plant nutrient they contain is drawn into the plant hydraulically once it is dissolved into the irrigation water. Unfortunately, the water solubility feature also allows these chemicals to quickly leach downward in the soil out of the reach of plant roots where they become useless as a fertilizer. That's where the problem starts because the leachate finds its way into the water supply and then the streams and rivers where it promotes the unwanted growth of plant species and algae in addition to its toxicity it delivers to humans in their water supplies.

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**scientific earthling**

March 20, 2009, 8:10 PM

First let me agree with albertsonrich, soluble fertilizers travel with water and move beyond the reach of the roots of the plants they are supposed to fertilize. This water percolates into the water table and river systems creating environmental problems.

Our planet maintained a fertile landscape for millions of years without fertilizers. Decaying organic matter and electric storms provided fertility. Biodiversity ruled, plants decided where they wanted to grow and no one stopped them. Plants themselves discharged chemicals to inhibit others of their own kind from overwhelming the environment (the original birth control - now desperately needed by man). Today we have monoculture across our agricultural landscape.

Our farmers classify any plant that does not directly put money into their pocket as weeds and spray them with the harshest chemicals with an intent to exterminate them. Weeds are part of the biodiversity and add organic matter to the soil when they shed leaves and eventually die. No one knows what the eventual results of chemical sprays (designed to kill) will be, evolution however will try to adapt to them.

Chemical fertilizers are like taking pills, you are better off with a nutritious diet.

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**Samadams**

March 22, 2009, 9:58 AM

You both make good points. There is the practical side to this. The world population would face a "Malthusian Disaster" if it stopped using this fertilizer this way. There are plants, like legumes, that fix their own nitrogen. I believe that a massive effort is needed to genetically engineer the rest of our food crops so that they too can fix their own nitrogen. This would not only stop pollution from fertilizers, it would also stop soil erosion.

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**scientific earthling**

March 22, 2009, 6:51 PM

Samadams:

No one is recommending that we stop using fertilisers immediately, but we must phase them out.

We have eliminated 25% of the vegetative cover of our planet. That means 25% less photosynthesis and 25% less food.

Plants also transpire during photosynthesis, the moisture released cause cooling. If this happens in a forest environment, the moisture then condenses at night, back into the soil for reuse by the trees. Condensation also causes warming. Lower day time temperatures warmer night temperatures.

Further loss of 25% forest the energy of the sun used to generate food is now warming the planet.

Further reading: <http://www.naturalsequencefarming.com/>

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**scientific earthling**

March 22, 2009, 6:59 PM

Samadams:

Sorry not to mention this: The site has a commercial feel to it. Consider the man went bankrupt and lost his family trying to fix salinity and other environmental issues on his farm.

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**Chaitanya Siriprolu**

March 23, 2009, 1:13 AM

The issue is not phasing out fertilizer use. Let's admit it. It is not practical. In the decades to come, many Asian countries are going to use many times more fertilizer than they do now.

We should rather focus on making fertilizer use less harsh on the environment. We can do this by encouraging a judicious use of both chemical and organic fertilizer.

Governments can educate citizens on the manifold benefits of using organic fertilizer. They can discourage the use of chemical fertilizer by cutting down on subsidies.

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**scientific earthling** → **Chaitanya Siriprolu**

March 23, 2009, 8:07 PM

The Asian nations need to learn from what has happened to the advanced nations. We have destroyed our land through clearing forests and use of fertiliser. To generate the same quantity of food keeps taking more and more fertiliser.

The land maintains its own fertility through biodiversity. Restore biodiversity solve fertility problems. Control human populations and allow other species to restore balance.

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**raseclamid**

March 24, 2009, 4:19 AM

I have never thought BLIND GREED is so much widespread in our world. As long as we are not able to control this irresponsibility, we are all in big trouble. An attitude of all man for himself would surely sealed our doomed.

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## Agecology

March 25, 2009, 2:46 PM

I am somewhat dismayed by the data being presented here regarding the production problems of corn and its uptake physiology. The agricultural production of corn on a wide scale is practiced because it does what we ask of it, and that is the harvest energy on a grand scale. In fact the net ecosystem exchange of carbon by a field of corn rivals that of a mature douglas fir forest in the pacific northwest and is far in excess of the native prairie it replaced. Only 10% of corn's huge large carbon harvest is expended as fossil fuel input in the production practice. None-the-less, corn production provides man with a tremendous harvest of useable energy. Please note that, in the USA, N fertilizer use per hectare of corn has remained constant since 1980 (check the USDA statistics) with an ever increasing efficiency of N use as yields have doubled over that same time. To be correct in the comparison made of corn and soybean in this article, corn has an active root system commonly extending to 1.2 meters in depth (not 2-4 cm!) and actively takes up nutrients in much the same timeline as indigenous perennials during its temperate lifespan. Where did you get these root numbers?? It is silly to say that we can phase out nitrogen fertilizer use when we have 6+ billion people to provide food and fiber for (that's 4 billion more than 1950)!. The contribution of N to the Gulf is in large part due to the degradation of soil's capacity to sequester N because of tillage and the massive harvest of C (energy) in crop yield but also to the growth in population, urbanization and municipal N waste loading to the Mississippi basin. If you do the population math, we will need to intensify agricultural production not extensify it and that will rely on judicious use of N fertilizer. Soil quality in the USA is rising and corn will be a major contributor to augmenting C to improve soil quality. Greater degradation of soil exists due to the presence of soybean than corn. While we (USA) have reduced our consumption of N fertilizer per unit of corn production, we must now turn our attention to judicious policies that concentrate on improving production efficiencies and appying the best science to solve our problems. At least Scientific American could check their facts before printing.

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JCC  Agecology

March 25, 2009, 6:44 PM

As Aecology said, the maize rooting depth provided in the article is totally wrong as it is the nitrogen uptake pattern. These articles should pass any type of review by experts such as those that you can find in the American Society of Agronomy.

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