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# Lifecycle Benefits and Costs of Inorganic Nitrogen Fertilizer

BY LYNN LAWS

Nitrogen is a primary component of a plant's photosynthesis machinery. The ability of a plant leaf to capture sunlight and carbon through photosynthesis is directly related to how much nitrogen is in the leaf. The agronomists who helped bring about the "Green Revolution" capitalized on this relationship by breeding varieties of corn, wheat and rice that have higher nitrogen-absorbing potential. Known as "high-yielding varieties," they outperform other varieties when given adequate inputs of nitrogen, water, sunlight and other nutrients.

Robert Anex, a professor at the University of Wisconsin and a principal investigator for the Sustainable Corn Project, says plant scientists have bred corn to have roots that grow deeper and seek soil moisture. "But the roots are also chasing the nitrogen, because a lot of the nitrogen put on a field is available as ammonium and nitrate in the soil moisture. Corn breeders have done lots of things to make corn grow better. The leaf angle is steeper and there are more leaves to capture more sunlight and moisture, for example. But at the end of the day, all the breeding in the world will not save you if you don't have nitrogen."

> 20 to 40 percent of the greenhouse gas emissions associated with farm production are due to the production of nitrogen fertilizer.

By the time high-yielding varieties of cereal grains became available commercially, scientists had developed a process to create inorganic nitrogen fertilizer in order to fulfill the higher demand. Crop yields and acres harvested increased year after year, as did the use of nitrogen. By the mid-20th century, this green revolution helped to avoid widespread famine in Asia and saved millions of lives.

But these super crops come with downstream and upstream costs.

## Downstream costs

"Right now the system is leaky," Anex says, referring to conventional corn-based cropping systems. "On average, 70 percent of plant-available nitrogen in the soil comes from applied inorganic fertilizer. Depending on how it is applied, only 40 to 60 percent of that goes to the plant. The rest of it is leaking out of the system somewhere."

Whether from organic matter in the soil or added during fertilizer application, mobile nitrogen not taken up by vegetation can move with water flowing through soil after rains and snow melt, and into streams and rivers where excess nitrogen can cause adverse effects on water conditions, aquatic organisms and habitats. Also, after fertilizer is applied, if conditions are right, microbes in the soil can convert the nitrogen into gases such as nitrous oxide that can escape into the atmosphere. Nitrous oxide emissions have a negative impact on air and water quality and result in ozone-depletion. Regardless of how the fertilizer is lost, it has a negative impact on the natural environment as well as a producer's bottom line.

## Upstream costs of inorganic fertilizers

Anex says the upstream costs in the lifecycle of inorganic nitrogen fertilizer, i.e., the costs incurred to make it, are significant, too. Inorganic nitrogen fertilizer is made from natural gas and nitrogen from the air. (Seventy-eight percent of the air we breathe is nitrogen.)

"Air consists of nitrogen, oxygen, and other gases like carbon dioxide. In the fertilizer manufacturing process, natural gas which is methane ($CH_4$) is split apart with the carbon molecule combining with oxygen (O) to make carbon dioxide ($CO_2$). The hydrogen reacts with nitrogen from the atmosphere ($N_2$) over a catalyst to make ammonia: $NH_3$," says Anex. "For every 10 pounds of ammonia made, about eight pounds of natural gas are used up. When I put nitrogen on the field, it's like I'm putting natural gas on the field." Each of those pounds of ammonia also comes with about 1.9 pounds of $CO_2$.

In addition to natural gas, large amounts of electricity are required to make the reaction happen. "Ammonia is equivalent to natural gas plus the energy it took to make it. It's an energy-intensive product," Anex says.

Greenhouse gas emissions from the industrial process are another lifecycle cost. In fact, 20 to 40 percent of the greenhouse gas emissions associated with farm production are due to the production of nitrogen fertilizer.

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## Big impacts make good targets for environmental and financial goals

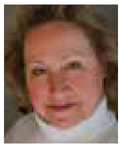
"When up to 45 percent of the energy use associated with corn production is due to upstream nitrogen production and close to 40 percent of the greenhouse gas emissions are from the upstream process, it really creates an incentive to try to reduce fertilizer use," says Anex. "And then there's the economic incentive – nitrogen is expensive."

> Reducing energy use while maintaining yield improve the bottom line and is good for the environment.

Farmers now have another economic incentive to reduce nitrogen: nutrient credit trading markets. The Delta Institute of Chicago announced February 19, 2014, that through its new nitrogen credit program, it will work with farmers across the Midwest to encourage voluntary changes to fertilizer applications to reduce emissions of nitrous oxide. Anex says more programs, like this one, are "just around the corner."

Central to these programs will be nitrogen-use protocols that give farmers guidance regarding qualifying practices. The practices that will qualify will likely be those that have shown consistent results in scientific peer-reviewed literature, such as the practices that the Sustainable Corn Project researchers are studying. Drainage water management, nitrogen sensing, split application of nitrogen, extended rotations, and use of cover crops, for example, are some of the practices that help farmers use nitrogen more wisely and/or limit its release into the environment.

"Given that using nitrogen properly can save farmers money and can reduce the upstream and the downstream environmental impacts, it's a win, win, win," says Anex.



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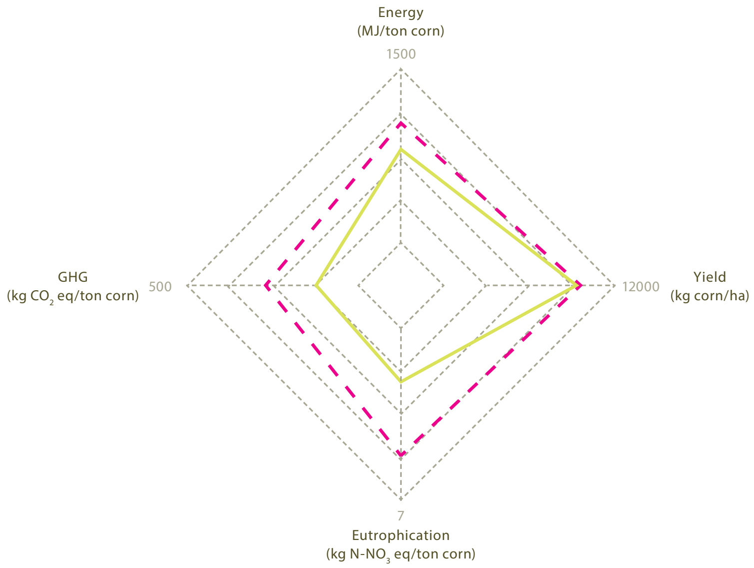
### FIGURE 1 | BENEFITS OF VARIABLE RATE N SYSTEM

This plot is the like a target where all values are smaller at the "bulls-eye." We prefer to use less energy to produce a ton of corn while releasing less environmentally harmful emissions. Therefore, on three of "spokes" of this plot we would prefer to be near the "bulls-eye" and the fourth – the corn yield per hectare – we would prefer to be as far out as possible. What this graphic shows is that the variable rate N system (represented by the solid green line) is superior to fixed rate application (represented by the red, dashed line) in all dimensions except yield – which is unchanged. Reducing energy use while maintaining yield improves the economic bottom line and is good for the environment.




### FIGURE 2 | TOTAL SOIL NITROGEN

Total Nitrogen: Soil can act as a nutrient reservoir. Most of the nitrogen contained in a soil is not immediately available to the plant. It has to go through a process called mineralization in order to become available. Mineralization occurs as microorganisms convert organic nitrogen to inorganic forms. If the rate of mineralization exceeds the rate of crop uptake, the mobile inorganic nitrogen is vulnerable to leaching from the soil which can have downstream environmental impacts. Nitrogen leached from the soil must be replaced to maintain fertility, costing the farmer money and creating upstream impacts due to fertilizer manufacturing. Nitrogen mineralization is closely linked with total nitrogen content. The chart to the right illustrates the measurements of total nitrogen in the soil at some of the Sustainable Corn Project field sites. Data interpreted and compiled by Landon Bunderson, Sustainable Corn Project data manager.