Nitrogen: at the nexus of food-energy-water systems

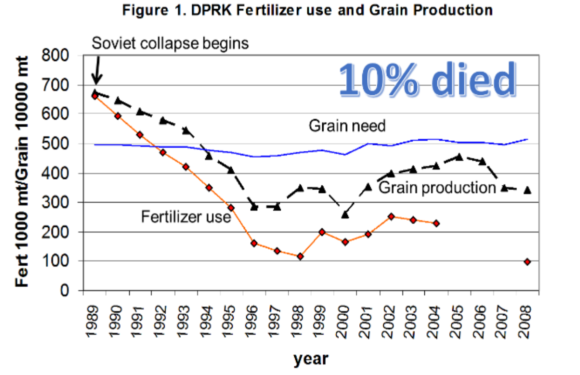
Peter Scharf, University of Missouri
Matt Ruark, University of Wisconsin
Bryan Hopkins, Brigham Young University
Deanna Osmond, North Carolina State University
Tony Vyn, Purdue University
John Lory, University of Missouri
Michael Maw, University of Missouri
Charles Shapiro, University of Nebraska
Miguel Cabrera, University of Georgia
Michael Russelle, University of Minnesota
Ann Hirsch, University of California, Los Angeles
Gurpal Toor, University of Florida

Nitrogen's position at the nexus

Nitrogen has a huge impact on crop growth, is the largest energy input to growing **food**, and is one of the biggest water issues in the U.S. and the world.

Stewart et al. (2005) attribute 40 to 60% of crop production in the U.S. and England to the use of fertilizer, and an even higher fraction in the tropics. Smil (2001) estimates that 40% of the human population would not be alive today without the advent of nitrogen fertilizer. The huge impact of nitrogen fertilizer on food production and availability has been demonstrated in North Korea. The collapse of the Soviet Union in 1989 cut off most of the country's supply of nitrogen fertilizer. Grain production fell by more than half (Figure 1), and approximately 10% of the country's population died of starvation or related disease.

Figure 1. DPRK Fertilizer use and Grain Production



Despite its importance in food production, nitrogen behavior in soils is so complex that management is still far from optimal. One outcome of this complexity is that the optimal fertilizer rate varies widely from place to place within crop fields (Scharf et al., 2005). Our ability to know ahead of time how much nitrogen fertilizer to use, and where, is still quite limited. As a result, nitrogen fertilizer is often over-applied and not infrequently under-applied, often in different parts of the same field. Farmers know the tremendous response that nitrogen fertilizer can produce in their crops, and are averse to risking deficiency. This leads them to over-apply more frequently than they under-apply.

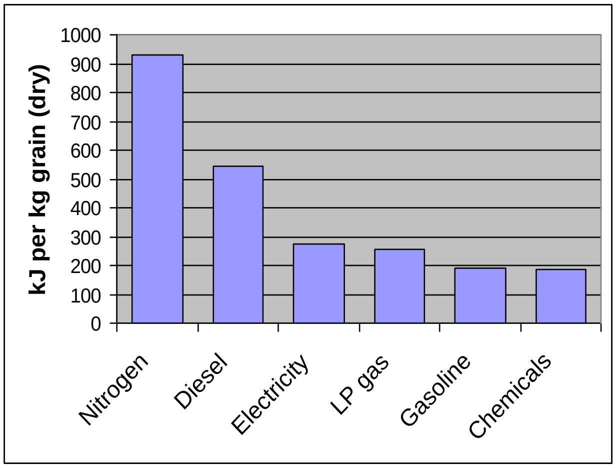


Figure 2. Energy inputs for U.S. corn production. Data from Shapouri et al. (2002), nine state average.

A tremendous amount of **energy** is used in producing nitrogen fertilizer, typically sourced from natural gas. The result is that nitrogen fertilizer is the largest energy input in U.S. corn production (Figure 2). The same is true for most other nitrogen-fertilized crops.

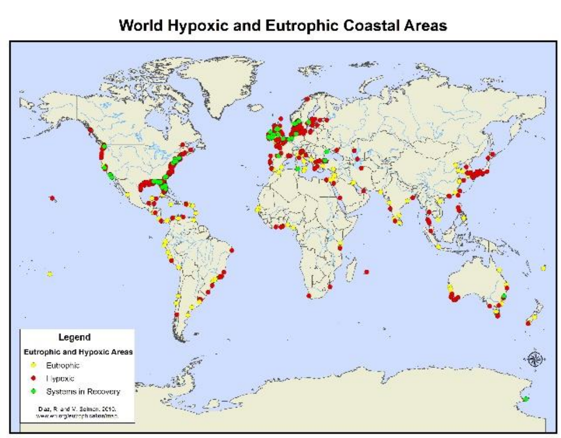
In addition, nitrogen is crucial to the production of energy crops. Despite its high energy cost, nitrogen fertilizer gives positive energy returns in most energy crop systems. This is due to the large yield responses to N commonly seen in corn, grass, sorghum, trees, and other common or proposed energy crops. Judicious use of nitrogen fertilizer (and other nitrogen inputs) is crucial to maximizing net energy production in these systems.

Nitrogen and **water** interact in important ways, both in crop fields and in coastal waters.

In crop fields, water and nitrogen are the two factors most limiting for crop production globally. If either is in short supply, this condition lowers the efficiency with which the other is used. Sadras et al. (2007) provide examples in several crops of how relieving nitrogen deficiency improves water use efficiency. Genetic improvements in efficiency of either nitrogen or water use (Ciampitti and Vyn, 2012) may lower the threshold at which the other can be used efficiently.

Water and nitrogen interactions in crop fields are also the driver for how much N is lost from the fields as nitrate. Agricultural water management (both irrigation and drainage) has a tremendous impact on this process. Nitrate moves with leaching waters to either groundwater or surface waters. In either location, it can result in drinking water above the EPA limit for nitrate. Nitrate moved to surface waters can also contribute to excess algal growth when the surface waters reach the coast.

In coastal waters worldwide, nitrogen inputs from rivers are linked to algal blooms and subsequent low-oxygen conditions (Figure 3). Most animal species cannot live in these low-oxygen waters, though the condition is often temporary and seasonal.



Nitrogen and NSF

Nitrogen is of such great import at the nexus of food-energy-water systems that **NSF's INFEWS initiative should have a stand-alone interdisciplinary program in Nitrogen Science.** This program should fund all areas of inquiry into nitrogen science, ranging from microbial processes in soil to human decision processes in nitrogen management. It should open the door to the creation of cross-disciplinary teams that can best answer the most important questions about nitrogen.

The most important questions about nitrogen can essentially all be put under one umbrella question: How can we benefit from the biological power of nitrogen while minimizing its negative impacts on us and the planet? Examples of more specific questions:

1. How can we change nitrogen fertilizer and manure nitrogen management to maintain benefits while reducing environmental costs?
2. Can we improve our understanding of soil organic nitrogen forms enough to help target rates of fertilizer and manure N better?
3. Is there a way to harness biological nitrogen fixation more effectively in order to reduce the need for industrial fixation? (The NSF-BBRC program Nitrogen: Improving on Nature is a good example)
4. Why do farmers manage nitrogen fertilizer the way they do, and what are the social and economic barriers to changes in management?
5. Can nitrogen fertilizer be produced using renewable energy sources?
6. Can we better couple water availability and nitrogen availability to optimize the performance of food production systems?
7. What policies are needed to support improvements in nitrogen management and outcomes?

Relative to its impact on food, energy, water, and society in general, research on nitrogen has been both under-funded and fragmented according to disciplines. NSF has an opportunity to address both problems within the INFEWS initiative, and to stimulate significant advances in our understanding and management of nitrogen. Getting buy-in from other agencies (USDA, DOE) on the Nitrogen Sciences program would be of great value both in terms of resources and in terms of getting scientists from different disciplines and cultures to work together.

A Nitrogen Science program within INFEWS should coordinate with NSF's existing grant-funded Research Coordination Network on Reactive Nitrogen, but have a broader scope and greater continuity. It should also coordinate with the International Nitrogen Initiative (http://www.initrogen.org/). A Non-Governmental Organization, the International Nitrogen Initiative has been the most effective voice globally in creating scientific dialogue about nitrogen. International Nitrogen Congresses have been held in Europe, North America, Asia, South America, and Africa. The 7th International Nitrogen Congress is scheduled for December 2016 in Australia. Although the issues surrounding nitrogen are different on different continents, on every continent nitrogen is a key factor at the nexus of food, energy, and water.

References

Ciampitti, I.A., and T.J. Vyn. 2012. Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: A review. F. Crop. Res. 133: 48–67.

Sadras, V.O., P. Grassini, and P. Steduto. 2007. Status of Water Use Efficiency of Main Crops, SOLAW Background Thematic Report. *Food and Agricultural Organization, Rome, Italy*.

Scharf, P.C., N.R. Kitchen, K.A. Sudduth, J.G. Davis, V.C. Hubbard, and J.A. Lory. 2005. Field-scale variability in optimal nitrogen fertilizer rate for corn. Agron. J. 97:452-461.

Shapouri, H., J.A. Duffield, and M. Wang. 2002. The Energy Balance of Corn Ethanol: An Update. AER-814. Washington, D.C.: USDA Office of the Chief Economist.

Smil, V. 2001. Enriching the Earth. MIT Press, Cambridge, MA.

Stewart, W.M., D.W. Dibb, A.E. Johnston, and T.J. Smyth. 2005. The Contribution of Commercial Fertilizer Nutrients to Food Production. Agron. J. 97:1-6.