Managing Nitrogen Pollution in the United States

A Success, a Challenge, and an Action Plan

In 2002, humans injected 29 teragrams (Tg) of reactive nitrogen (Nr) into the U.S. environment: agriculture, 19 Tg N; fossil fuel combustion, 5.7 Tg N; industry, 4.2 Tg N.¹ This is in contrast to 6.4 Tg N/yr from the natural source of Nr—biological nitrogen fixation (BNF) in noncultivated terrestrial ecosystems (see Figure 1).¹ This means that human Nr sources are ~5-fold greater than natural sources. As noted in the cover story article, this over-abundance of Nr causes a myriad of environmental impacts.²⁻⁴

Since this analysis was done, two important new pieces of information have become available—an update on the magnitude of natural BNF⁵ and an estimate of Nr inputs to the United States in 2007.⁶
On the former, the natural BNF estimate of 6.4 Tg N/yr\(^1\) was made in the context that global BNF in noncultivated systems was on the order of 100 Tg N/yr.\(^7,8\) More recently, it has been estimated that global pre-industrial N fixation was 58 (range: 40–100) Tg N/yr,\(^5\) substantially smaller than the previous estimate. With this new understanding, it is probable that natural terrestrial BNF in the United States is ~3 Tg N/yr (P. Vitousek, personal communication). This means that humans introduce \(\text{Nr}\) into the United States at rates that could be ~10-fold greater than the amount introduced by natural sources. This underscores the impact that humans have had on the introduction of \(\text{Nr}\) to U.S. systems. The consequences of this added \(\text{Nr}\) are very real. It is estimated that the potential health and environmental damages of anthropogenic N in the early 2000s in the United States totaled $210 billion/yr (range: $81–$441 billion/yr).\(^9\)

On the latter, in 2002, anthropogenic \(\text{Nr}\) sources totaled 29 Tg N.\(^1\) In 2007, they totaled 30 Tg N.\(^6\) While the difference between these two is small, the importance of this comparison is not in the total, but rather in the sources that contribute to the total. Specifically, fossil fuel combustion sources of \(\text{Nr}\) decreased from 6 to 5 Tg N/yr and agriculture increased from 23 to 25 Tg N/yr. The direction of these changes underscores both the successes and the challenges facing \(\text{Nr}\) management in the United States.

### Success Story and Challenge

The success story is fossil fuel combustion. U.S. nitrogen oxides (\(\text{NO}_x\)) emissions have decreased over 2-fold since 1970. They are 5-fold lower than what they would be without appropriate action. In addition, \(\text{NO}_x\) emissions are projected to decrease significantly in the future. This improvement is due to the marked success of the U.S. Clean Air Act (and its amendments) and the fact that \(\text{NO}_x\) is a waste product and comes from point sources (e.g., tail pipes, smokestacks). Thus, the \(\text{NO}_x\) is not a needed resource and it is relatively easy to control.

The challenge is agriculture. Food cannot be produced without N, and approximately 80% of the N used in agriculture is lost to the environment along the food supply chain. Of the estimated 20% of N that is actually consumed by people, most of that is lost to the environment due to insufficient treatment in septic systems and in municipal waste water treatment plants. So unlike fossil fuel combustion, N has to be used to grow food, and it is lost to the environment from numerous diffuse sources along the food supply chain.\(^10\)

To change this challenge to a success story requires integrated management strategy along the food supply chain. This, in turn, requires coordination among the numerous stakeholders who have the opportunity to control \(\text{Nr}\) losses at specific points in the food supply chain (see Figure 2).

The major loss points of \(\text{Nr}\) to the environment are at either end of the food chain—production and consumption. For production, the challenge is to increase N use efficiency of crop and animal production. For consumption, the challenges are to (1) consume more of the food that is purchased, (2) consume protein to the U.S. Department of Agriculture (USDA) dietary guidelines, and (3) reuse the N in human waste.
The Life Cycle of Food

Figure 2 represents various stages in the life cycle of the food system. The modern food life cycle involves complex linkages among production, processing, transportation, markets, and acquisition and consumption with wastage occurring at each stage. It begins with activities on the field, where seeds are planted and chemicals, including fertilizer and pesticides, are applied. Wastage begins almost at once as water soluble chemicals are drained from the field during rainfall events, and continues through the production, processing, retailing, acquisition, preparation, processing, and disposal life cycle stages. Although some attempts within each stage are made to recover wasted byproducts, ultimately from 30% to as much as 50% of food matter is wasted, and as noted above up to 80% of Nr is discharged to the environment.

The modern food cycle is driven by consumer needs and demand. Over time, the human diet has shifted, from ancient intake based on game, nuts, and berries (the “Paleolithic” diet) to subsistence agriculture made possible by the advent of early cultivars of maize, beans, and vegetables, and to modern agricultural systems with widely varying types of grains, and the proliferation of dairy, domesticated animals, and processed foods. In all cases, these “food systems” have been adapted to, and in turn are driven by, human consumption preferences and demands. Thus, while present and past technological and regulatory focuses have been on waste (which includes soil and nutrients) associated with on-field production, the habits and preferences of consumers ultimately determine environmental and human health impacts. And yet, little attention has been paid to policies that can affect consumer decisions on diet and other food acquisition and handling procedures, and how these are linked throughout the food cycle, influencing wastage at all stages.

While the United States, and most developed countries, have a well-developed agricultural policy, equal effort has not been expended on the complexities of the food system, and the need for the development of a health-based food policy. A first step in that regard is the recently released draft recommended dietary guidelines that take into account the environmental impacts of food production (see http://www.health.gov/dietaryguidelines/2015.asp). This is, however, only a first step. As noted below, what is needed is a policy that would bring to bear the full economic, budgetary, regulatory, and taxing functions of the government; in this case, to bring about a desirable end—reduction of excess Nr in the whole food system and a healthier population.

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Control strategies to remove Nr include source limitation (i.e., reducing the amount of Nr entering the environment); increased efficiency, which will lower the requirement for new Nr; and sequestering of existing Nr in the environment. Efforts to implement these strategies may involve command and control through regulations, other government-based incentives like taxes or subsidies, voluntary actions, and market-based instruments. These actions are seldom single approaches and often involve several actions that are complementary or reinforcing.

For example, a voluntary approach might be successful because of impending regulations and the additional incentive of a government subsidy. There has been great success in the United States reducing Nr in the environment where there were point sources that came under the U.S. Clean Water Act and the Clean Air Act. Regulations, government incentives, market-based instruments, and even voluntary action all played a role in bringing about change. The situation is different for agricultural production and the food chain. Here, the major challenge for Nr decrease is primarily nonpoint sources on the production side and something quite different on the consumption side.

The opportunities for decreasing the introduction of Nr to the environment identified in Figure 2 can be broadly classified as those that attempt to limit Nr from the production side of the system, and those that might limit Nr on the consumption side. Success has been mixed in reducing Nr from agricultural production in the United States. However, advancements have been made in monitoring and validating adaptive N management designed to reduce Nr applications on working
farm fields, while maintaining overall productivity. Engineered wetlands have, in some cases, successfully closed the N-cycle through denitrification and in high-value watersheds denitrification of wastewater effluents is proactive.

Still, agriculture has specific exemptions from regulation as compared with point sources under the Clean Water Act and the Clean Air Act. Programs to encourage conservation and limit excess nutrients have been largely voluntary since such programs were first developed in the 1930s. These programs encourage farmer participation through substantial incentive payments to cover the cost of actions and sometimes provide additional incentives. The USDA is the primary source of these funds and programs.

The best example of this is the TMDL for the Chesapeake Bay, which includes the six states surrounding the Bay as well as the U.S. Environmental Protection Agency (EPA) in the determination and enforcement of nutrient reductions that include both nonpoint and point sources (see http://www.epa.gov/chesapeakebaytmdl). Increasingly, environmental groups are pressing for impaired watershed status and the development of TMDLs for reductions in excess nutrients, given that voluntary efforts supplemented by incentives have not resulted in the level of reductions these groups desire.

We believe that management to reduce Nr through changes in the consumption of food products will become an increasing Nr management focus, likely starting with the low hanging fruit of waste reduction. The approach thus far for reducing the demand for products that require large Nr inputs and contribute substantial amounts of excess reactive nitrogen have consisted primarily of dietary guidance, the principle aim of which is proper nutrition and health (e.g., USDA and World Health Organization guidelines). Of course, these too are voluntary in nature. Promulgation of more robust policies for limiting demand-side Nr would be a new and different challenge. Policies based solely on regulatory command and control approaches are unlikely to be politically or popularly feasible.
The question becomes where leverage might be exerted to inform and/or influence consumer choices. This might involve the role of subsidies in the pricing of food, local access to healthy food alternatives (alleviation of “food deserts and food insecurity), revision of various taxation policies (including the imposition of targeted taxation of certain food and beverage products), facilitation of food waste recycling, regulatory approaches for restaurants (e.g., limits on trans fats), and dietary and nutrition education.15-18 For example, efforts to change food choices available under the school lunch program and the Supplemental Nutrition and Assistance Program (SNAP) in the United States, which together affect 75 million people, have been proposed (beneficiaries of SNAP now have almost complete latitude in the choice of foods).

Many justify restrictions as a means of achieving better nutrition and improving the health outcomes of the program. In addition, choice restrictions could also operate to limit the choice of food classes whose production results in the greatest level of excess Nr. The dilemma is that freedom of choice in areas like this is highly prized and politically difficult to negotiate even within government food programs. Yet, recent studies by the USDA indicate that education within its food programs can make significant differences. The diets of children in the Special Supplemental Nutrition Program for Women, Infants and Children (WIC), which included a strong educational component, were more in line with nutritional guidelines than those of SNAP recipients whose program did not include such education.19,20

And yet, unlike many production-side programs, virtually none of the demand-side approaches outlined above is specifically targeted at reducing the amount of Nr reaching the environment. It must be remembered that while Nr is a necessary nutrient, its dietary requirement for humans is only a little over 4 grams/capita/day out of a total food need of about 600 grams/capita/day. Thus,
crafting demand-side policies to control Nr will almost certainly need to have multiple objectives.

Addressing these issues related to N production and demand will require cooperation across disciplines, agency missions, and multiple stakeholders. Spurred by the 2011 recommendations of the EPA Science Advisory Board,1 scientists and managers from government, academia, non-government organizations, and the private sector gathered in 2014 to review science and management related to reactive nitrogen Nr across EPA, USDA, and U.S. Geological Survey agencies. The purpose of the meeting was to develop a research and management partnership among these agencies, in order to promote sustainable management of Nr. Workshop participants identified research needs in monitoring, policy research, technical solutions research, collaboration, communication, and database alignment. Achieving the common goals of improving air and water quality, food security, and human health and welfare will require coordination of research, policies, and management across agencies and partnerships with the private sector.21,22

**Summary**

Anthropogenic activities in the United States inject up to 10-fold more Nr into the environment than do natural terrestrial processes. This imbalance has significant negative impacts on both environmental and human health. Significant success has been achieved in the decrease of NOx emissions from fossil fuel combustion. Equivalent successes are needed in the area of food production, but there are significant challenges at both the food production and consumption portions of the food supply chain. Ultimate success will only come when the entire system is optimized to produce food with the minimum of environmental cost. For this to occur, all stakeholders must be seated at the table!

**References**

5. Vitousek, P.M., Menge, D.N.L., Reed, S.C.; Cleveland, C.C. Biological Nitrogen Fixation: Rates, patterns, and ecological controls in terrestrial ecosystems; Phil. Trans. R. Soc. B 2013, 368, 20130119.