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A Menace Reconsidered, Part 4: Losing Nitrogen

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Amid the wind and rain of Midwestern April, the Farm Bill faithful may detect stirrings of a possible start to the long, difficult reauthorization process (Clayton, April 16, 2024; Hagstrom, April 17, 2024; Baethge, April 17, 2024; Abbott, April 16, 2024; Downs, April 8, 2024). Alexander Pope famously wrote that "Hope springs eternal in the human breast" and the line continues to resonate (Pope, 1732; Matteo, March 26, 2022). The challenges inherent in soil erosion seem also to spring eternal and this article continues that discussion by incorporating an exploration of the research on nitrogen losses, seeking to further build risk-based perspectives (*farmdoc daily*, March 14, 2024; March 21, 2024; March 28, 2024; see also, December 7, 2023; January 4, 2024; and January 15, 2024). In the spirit of the season, it may be hoped that applying research to develop a wider, more comprehensive perspective on farm risk—one that incorporates natural resource risks—can inform the development of more effective farm polices.

Background

Soil erosion adds risk to farming. It can magnify complications in farm management. It also carries significant cost implications. These realities are supported by a substantial body of research (*farmdoc daily*, March 14, 2024; March 21, 2024; March 28, 2024). Soil erosion possesses a long history and has menaced many societies, persisting as a perennial complication of farming and the production of food (Dotterweich, 2013; Brevik, 2018; Gibbard and Mead, 2020). Among the many challenges of soil erosion is designing effective policy responses. Soil erosion is a complex menace and the loss of nitrogen from fields helps demonstrate the point. One of the most critical nutrients for plant growth, and a major component of topsoil fertility, nitrogen is exported from farm fields in a different process than soil erosion. The two are connected in important ways, however. Erosion of fertile topsoil, for example, requires applications of nitrogen to compensate. Together, they can drive self-feeding cycles, compounding and complicating the challenges. Additionally, neither constitutes actual loss but rather misplacement or displacement, deposited in waterways or somewhere other than the fields where they are needed for crops.

Summarizing the research on the topic is daunting. Humans have likely doubled the amount of reactive nitrogen that cycles through ecosystems across the planet, a substantial portion of which is not consumed as intended. Organic nitrogen abounds in soils but is not available for plants to consume. Bacteria and other microorganisms produce inorganic, plant-available, nitrogen, while ammonium forms of nitrogen are generally added by fertilizer inputs. Nitrogen fertilizers are subject to rapid nitrification to nitrate, the form of nitrogen favored by plants but also the one most soluble and easily transported such as being leached through the soil with water. Nitrate is especially mobile and susceptible to being leached, a risk that is most prominent early in the season when crop growth and nitrogen uptake is low, but mineralization of nitrogen (especially from fertilizer) is high. The complex system of artificial drainage contributes by quickly moving water from precipitation and snowmelt out of farm fields. That water, however, carries significant quantities of nitrates to lakes, reservoirs, and natural waterways such as the Mississippi River and the Gulf of Mexico. The result is that nutrients intended for crops degrade water quality and contribute to hypoxic or dead zones (Gentry et al., 2024; Li et al. 2022; Myrold, 2021; Cao, Lu and Yu, 2018; Fernández, Fabrizzi and Naeve, 2017; Pittlekow et al., 2017; Christianson and Harmel, 2015; Robertson et al., 2013; Dessureault-Rompré et al., 2011; David, Drinkwater, and McIsaac, 2010; Gentry et al., 2009; Robertson and Vitousek, 2009; Robertson and Groffman, 2007; Paul et al., 2003; Cassman et al., 2002; Smil, 2002; Williams, Hutchinson and Fehsenfeld, 1992; Kladivko et al., 1991; Russel and Williams, 1977; see also, *farmdoc daily*, February 8, 2024; March 10, 2016; March 17, 2016; February 17, 2021).

Discussion

Agriculture, especially row crop agriculture, is the largest contributor of nitrogen to the environment in the United States, previously reported as contributing 54 percent of nitrate emissions (Ribaudo, September 1, 2011). Today's loss of nitrogen has been linked to the huge wave of investment, research, infrastructure, market development, and policy under the rapid technological changes in farming known as the Green Revolution (1966-1985) (see, Pingali, 2012; Mann, 2018; Anderson, 2006). For example, commercial and manure fertilizer application increased from 1 million metric tons in 1951 to 13 million metric tons in 2017 (Del Rossi et al., 2023). Figure 1 illustrates the total U.S. consumption of nitrogen as last reported by USDA's Economic Research Service (ERS) in 2019 through year ending June 30, 2015 (USDA-ERS, Fertilizer Use and Price, October 30, 2019). It also includes the acres planted to corn and other feed grains (sorghum, oats, and rye), wheat, upland cotton, and rice.

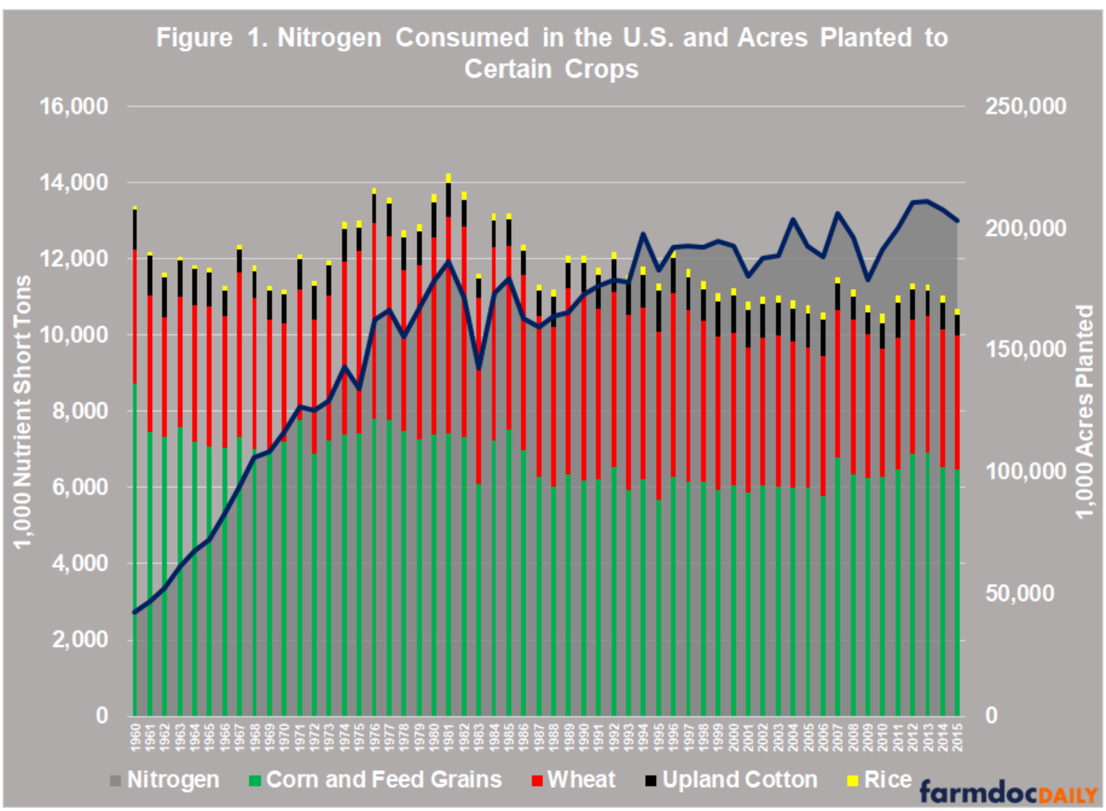
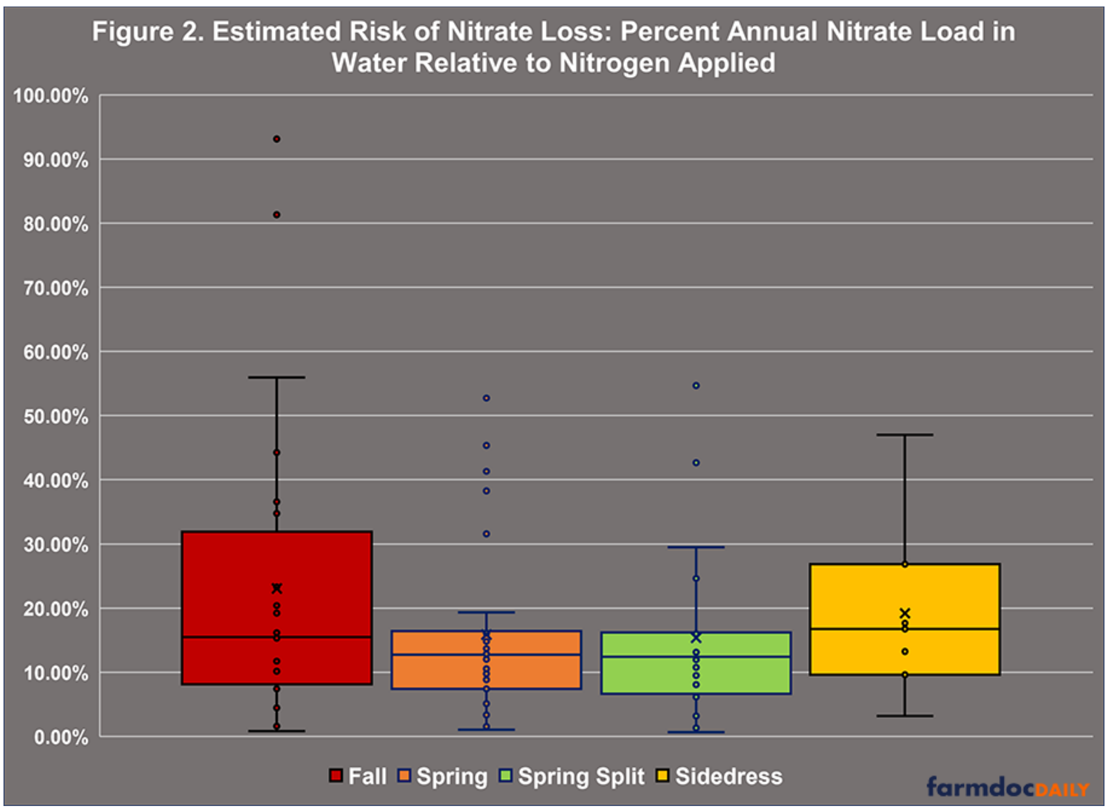


Figure 1 raises tough questions about whether farmers are overapplying nitrogen for these crops. Total nitrogen consumption has generally increased (and remained at elevated levels) even as acres planted to these crops initially decreased and have remained relatively constant in the later years of the reported data. Overapplication of nitrogen, as well as application of nitrogen in the fall after harvest, contributes to water quality degradation. As discussed above, the research is clear that nitrogen fertilizer not consumed by the plants accumulates in the soil and that the mobile nitrate form is easily transported out of the fields, carried by water. For example, one study in Iowa found residual nitrate in the soils after corn harvest that ranged in amounts equal to between 16% and 26% of the applied rate of nitrogen in 2002 and 2004 (Jaynes and Covin, 2006).

As with soil erosion, we begin by applying the research on nitrogen losses to estimate this complex issue in terms of risk of loss. Nitrogen loss is extremely variable, which makes sense given the extent to which the transport of the nitrate form depends on water. For example, USDA previously estimated a range from less than 20 pounds per acre to more than 70 pounds per acre each year from 2003 to 2006 (USDA-NRCS, 2017). Figure 2 is the first attempt at illustrating the risk of nitrogen losses in farm fields each year based on a compilation of research findings over multiple years and sites in the Midwest (Gentry et al., 2024; Waring et al., 2022; Preza-Fontes et al., 2021; Pittlekow et al., 2017; Jaynes, 2015; Jaynes, 2013; Randall et al., 2003). Specifically, Figure 2 charts ranges of nitrogen loss measured as a percentage of the annual nitrate load measured in subsurface tiles relative to the amounts of nitrogen applied as fertilizer. It compares four different nitrogen application practices: fall-applied, spring-applied, split application in the spring, and side-dress (nitrogen applied between the rows of the growing crop).



Residual N pools, present in the soil of farm fields after commercial crop harvest, cost the farmer and society. Because of the nearly guaranteed loss of nitrogen, farmers are spending income for some amount of nitrogen that will not be utilized by the plant. Additionally, farmers are potentially absorbing extra costs that outweigh any benefits in crop yield. This concern has been magnified in recent years with the skyrocketing cost of nitrogen (see e.g., *farmdoc daily*, August 15, 2023; September 12, 2023). While overapplication of this expensive input means farmers have sunk in more cost than needed and diminished profitability, it also creates burdens on (and costs to) society in the form of drinking water contamination by excess nitrates, presence of cyanotoxins (cultivated by harmful algae blooms), and excess turbidity (Del Rossi et al., 2023). These costs include negative health effects, recreational and aesthetic damages, remediation actions for contaminated wells, installing filtration or treatment systems, as well as avoidance behaviors like purchasing bottled water. These costs are more intensely felt by the 43 million, mostly rural households, who source their water from a private well and live near the source of this nonpoint source of pollution, agricultural lands (Del Rossi et al., 2023). Another deep well of complex issues to be explored further.

Concluding Thoughts

This article expands upon the complex, complicated challenges of soil erosion by incorporating those of nitrogen losses from farming. Congress first proclaimed soil erosion to be a menace to society in 1935 in response to the Dust Bowl and Great Depression catastrophes; soil erosion, however, has a much longer history. It has menaced many societies throughout human history, persisting as a perennial complication of farming and the production of food. The Dust Bowl was a dramatic example of soil erosion and offers critical lessons. Ironically, its prominent position in history risks obscuring many of them. It can be narrowed to a single dimension in the popular imagination, isolated in time and place to moving mountains of soil across the drought-ravaged and wind-swept southern Great Plains. Soil erosion is a much more complex menace and the challenges are especially acute for designing effective policy responses. As discussed herein, the risks of losing nitrogen help demonstrate the point. One of the most critical nutrients for plant growth, and a major component of topsoil fertility, nitrogen is exported from farm fields in a different process than soil erosion. The two are connected in important ways, however. Erosion of fertile topsoil, for example, requires applications of nitrogen to compensate. Together they can drive self-feeding cycles, compounding and further complicating the challenges of each. The common ground is bare soil; farm fields left fallow and exposed after harvest are at an increased risk of both soil erosion and nutrient loss, critical consequences that result when the bare soils of farm fields are exposed to the elements. To initial evaluations of the risks of soil erosion, this article adds evaluation of the risks of nitrogen losses; applying research to develop a wider, more comprehensive perspective of farm risk that incorporates natural resource risks and in turn, accepts the multi-dimensional realities which could inform the development of more effective, multi-dimensional farm polices.

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