

Best Management Practices to Minimize Greenhouse Gas Emissions Associated with Fertilizer Use

This article is an Executive Summary of a literature review in preparation by the International Plant Nutrition Institute (IPNI).

By C.S. Snyder, T.W. Bruulsema, and T.L. Jensen

Climate change and global warming continue to be topics of considerable scientific debate and public concern. Increasingly, agriculture is viewed as a large contributor to GHG emissions which drive GWP, and fertilizer N use has been identified as a major factor. This paper presents a review of the scientific literature on the impacts of fertilizer use and management on GHG emissions, and represents a brief overview of the current science.

Agriculture plays a substantial role in the balance of the three most significant GHGs whose emissions are influenced by humankind. The three gases are – CO₂, N₂O, and CH₄. The GWP of each of these gases can be expressed in CO₂ equivalents. The GWPs of N₂O and of CH₄ are 296 and 23 times greater, respectively, than a unit of CO₂. Among the three gases, N₂O may be the most important to fertilizer use because of its large CO₂ equivalent influence on GWP.

Agriculture represents less than 8% of the total GHG emissions in Canada and less than 10% in the United States, and it is not increasing (Figure 1). For the total economy, CO₂ emissions are the most important, but for agriculture the most important is N₂O (Figure 2). Emissions of CH₄, mainly from livestock, are also substantial contributors to the GWP. Even though N₂O constitutes only a small part of U.S. GHG emissions (Figure 2), it becomes the major focus of this review because agriculture is its major source, and it is linked to soil management and fertilizer N use.

Atmospheric concentrations of N₂O have risen from about 270 parts per billion (ppb) during the pre-industrial era to 319 ppb in 2005. Emission of N₂O from the Earth's surface has increased by about 40 to 50% over pre-industrial levels as a result of human activity. The proportion of cropland N₂O



emissions directly induced by fertilizer are estimated at about 23% world-wide, and range from about 24% to 35% in North America.

Fertilizer N – Source, Rate, Timing, Placement

The foundation of good fertilizer stewardship rests on the principles of using the right source, at the right rate, at the right time, and with the right placement (Roberts, 2007). Most studies have shown that soil conditions such as water filled pore space, temperature, and soluble C availability have a dominant influence on N₂O emissions. Fertilizer source and crop management factors may affect N₂O emissions, but due to interactions with soil conditions it is difficult to make general conclusions. Mismanagement of the appropriate rate, source, timing, or placement of fertilizer N, and lack of proper balance with other essential nutrients can increase overall N loss and N₂O emissions. When N is applied above the economic optimum N rate, or when available soil N (especially in NO₃⁻ form) exceeds crop uptake, the risk of increased N₂O emissions rises. When legumes or other N-fixing crops are included in cropping system rotations, they may also contribute post-season N₂O emissions as their plant residues decompose. Research around the world has shown contrasting results in emissions of N₂O from various fertilizer N sources. At the present time, based on the available literature, no conclusions can be made that differentiate one source of N as having a greater risk of loss as N₂O than another.

Urease and Nitrification Inhibitors, and Enhanced Efficiency Products

Enhanced efficiency fertilizers (slow and controlled-release fertilizers and stabilized N fertilizers) have been defined as

Abbreviations and notes for this article: GHG=greenhouse gas; GWP=global warming potential; N=nitrogen; CO₂=carbon dioxide; N₂O= nitrous oxide; NO₃⁻= nitrate; CH₄=methane; SOM=soil organic matter; C=carbon; SOC=soil organic C.

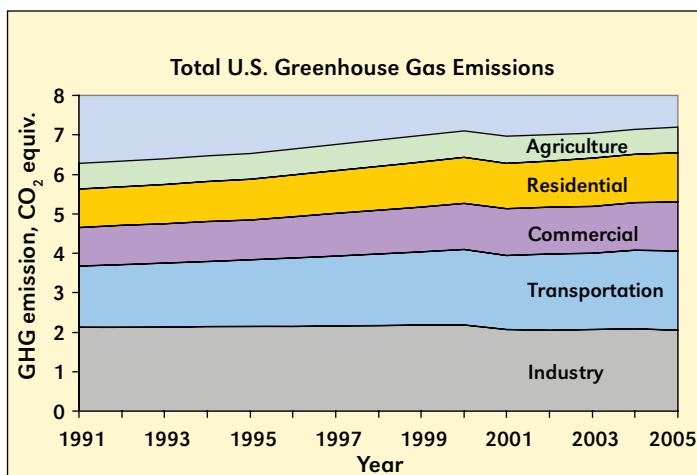


Figure 1. Greenhouse gas emissions from the U.S. economy, by sector, in billion (10⁹) tonnes of CO₂ equivalents.

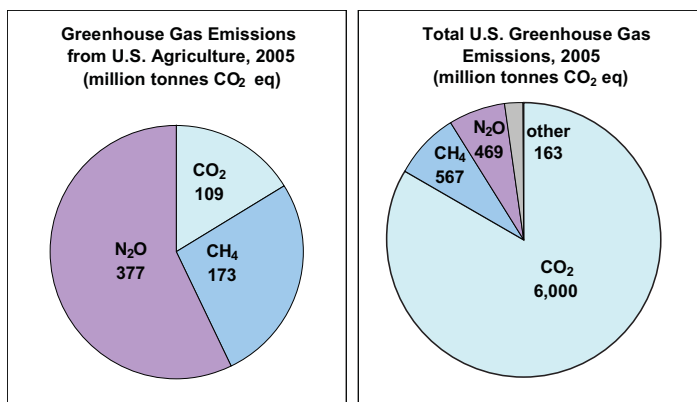


Figure 2. Distribution of greenhouse gas emissions from U.S. agriculture and total.

products that minimize the potential of nutrient losses to the environment, as compared to “reference soluble” fertilizers. Urease and nitrification inhibitors have shown good potential in increasing soil retention and plant recovery of applied fertilizer N, but less is known about their impacts on reductions in total N₂O emissions. Slow release, controlled release, and stabilized fertilizers have been shown to enhance crop recovery and reduce losses of N via drainage or atmospheric emissions. Their benefits in reducing N₂O emissions have been explored to a lesser degree. Recent evidence suggests they can be effective in reducing short-term emissions, but the effect on long-term losses is less clear. Studies are underway to better quantify these emissions and potential benefits.

Global Warming Potential of Intensive Cropping Systems

Although often considered a GHG source, in some conditions agriculture can also be a net sink for CO₂ and actually cause a net reduction in GWP. Adequate fertilization can contribute to the increase of SOM or slow its decline. Inadequate fertilization limits crop biomass production, and can result in less C returned to the soil, lower SOM, and potentially impaired long-term soil productivity.

Optimum N inputs are essential for supporting primary plant productivity and stabilization of SOM, upon which SOC storage depends. Combinations of fertilizer source, rate, timing and placement that optimize crop yields minimize the GWP of emissions per unit of production and reduce the need for conversion of natural lands to agriculture.

Intensive crop management practices to enhance nutrient uptake while achieving high yields can be a principal way to achieve reductions in GHG emissions from crop production. High-yielding crops can increase soil C storage. The following crop, soil, and fertilizer management factors help minimize net GWP: (1) choice of the right combination of adapted varieties or hybrids, planting date, and plant population to maximize crop biomass production; (2) use of tactical water and N management, including frequent N applications to achieve high N use efficiency with minimal opportunity for N₂O emissions; and (3) use of crop residue management approaches that favor a build-up of SOC, as a result of large amounts of crop residues returned to the soil.

Recent measurements show that the largest factors contributing to differences among cropping systems in net GWP

are linked to soil C change and N₂O emissions (**Table 1**). The same data show that increases in N fertilizer use do not always increase net GWP, and that intensive production systems using higher rates of N may have lower net GWP per unit of food production than low-input and organic production systems.

Sparing Natural Areas through Intensive Crop Production

An intensive production approach can result in more food produced per unit of land area. For example, the less intensive systems in MI required almost three times the land area as in the NE systems to achieve the same amount of corn production (**Table 1**). The importance of assessing cropping systems for their GWP per unit of productivity is underscored by the fact that for net GWP mitigation, land spared from production presents a greater opportunity (an example of cropland conversion to poplar forest is included in **Table 1**). Fertilizer best management practices (BMPs), and related practices which tend to enhance crop recovery of applied N, increase yield, and reduce the risk of GHG emissions include: appropriate N source, rate, timing and placement; application equipment calibration; crop-tillage-nutrient management system planning and evaluation; appropriate use of N conversion inhibitors (urease, nitrification) and enhanced efficiency sources; and consideration of site-specific soil and water conservation practices, since they may interact with other management practices and also serve as a secondary line of defense in limiting environmental nutrient losses.

Fertilizer Management Actions – Environmental Challenges and Opportunities

This review exposed many challenges in proper measurement of the combined effects of different cropping-tillage-nutrient management systems on GHG emissions. One critical challenge is the lack of simultaneous measurement of all three GHGs (CO₂, N₂O, and CH₄) over extended time periods in agronomic and environmental studies. It became apparent during this review that many studies report emissions of only one GHG, based on measurements only over a relatively short time span, often less than 30 days. This “snapshot” evaluation of GHG emissions limits the ability to accurately determine system-level crop and nutrient management effects on net GWP. Another short-coming exposed in this review is the inadequate sampling of SOC among tillage systems. Many studies soil sampled no deeper than the surface 15 cm, which results in imprecise and inaccurate measurement of the mass of C stored, due to differences in soil bulk density, rooting patterns, and rhizosphere biology.

There are many opportunities to expand our knowledge about the full environmental effects of proper nutrient management on reduced GHG emissions and GWP. Greater collaboration between agronomic and environmental scientists will be required in the future to achieve global food, fiber, and fuel production and environmental goals. Some of these collaborative research opportunities are identified in the conclusions of the paper and include: proper nutrient management for cellulosic (annual and perennial) biofuel crops; long-term evaluation of nutrient losses via leaching/drainage/runoff and simultaneous measurements of atmospheric emissions of CO₂, N₂O, and CH₄ for major world cropping-tillage systems; and

Table 1. Comparison of selected agricultural cropping systems for net GWP.

Cropping system			GWP in CO ₂ equivalents, kg/ha/yr					Mean crop yields, t/ha			Food yield ¹
Location	Rotation ⁴	Tillage	Soil C ⁵	N fert. production ⁶	Fuel	N ₂ O	Net GWP	Corn	Wheat	Soybean	Gcal/ha/yr
MI ²	C-S-W	CT	0	270	160	520	1,140	5.3	3.2	2.1	12
MI ²	C-S-W	NT	-1,100	270	120	560	140	5.6	3.1	2.4	13
MI ²	C-S-W low input with legume	CT	-400	90	200	600	630	4.5	2.6	2.7	12
MI ²	C-S-W organic with legume	CT	-290	0	190	560	410	3.3	1.6	2.7	9
NE ³	CC BMP	CT	-1,613	807	1,503	1173	1,980	14.0			48
NE ³	CC intensive	CT	-2,273	1,210	1,833	2090	3,080	15.0			51
NE ³	C-S BMP	CT	1,100	293	1,283	917	3,740	14.7		4.9	35
NE ³	C-S intensive	CT	-73	660	1,613	1247	3,740	15.6		5.0	37
MI ²	Cropland conversion to poplar forest	NT	-1,170	50	20	100	-1,050				

¹ Food energy calculated from crop yields and USDA national nutrient database <http://riley.nal.usda.gov/NDL/index.html>

² Rainfed cropping system (Robertson et al., 2000)

³ Irrigated cropping system (Adviento-Borbe et al., 2007)

⁴ C-S-W = corn - soybean - wheat; CC = continuous corn

⁵ Estimates of net soil C storage are based on changes in soil C measured to a depth of 7.5 cm in the MI study and 30 cm in the NE study. Shallower sampling depths tend to upwardly bias the C sequestration estimates in no-till systems.

⁶ GWP for manufacture and transport of fertilizer N was assumed to be 4.51 and 4.05 kg CO₂/kg N in the MI and NE studies, respectively.

large plot or field-scale studies of crop N sensing and variable rate and/or variable N source application evaluations to include environmental loss and emissions measurements.

Significant conclusions from this review include:

- 1) appropriate fertilizer N use helps increase biomass production necessary to help restore and maintain SOC levels;
- 2) BMPs for fertilizer N play a large role in minimizing residual soil NO₃⁻, which helps lower the risk of increased N₂O emissions;
- 3) tillage practices that maintain crop residue on the soil surface can increase SOC levels, but usually only if crop productivity is maintained or increased;
- 4) differences among fertilizer N sources in N₂O emissions depend on site- and weather-specific conditions; and
- 5) intensive crop management systems do not necessarily increase GHG emissions per unit of crop or food production; they can help spare natural areas from conversion to cropland and allow conversion of selected lands to forests for GHG mitigation, while supplying the world's need for food, fiber, and biofuel.

Short-term, a greater emphasis is needed in educating agricultural practitioners about: 1) the basic principles of productive, sustainable cropping system management; 2) pathways of nutrient loss to air and water resources; 3) opportunities to mitigate GHG emissions through existing and promising fertilizer BMPs which address loss pathways; and 4) greater dialogue between agronomic scientists and environmental scientists, which encourages mutual understanding and col-

laboration, to avoid polarization and adversarial relationships on GHG emissions and other environmental issues. The GHG emissions issue increases the need for a high level of management applied to the use of fertilizers in cropping systems. As with all fertilizer BMPs, those selected need to be evaluated in the context of mitigation of all GHG emissions from the full cropping system. **BC**

Dr. Snyder (e-mail: csnyder@ipni.net) is IPNI Nitrogen Program Director, Dr. Bruulsema is IPNI Northeast Region Director, and Dr. Jensen is IPNI Northern Great Plains Region Director.

References

- Adviento-Borbe, M.A.A., et al. 2007. Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. *Global Change Biology* 13 (9): 1972–1988. doi:10.1111/j.1365-2486.2007.01421.x
- Roberts, T.L. 2007. Right product, right rate, right time and right place...the foundation of best management practices for fertilizer. pp 29-32. *Fertilizer Best Management Practices. General Principles, Strategy for Their Adoption, and Voluntary Initiatives vs Regulations. Proc. of IFA International Workshop 7-9 March 2007. Brussels, Belgium. International Fertilizer Industry Association. Paris, France.*
- Robertson, G.P., et al. 2000. Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. *Science* 289:1922–1925.
- USEPA. 2007. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2005. EPA 430-R-07-002. U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., N.W. Washington, DC 20460.