Forecasting the Contribution of Nitrogen Fertilizer to Greenhouse Gas Emissions from Corn Production

Tom Bruulsema
Northeast Director
North American Program
Guelph, Ontario, Canada
Tom.Bruulsema@ipni.net
(519) 821-5519

INTERNATIONAL PLANT NUTRITION INSTITUTE

ABSTRACT

- Current trends in North American corn production show an increasing trend in use efficiency of nitrogen fertilizers. As yields continue to improve, there is potential for increased return of crop root and residue carbon to the soil. If future management can reduce losses of nitrous oxide, and if efficiency of nitrogen fertilizer production can continue to improve, large changes in the net greenhouse gas balance of agriculture could be effected. This paper will outline the technology available and the research needed for ecological intensification to meet society's future needs for food, fuel and fiber while protecting the environment.

INTRODUCTION

- A continuing challenge in managing N is to predict the most economic rate (**MERN**) to apply. Owing to unpredictable variability, rates somewhat above MERN are often applied as production insurance. Continuing refinement of recommendation methods accounts for more of the factors controlling MERN. The combination of increasing energy efficiency of N fertilizer manufacture, increasing corn yields and improved N recommendations may reduce the greenhouse gas impact associated with N use on corn.

TRENDS

- **Past Improvements: Figure 1** illustrates that the ratio of N removed in corn harvest over that applied as fertilizer has improved in a linear manner since 1970. Projecting this trend forward indicates that inputs and outputs may balance sometime beyond 2030.
- **Improving Manufacturing Efficiency: Figure 2** illustrates that as facilities are modernized, CO_2 emissions per unit of N produced decline. Combining gains in both manufacturing and field N use efficiencies, the reduction in emission per unit of corn grain produced could decline by half between today and 2030 (**Figure 3**). Increasing use of coal gasification, however, could reverse this improvement.
- **Nitrous oxide emission** is and will continue to be the largest greenhouse gas impact associated with N use on corn, as illustrated in **Figure 4**.

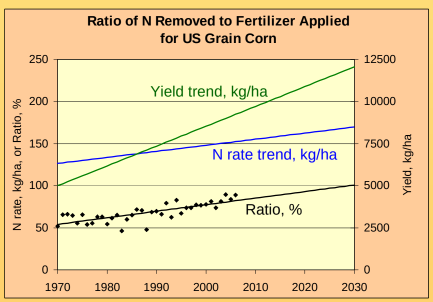

Figure 1. Ratio of N removed to fertilizer applied, for grain corn grown in the United States. Data sources: USDA-NASS Crop Production Summary, USDA-NASS-ERS Agricultural Chemical Use Survey, Fertilizer and Price Statistics, Statistical Bulletin 780. Removal assumes N content of 13 g per kg corn.

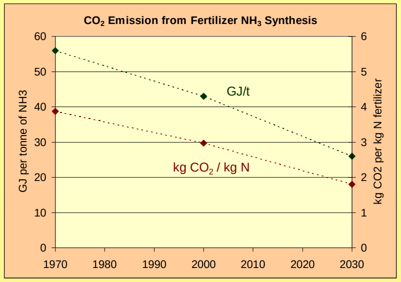

Figure 2. Estimated trend in emission of CO_2 associated with global manufacture of N fertilizers. Energy (GJ/t) requirements adapted from global average efficiencies reported in Smil (2001) and assume that industry average moves to current best achievable by 2030. Emissions of CO_2 calculated from stoichiometry reported in USEPA (2006) and Smil (2001).

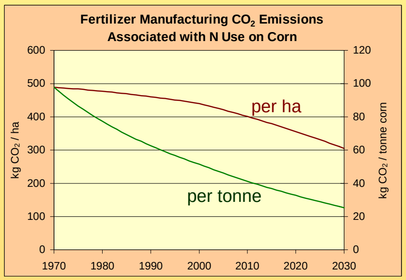

Figure 3. Trends in emissions of carbon dioxide resulting from ammonia manufacturing for the nitrogen used in corn grain production, based on trends from Fig. 1 & 2.

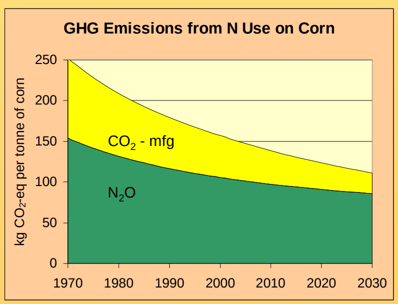

Figure 4. Trends in emissions of greenhouse gases resulting from nitrogen used in corn production, including both ammonia manufacturing and N_2O emission. Emission of N_2O estimated as 1.25% of N fertilizer use, with CO_2 equivalence of 310.

CASE STUDY METHODS – Ontario, Canada

- 109 on-farm trials measuring corn response to N; conducted between 2001 and 2005.
- Previous crops were: Soybeans – 60; Wheat – 31; Maize – 12; Misc. – 6.
- Experiments had a minimum of four different N rates, and at least 8 plots.
- Most on-farm trials used strips the full length of the field.
- Response curves were fit using a **Crop Nutrient Response Tool** (IPNI, 2006) to determine site-specific optimum rates (MERN; Most Economic Rate of N).
- Using the mean of four fitted curves, weighted by the R^2 of the fit, the following attributes were calculated for each site-year:
  - MERN, yield, response and removal N recovery efficiencies, and postharvest C:N ratios (see Table 1).

Table 1. Economic and environmental aspects of N use in Ontario corn production, as a function of N rate recommendation scenarios. Based on N response curves obtained from experiments at 109 site-years conducted between 2001 and 2005.

Recommendation Scenario	N rate (mean)	Grain Yield (mean)	Response N recovery[1]	Removal N recovery[2]	Postharvest C:N[3]	Postharvest C:N > 30[4]	N-related GHG balance: C storage[5]	Mfg. & N_2O[6]	Net
	kg/ha	kg/ha	%	%	ratio	%	kg CO_2/ha		
CURRENT - High[7]	157	8710	37%	76%	26	30%	154	-1038	-884
CURRENT - Low[7]	134	8645	42%	87%	31	51%	223	-889	-666
ONC[8]	120	8580	45%	94%	33	63%	250	-797	-547
MERN[9]	106	8661	49%	106%	43	73%	226	-701	-476
MERN - 2030[10]	119	11311	57%	124%	51	77%	266	-784	-518

[1](N uptake at rate applied - N uptake with zero applied) divided by rate applied
[2]N in grain divided by N applied
[3]Postharvest C:N = C in corn stover divided by (N in stover plus surplus N). Surplus N = N uptake with zero applied + N applied - N removal.
[4]percent of site-years with postharvest C:N greater than 30. Where C:N is less than 30, it is assumed that no N participates in soil C storage.
[5]soil C storage, assuming that, at sites with C:N>30, 10% of the residual N stabilizes C from corn stover at a C:N ratio of 10:1
[6]CO_2-equivalent of greenhouse gas emissions from ammonia manufacturing and nitrous oxide losses (from Figures 3 & 4)
[7]Current N rate range, based on a December 2006 Canadian Fertilizer Institute survey conducted by Ipsos-Reid. Site-year specific rates assumed proportional to ONC recommendation.
[8]Ontario Nitrogen Calculator = official recommended rate based on yield goal, price ratio, preceding crop, soil and climate factors
[9]post-hoc most economic rate of N for price ratio of 6 kg corn per kg of N fertilizer
[10]MERN scenario projected to the year 2030 using N rate and grain yield trends identified in Figure 1

NITROGEN RESPONSES (TABLE 1)

- **Recovery Efficiencies:**
  - **Response:** With current practices, 37 to 45 percent of applied N is taken up into the crop. This improves to 49 percent if MERN could be accurately predicted. Its increase to 57% in 2030 would depend on improvements in both management and genetics.
  - **Removal:** With current practices, 76 to 94 percent as much N as applied is removed by grain harvest. The greater values for removal compared to response indicate substantial soil residual or mineralized N contributing to corn nutrition. Removals above 100% associated with MERN scenarios imply a net loss of N from the soil-crop system.
- **Post-harvest C:N Ratio:** this ratio is increased by higher yields of crop residue and by lower amounts of residual N. Harvest indexes assumed were 47% for C and 73% for N. When C:N ratios are less than 30, mineralization commences without delay and is assumed to be complete (no formation of new organic matter, no C storage). For higher C:N ratios, it is assumed that stabilized organic matter is formed, and that 10% of available N stabilizes with available C resulting in new soil organic matter with a C:N ratio of 10. The role of N in soil organic C stabilization is described in Paustian et al., 1997.

CONCLUSIONS

- **Greenhouse Gas (GHG) Balance:** The data suggest that the amount of N that participates in soil C storage may increase somewhat as N rates applied diminish. At MERN, however, soil C storage may become N-limited.
- Net GHG emission per unit cropped area may increase by 2030, but projected higher yields imply a 17% reduction per unit of corn grain produced. A fraction of residual N greater than 10% would need to participate in soil C storage to balance GHG emissions associated with manufacturing ammonia and nitrous oxide.

TECHNOLOGY AND RESEARCH

- **Technologies Available:** urease and nitrification inhibitors, placement, timing, improved prediction of weather and soil water movement.
- **Research Needed:**
  - Specific products, placement and timing to reduce nitrous oxide emissions.
  - Plant breeding, genetic engineering to further improve yield and N recovery efficiency.
  - Methods to reduce post-harvest soil residual N and thus increase response recovery efficiency.

ACKNOWLEDGMENT

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