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PAGES 529–540

Estimating Agricultural Nitrous Oxide Emissions

PAGE 529

Emissions of nitrous oxide (N_2O), a potent greenhouse gas, tend to be underestimated by standard methods of quantification provided by the Intergovernmental Panel on Climate Change (IPCC) [*IPCC*, 2006], recent research suggests. Better quantification of agricultural N_2O emissions improves greenhouse gas inventories, allows for better evaluation of the environmental impacts of different cropping systems, and increases the understanding of the nitrogen (N) cycle in general. Proper quantification of N_2O emissions is particularly important in the context of calculating net greenhouse gas emissions from biofuel cropping systems because these emissions offset the greenhouse gas benefits of displacing fossil fuel and can even lead to biofuel systems being a net greenhouse gas source [*Crutzen et al.*, 2008].

The global warming potential of N_2O is approximately 300 times that of carbon dioxide, and N_2O emissions represent approximately 6% of the global anthropogenic greenhouse gas source [*IPCC*, 2007]. N_2O also contributes to stratospheric ozone destruction. N_2O is produced in soils through the microbial processes of nitrification and denitrification. Soil water content, temperature, texture, and carbon availability influence N_2O emissions, but the strongest correlate is usually N inputs to the system, especially at large scales [*Stehfest and Bouwman*, 2006]. In addition to direct emissions, N inputs to agricultural soils also contribute to N_2O emissions indirectly [*IPCC*, 2006] when nitrate that has leached or run off from soil is converted to N_2O via aquatic denitrification and when volatilized non-N_2O N-oxides and ammonia are redeposited on soils and converted to N_2O.

Two general methods used to estimate soil N_2O emissions can be broadly considered as either (1) bottom-up approaches based on soil surface gas flux measurements or models based on soil application of N, or (2) top-down approaches based on changes in atmospheric concentration of N_2O and estimates of sink strength. The bottom-up approaches considered in this article are (1) the *IPCC* [2006] methodology, (2) DAYCENT (daily century) ecosystem model estimates of direct N_2O emissions, and (3) field-scale estimates based on soil surface gas flux measurements.

The method of *IPCC* [2006], which is the most common bottom-up method used to estimate N_2O emissions for national inventories, is based on soil surface gas flux measurements from numerous global sites. Emissions are assumed to be proportional to soil N inputs from various sources (Table 1). This method also accounts for emissions from burning crop biomass and from N transformations occurring in manure management systems. The DAYCENT model is an example of a more sophisticated bottom-up approach. In addition to N inputs, DAYCENT accounts for the influence of other factors (water, temperature, O_2 and labile C availability, and plant N demand) that influence direct soil N_2O emissions [*Del Grosso et al.*, 2006], and model predictions are evaluated based on soil surface flux measurements. In contrast, the top-down approach considered here infers anthropogenic N_2O emissions from changes in atmospheric N_2O concentration and N_2O removal rates [*Crutzen et al.*, 2008].

Do Approaches for N_2O Estimates Agree at National and Global Scales?

To address how closely top-down and bottom-up approaches for N_2O estimates agree at national and global scales, we calculated N_2O emissions from agricultural systems in the United States and for the entire globe using bottom-up approaches, and we compared these results with the range of N_2O emissions estimated using the top-down approach [*Crutzen et al.*, 2008]. As suggested by *Crutzen et al.* [2008], we multiplied N inputs from symbiotic N fixation and synthetic fertilizer production by 3% and 5% to calculate the range of emissions based on the global top-down approach. For the U.S. national greenhouse gas inventory, N_2O emissions are based on DAYCENT model simulations for major crops and grasslands and on the *IPCC* [2006] methodology for other crops, manure management systems, and indirect emissions [*U.S. Environmental Protection Agency (EPA)*, 2008]. DAYCENT results

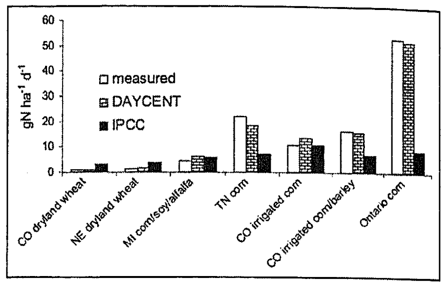

Fig. 1. Mean daily direct soil N_2O emission measurements compared with estimates using the DAYCENT (daily century) ecosystem model and the IPCC [2006] methodology. CO is Colorado, NE is Nebraska, MI is Michigan, and TN is Tennessee.

for N volatilization and N leached/runoff were combined with *IPCC* [2006] methodology to estimate indirect N_2O emissions. The N_2O emission from agricultural systems in the United States for 2005, obtained using the bottom-up approaches, is 0.9 teragram N (Table 1), which is within the range of 0.8–1.4 teragrams N based on the top-down approach.

Using the *IPCC* [2006] methodology, we found that approximately 5.8 teragrams of N from N_2O currently are emitted from agricultural systems at the global scale (Table 1). This is close to the middle of the range (4.2–7.0 teragrams) based on the top-down approach. We conclude that on sufficiently large scales, top-down and bottom-up approaches used to calculate N_2O emissions from agricultural systems yield similar estimates. We emphasize that the emission factor for the global top-down approach (3–5% of N inputs from symbiotic N fixation and synthetic fertilizer production) cannot be compared directly with the emissions factors used in the *IPCC* [2006] method because the methods consider different sources of N inputs.

Do Different Methods for Estimating N_2O Emissions Agree at the Field Scale?

To analyze how closely different methods for estimating N_2O emissions agree at the field scale, we compared DAYCENT and *IPCC* [2006] methodologies with soil N_2O emissions measurements from different agricultural systems in the United States and Canada [*Del Grosso et al.*, 2005]. The global top-down approach was not considered here because it estimates total N_2O emissions (direct plus indirect), whereas field-level measurements only include direct soil emissions. The process-

BY S. J. DEL GROSSO, T. WIRTH, S. M. OGLE AND W. J. PARTON

Table 1. Global and U.S. N_2O Sources and Emissions for Agriculture[a]

Region	N Sources (teragrams N)					N_2O Emissions (teragrams N)						
	Synthetic Fertilizer	Symbiotic N Fixation	Grazing Animal Manure	Managed Manure	Crop Residue	Soil Direct	Soil Indirect	Residue Burning	Cropped/ Grazed Organic Soils	Managed Manure	Total Bottom-up	Total Top-Down
United States	10.4	16.8	3.7	3.0	5.2	0.68	0.15	0.00	0.01	0.03	0.9	0.8–1.4
Globe[b]	88.0	53.0	97.5	63.1	30.7	3.77	0.76	0.70	0.10	0.43	5.8	4.2–7.0

[a]Global calculations are based on *IPCC* [2006] methodology, and U.S. calculations combine DAYCENT model simulations and *IPCC* [2006] methodology [*U.S. Environmental Protection Agency (EPA)*, 2008]. Top-down emissions are based on *Crutzen et al.* [2008].
[b]Global N sources are from *EPA* [2006], *Mosier et al.* [1998], and United Nations Food and Agriculture Organization (http://faostat.fao.org/site/567/default.aspx).

based DAYCENT model yielded estimates closer to measured values than *IPCC* [2006] methodology at most of the sites tested (Figure 1). This is not surprising because DAYCENT accounts for variability in spatial and temporal factors (weather, soil type, plant N demand, and so forth) not included in the *IPCC* [2006] methodology. Although DAYCENT results show good agreement with mean flux rates from different fields (Figure 1), model errors are often large when compared with a time series of daily flux measurements for a particular plot within a field (data not shown). Thus, future work is needed to improve DAYCENT model performance at small spatial and temporal scales of individual plots.

Top-Down and Bottom-Up Methods Converge at Large Scales

N_2O emissions are highly variable in space and time, and different methodologies have not agreed closely, especially at small scales. However, as scale increases, so does the agreement between estimates based on soil surface measurements (bottom-up approach) and estimates derived from changes in atmospheric concentration of N_2O (top-down approach). Indeed, the convergence of top-down and bottom-up approaches increases confidence in emissions estimates because the methods are based on different assumptions, and this convergence suggests that we have at least a rudimentary understanding of the factors that control emissions at large spatial and temporal scales.

But simple bottom-up approaches based solely on N additions are not reliable for discerning the smaller-scale temporal and spatial patterns of emissions; and top-down approaches, as currently applied, are also not expected to be applicable at small spatial and temporal scales because the density of atmospheric N_2O measurements does not allow attribution of emissions to finer scales. Thus, these approaches are not expected to reliably identify hot spots and time periods of emissions from individual fields, including fields used for biofuel feedstock production, where and when mitigation efforts could be targeted by recommending alternative cropping practices to farmers managing those lands. However, bottom-up models, such as the DAYCENT model, that include more of the processes controlling emissions besides N additions often show reasonably good agreement with field-scale data. Consequently, these models provide a viable approach for estimating soil N_2O emissions at field scales, identifying hot spots of N_2O emissions, and fostering the development of mitigation strategies for agricultural emissions.

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Author Information

Stephen J. Del Grosso, Soil Plant Nutrient Research Unit, Agricultural Research Service, U.S. Department of Agriculture, Fort Collins, Colo., and Natural Resource Ecology Laboratory, Colorado State University, Fort Collins; E-mail: delgro@nrel.colostate.edu; Tom Wirth, Climate Change Division, U.S. Environmental Protection Agency, Washington, D. C.; and Stephen M. Ogle and William J. Parton, Natural Resource Ecology Laboratory, Colorado State University