# Bias in IPCC Methodologies for Assessment of $N_2O$ Emissions and $N_3O$ Leaching from Crop Residue*


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## Abstract

Studies from around the world (20+) conducted with precise $^{15}N$ techniques that trace the fate of N found that an average of 66% of the fertilizer was recovered in crops and soils. In other words, 34% of the added N was lost from the cropping systems. There are no extensive $^{15}N$ recovery data tracing the fate of organic N from crop residues after a year of crop residue incorporation. Four rotations using the Delgado et al. (2004) large $^{15}N$ cover crop residue exchange design resulted in an average recovery of 87% of the organic N from crop residues in soil and plants. The average losses from organic N added with crop residue were about 13%, much lower than the 32% N lost from inorganic N fertilizer in these four cropping systems. Additionally, we conducted DAYCENT evaluations on the effects of adding or removing crop residue on $N_2O$ emissions and nitrate ($NO_3$-N) leaching. We used these $^{15}N$ findings and DAYCENT simulations to evaluate the accuracy of the methodologies currently used by the Intergovernmental Panel on Climate Change (IPCC). The current approach for measuring $N_2O$-N emissions, $NO_3$-N leaching and indirect $N_2O$-N emissions from $NO_3$-N leaching does not reflect the relatively higher N losses from inorganic N fertilizer compared to the lower N losses from the much slower decomposition of the organic crop N residue pool. Default IPCC methodology uses the same $N_2O$ emission factor (1%) and 30% $NO_3$-N leaching losses for N from crop residues, as for N from applied fertilizer. These unique $^{15}N$ crop residue exchange studies and our DAYCENT simulation evaluations support the suggestion that the current IPCC methodology should be changed by lowering the $N_2O$-N emission and $NO_3$-N leaching losses coefficients in order to reflect lower $N_2O$-N emissions and leaching from crop residue N inputs when compared to N fertilizer.


## Introduction

Several scientists have reported that excessive N inputs in cropland increase N losses, which impact groundwater, large water bodies and air quality, and contribute to Global Warming Potential. Better assessment of N cycling and the mechanisms used to reduce N losses will help increase N use efficiencies and reduce N losses to the environment. Management practices can be used to better synchronize N inputs with crop uptake and reduce nitrate leaching while mitigating $N_2O$-N and other N-gas emissions. Global concentrations of $N_2O$-N have been increasing at a faster rate in the last three decades (Houghton et al. 1992; Eggleston et al. 2006), and agriculture is responsible for a significant percentage of all anthropogenic emissions of $N_2O$-N. It is very important that we improve N management because N inputs from crop residues and fertilizers account for a large proportion of greenhouse gas emissions ($N_2O$-N) from croplands soils; for example, over 30% of N2O-N emissions in the United States are associated with sources of N (U.S. EPA 2008).

The IPCC has recommended accounting for the fertilizer-N, manure-N, crop residue-N inputs, and N released via mineralization associated with soil organic matter losses (mineralization-N) when assessing direct and indirect emissions of $N_2O$-N (Eggleston et al. 2006). The IPCC's methodology assumes that 1% of fertilizer-N, crop residue-N, manure-N, and mineralization-N added to cropland are emitted to the atmosphere as direct emissions of $N_2O$-N. This methodology also assumes that 30% of the fertilizer N from these sources is leached and/or lost in runoff of water to streams and rivers, and 0.75% of this N is indirectly emitted as $N_2O$-N beyond the original site of the N additions (Eggleston et al. 2006; De Klein et al. 2006). In addition, it assumes that 10% of the fertilizer and 20% of the manure N applied to agricultural fields is lost through $NH_3$-N volatilization and $NO_x$-N emissions, and about 1.0% of this N is later emitted as $N_2O$-N. These methods have broad implications for domestic and international policy because countries use these approaches for reporting agricultural emissions of $N_2O$-N to the United Nations Framework Convention on Climate Change (UNFCCC).

Meisinger and Delgado (2002) reported that average leaching losses typically range from 10 to 30% of the total N input, in agreement with IPCC reports; however, they differentiated from IPCC assumptions in that they reported that crop residue cycling will contribute to lower nitrate leaching losses. They reported that adding a leguminous crop to a rotation and cover crops will reduce $NO_3$-N leaching losses. Al-Sheikh et al. (2005) reported that cover crop systems contributed to the sequestration of N. Cover crops could recover and reduce $NO_3$-N leaching from previous and subsequent crops including the mining of $NO_3$-N from groundwater (Delgado 1998). This is in agreement with Delgado and Follett (2002) that reported that systems that increase soil organic matter accumulation and carbon sequestration and improve N management with N sinks will reduce $NO_3$-N leaching losses to the environment. The IPCC does not account for the positive effects of crop rotations and assigns the same $NO_3$-N leaching coefficient to N from fertilizer and crop residue.

We analyzed data from several $^{15}N$ studies and we conducted DAYCENT evaluations on the effects of adding or removing crop residue on $N_2O$ emissions and $NO_3$-N leaching. We used these $^{15}N$ findings and DAYCENT simulations to evaluate the accuracy of the methodologies currently used by the IPCC.

## Methods

***$^{15}N$ Methodologies Used for Crop Residue Studies*:** Delgado et al. (2004) described the procedure for monitoring the N inputs and cycling from crop residues using unique large $^{15}N$ plot studies in Colorado (Delgado et al. 2004) and Washington (Collins et al. 2007). For additional details about $^{15}N$ studies see Delgado et al. (2004) and Collins et al. (2007). At each site the aboveground $^{15}N$-labeled crop residue was exchanged with the unlabeled residue following harvest of the $^{15}N$-labeled cover crops (**Figure 1**). Potato (*Solanum tuberosum* L.) crops were planted following the cover crops in Colorado and Washington. At harvest, potato and soil samples were collected and analyzed for $^{15}N$. Soil samples were extracted using 2N KCl and extracts and were analyzed for $NO_3$-N and $NH_4$-N with colorimetric analysis by a Technicon©1 auto-analyzer. Plant and soil material were analyzed for total N and $^{15}N$ atom % using a Carlo-Erba automated C/N analyzer coupled with a VG-903 mass spectrometer.

***Modeling:*** A selected unique set of studies conducted across the USA where $N_2O$ emissions were monitored were used to test the accuracy of the DAYCENT model (for details about simulated sites, see Delgado et al. Nutr Cycl Agroecosyst DOI 10.1007/s10705-009-9300-9). The management, weather and soil data from each of these studies were used to conduct DAYCENT model simulation of $N_2O$ emissions and to correlate the simulated versus measured values (**Figure 2**). Since the model simulation values were correlated to the measured values we used the DAYCENT model to assess the effects of N fertilizer and crop residue inputs in $N_2O$ emissions.

To test the effect of crop residue and/or fertilizer on $N_2O$ emissions we used the DAYCENT model to conduct a simulation of: 1) dryland wheat (*Triticum aestivum* L.)-fallow rotation from northeastern Colorado; 2) corn (*Zea mays* L.)-corn rotation from central Iowa and 3) corn-soybean (*Glycine max*) rotation from central Iowa. Conventional farmer management practices and local weather data were used from each site (Del Grosso et al. 2008b, EPA 2008). The soil type in Iowa was a loam and in Colorado it was a sandy loam. Evaluations of the model scenarios to determine the effects of N fertilizer and crop residue on $N_2O$ emissions were conducted with a decade of traditional management practices and site-specific weather. For Colorado, the site history was wheat/fallow (WF) with 70 kg N $ha^{-1}$ added every other year and no residue harvested. For Iowa, the site history was assumed to be a corn/corn (CC) rotation and a corn/soybean (CS) rotation. The N fertilizer applied was 150 kg N $ha^{-1}$ added every year to the CC and every other year to CS. For these simulations the N content in the crop residue removed was equivalent to about 40 and 20 kg N $ha^{-1}$ for corn and wheat, respectively.

The N fertilizer removed from the dryland WF rotation was 20 kg N $ha^{-1}$ during the wheat year. Similarly, 40 kg N $ha^{-1}$ annually was removed for the CC rotation and every other year from the CS rotation.

Since a leguminous crop is not fertilized and the soybean residue is traditionally left in the field, we kept the legume residue in the field for the corn-soybean simulation. The crop residue scenarios simulated were: 1) aboveground crop residue kept in the field for the WF, CC and CS rotations (residue retained); 2) removing aboveground corn and wheat residue for the WF, CC and CS rotations (residue removed); and 3) aboveground crop residue kept in the field but removing a similar amount of N from the fertilizer input for the fertilized corn and wheat for WF, CC and CS rotations (residue retained, decreased fertilizer).

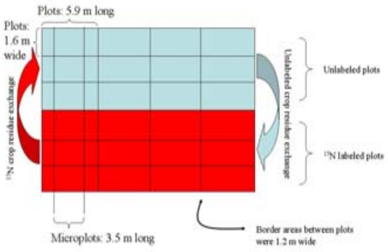


**Figure 1**. Plot layout for the $^{15}N$ crop residue exchange study (*Delgado, et al., 2004*).

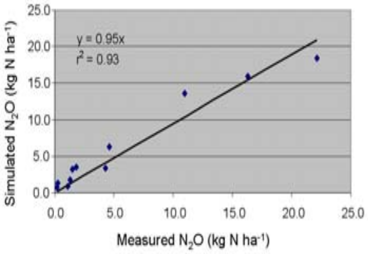


**Figure 2**. DAYCENT-simulated versus measured $N_2O$ emissions at different field sites that were used to test the model .

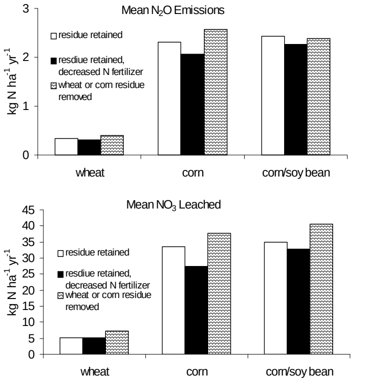


**Figure 3**. Mean Nitrous Oxide ($N_2O$) and nitrate leaching ($NO_3$-N) from a 10 year site-specific simulation of a dryland wheat – fallow rotation in Colorado (wheat); corn-corn rotation in Ohio (corn) and a corn-soybean rotation in Ohio (soy). The simulated scenarios were: 1) aboveground crop residue kept in the field (residue retained); 2) removing aboveground crop residue (residue removed); and 3) aboveground crop residue kept in the field but removal of a similar amount of N from the fertilizer input (residue retained, decreased fertilizer).

Table 1. $^{15}N$ applications, recoveries and losses in irrigated cover crop studies.

| Location | Crop | N Source | Applied $^{15}N$ (Kg N $ha^{-1}$) | Soil Recovery | Plant Recovery | Lost |
|---|---|---|---|---|---|---|
| | | | | ------ | % $^{15}N$ | ------ |
| Colorado | [1]Wheat | Fertilizer | 95 | 27 | 47 | 26 |
| | [2]Potato | Wheat Residue | 37 | 79 | 7 | 14 |
| Colorado | [1]Wheat | Fertilizer | 95 | 25 | 49 | 26 |
| | [2]Potato | Wheat Residue | 41 | 79 | 6 | 15 |
| Colorado | [1]Barley | Fertilizer | 95 | 28 | 40 | 32 |
| | [2]Potato | Barley Residue | 35 | 69 | 13 | 18 |
| Washington | Mustard | Fertilizer | 56 | 24 | 34 | 42 |
| | [3]Potato | Mustard Residue | 142 | 66 | 30 | 5 |
| *Average* | | Fertilizer | | 26 ± 2 | 43 ± 7 | 32 ± 8 |
| | | Crop Residue | | 73 ± 7 | 14 ± 11 | 13 ± 6 |

[1] Received an additional 28 kg unlabelled fertilizer-N $ha^{-1}$
[2] Received 135 kg unlabelled fertilizer-N $ha^{-1}$
[3] Received 375 kg unlabelled fertilizer-N $ha^{-1}$

## Summary and Conclusions

The $^{15}N$ analysis presented in **Table 1** and $N_2O$ simulations in **Figure 3** are in agreement with several recent papers that studied the effects of crop residues on $N_2O$-N emissions (Malhi and Lemke 2007; Toma and Hatano 2007). These data sets suggest that the IPCC's $N_2O$-N emission assessment methodology should be reevaluated, because there are differences in N use efficiencies of the crops (recoveries in soil and plant) between N fertilizer and crop N residue inputs, and consequently the methods should use different $N_2O$-N emission coefficients for inputs from the readily available inorganic N fertilizer and from the slower, microbe-dependent crop residue N inputs (**Table 1, Figure 3**). Accounting for these differences in N cycling within soils has far-reaching consequences for $N_2O$-N emission inventories reported by countries, including established baselines and meeting mitigation commitments agreed upon through the climate change convention. We suggest that the leaching losses from crop residues will be lower than those from fertilizers; thus, the indirect $N_2O$-N emission from crop residue will also be lower.

The data presented in **Table 1 and Figure 3** suggest that the IPCC crop residue $N_2O$-N emissions and $NO_3$-N leaching coefficients should be lowered (Delgado and Follett, 2002). Analysis of these $^{15}N$ crop residue studies and simulated crop residue scenarios, especially those for high C/N crop rotations such as wheat and corn, suggests that the national inventories submitted to the UNFCCC may be overestimating the effect of N inputs from crop residues on direct and indirect $N_2O$-N emissions relative to mineral N fertilization, based on the IPCC methods and default coefficients (Eggleston et al. 2006; De Klein et al. 2006). In turn, this overestimation will lead to policy which does not properly address the direct and indirect source of the $N_2O$-N emissions, and mitigation efforts that do not produce the results suggested by emission calculations conducted using the IPCC method. Such accounting of emissions would not be desirable as countries deal with the growing $N_2O$-N emissions associated with mineral N fertilization in agricultural lands, and attempt to reduce anthropogenic impacts on the Earth's climate system. Use of N cycling such as those from cover crops and deep rooted systems may be an alternative method to reducing direct and indirect N losses to the environment while increasing N use efficiencies (Delgado 1998; Delgado et al. 2001; Delgado et al 2004; Collins et al 2007; Delgado et al 2008). There is a need for additional nutrient cycling research and this research could affect policies of the United Nations and individual countries that relate to our biosphere as far as the accountability of trace gases such as $N_2O$-N.

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**** From Delgado et al. Nutr Cycl Agroecosyst DOI 10.1007/s10705-009-9300-9***