Update of Direct N_2O Emission Factors from Nitrogen Fertilizers in Cornfields in GREET® 2019

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Background

Corn farming requires intensive nitrogen fertilizer input. When applied in cornfield, a portion of nitrogen fertilizers is directly converted to nitrous oxide (N_2O) through the soil microbial processes of nitrification and denitrification and released to the atmosphere. In addition to direct N_2O emissions, N_2O emissions can also be produced through indirect processes including volatilization of nitrogen fertilizers and leaching and runoff of nitrate from the fertilizers. In 2012, Argonne National Laboratory estimated a direct nitrogen fertilizer-induced emission factor (hereafter direct N_2O EF) of 1.2% through literature review (Wang et al. 2012). Since then, according to Web of Science, about 263 new studies on this topic have been published. This technical memorandum documents a new update aiming to expand the previous literature review with new studies to reflect recent empirical evidences of nitrogen fertilizer-induced N_2O emissions. This update focuses on direct N_2O EF for major cornfields in the United States (US). On the other hand, we continue to adopt the indirect N_2O EF according to the Intergovernmental Panel on Climate Change guideline (IPCC 2006) (Eq.1). IPCC (2006) estimates a volatilization rate for soil nitrogen of 10% and emission factor for N_2O from atmospheric deposition of N volatilized from managed soils is 1%. The leaching and runoff rate of soil nitrogen in the form of nitrate is estimated to be 30% and the conversion rate of leached and runoff nitrogen to N_2O emissions is 0.75%. Thus, the indirect N_2O EF is estimated to be 0.325% (10% × 1% + 30% × 0.75%). We add this indirect N_2O emission factor to the direct one that is documented in this memo to estimate N_2O EF for cornfield. As a result, total fertilizer-induced N_2O emissions associated with corn farming are calculated as the product of N fertilizer input rates and the direct and indirect N_2O EFs (Eq.1).

$$N_2O - N = F_{SN} * EF_{direct} + F_{SN} * (Frac_{vol} EF_{vol} + Frac_{leach} * EF_{leach}) \qquad \text{(Eq.1)}$$

Where:

N_2O-N = fertilizer-induced N_2O emissions, kg N_2O-N yr^{-1}

F_{SN} = amount of synthetic fertilizer N applied to soils, kg N yr^{-1}

EF_{direct} = direct N_2O EF

$Frac_{vol}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, 10% (uncertainty range of 3 – 30%)

EF_{vol} = indirect N_2O EF for atmospheric deposition of N on soils and water surfaces, 1% (0.2 – 5%)

$Frac_{leach}$= fraction of synthetic fertilizer N that is lost through leaching and runoff, 30% (10 – 80%)

EF_{leach} = indirect N_2O EF from N leaching and runoff, 0.75% (0.05 – 2.5%)

Data and methods

We expanded our 2012 database through a meta-analysis of literature regarding N_2O emissions from corn farms in the US. Literature review covers US-based studies published between 1990 and 2019 to update direct N_2O EFs in the GREET model. Specifically, we searched published journal articles through querying Web of Science Core Collection database, using keywords listed in Table 1. In addition, selection was limited to Science Citation Index and Social Science Citation Index papers, and the region of studies was constrained to the US. With this, 263 journal articles meeting the search criteria were identified. Individual publications were then screened based three criteria: (1) studies must be field experiments, not laboratory incubation studies or modeling-based analysis, (2) corn must be the major crop, and (3) N_2O emissions for both control (no nitrogen fertilizer input) and treatment (with synthetic nitrogen fertilizers) plots must be measured.

Table 1. Key words used in Web of Science search

Crop Key words	Logical Operator	N_2O keywords	Logical Operator	Fertilizer keywords
Corn	**AND**	N_2O	**AND**	fertilizer
OR "Maize"		**OR** "Nitrous oxide"		**OR** "Urea"
OR "Zea mays"		**OR** "dinitrogen monoxide"		**OR** "Anhydrous ammonia"
				OR "UAN"
				OR "urea ammonium nitrate"
				OR "ammonium nitrate"
				OR "Nitric acid"

The screening process further identified 42 eligible studies that cover 27 unique experiment sites spanning across 13 states in the US. In total, the expanded database includes 318 experimental comparisons, and about 53% (164) data points are from studies conducted in nine Midwestern states (Illinois, Indiana, Iowa, Minnesota, Nebraska, Ohio, Michigan, South Dakota, and Wisconsin)(blue line in Fig. 1), which account for 75% of US total corn production (USDA 2019). For each study, N_2O EF was extracted from a study if provided. If not, an emission factor was calculated by subtracting the cumulative growing-season N_2O emissions for the unfertilized

(control) plots from the corresponding N_2O emissions of the treatment plots divided by the amount of nitrogen fertilizer applied.

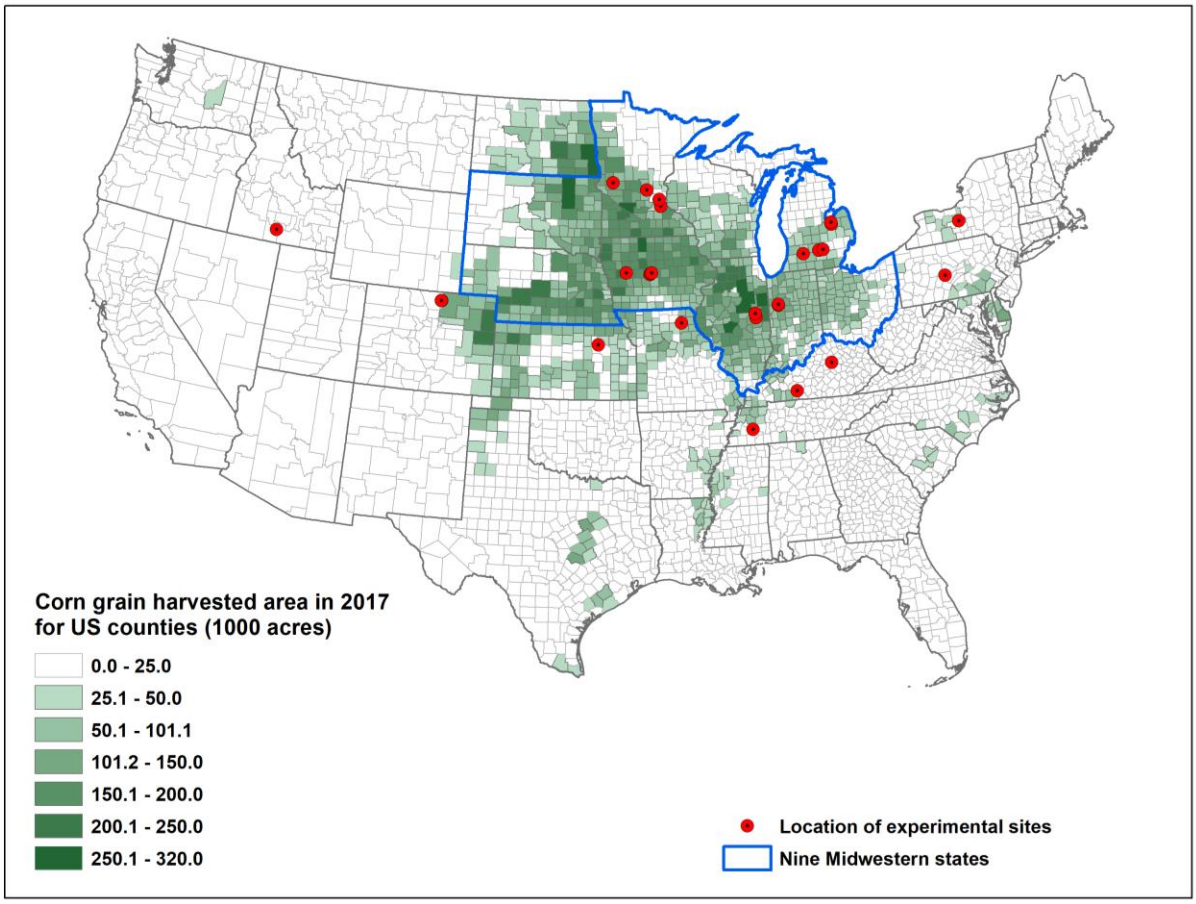

Fig.1 Location of field experiments included in the expanded database.

Updated nitrogen fertilizer-induced direct N_2O emission factor

For this update, we focused on evaluating direct N_2O EFs for studies conducted within the major corn-growing Midwestern states region (Fig.1). The database includes data points from Minnesota (n= 54), Iowa (n=39), Illinois (n=21), Michigan (n=40), and Indiana (n=10). Studies focusing on the other four states (South Dakota, Nebraska, Ohio, and Wisconsin) in this review did not include control plots, so background N_2O emissions were not provided, and are not considered in this update. Measurement-based direct emission factors range from 0% to 8.16% (Fig.2), depending on fertilizer types, fertilizer application methods, local climate, soil type, farm management practices, among other factors. Averaged across the five states, mean N_2O EF is about 1.02% (n=164, standard error (SE) = 0.09). The SE is an estimate of how far sample mean deviates from

actual population mean. The mean N_2O EF (1.02%) is almost identical with the default direct N_2O EF (1%) for mineral fertilizers (Tier 1) reported in the 2006 IPCC report (IPCC 2006). Given that 1% is within the uncertainty range of the direct N_2O EF estimated in this study, we adopted 1% as the updated direct N_2O emission factor. N_2O EF for studies outside the Midwestern states are relatively lower (mean= 0.61%, n=148, SE=0.06), but those states are not major corn producing regions (Fig.1) so we did not include them in this update.

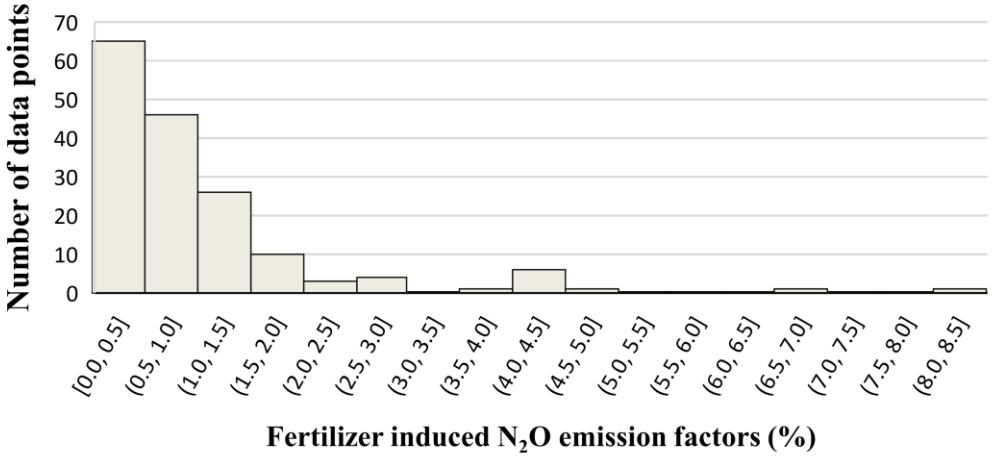

Fig. 2 Distribution of nitrogen fertilizer-induced direct N_2O emission factors for the 164 data points collected from five Midwestern States.

Summary

Based on the expanded database, the direct N_2O EF was reduced from 1.2% to 1%, which means total (direct + indirect) N_2O EF was reduced from 1.525% to 1.325%. Average nitrogen fertilizer application rate is about 63.6 kg N/acre for corn production in the nine Midwestern states. With the updated direct N_2O EF, N_2O emissions from cornfields are estimated to reduce by 13% or by 127 g N_2O-N /acre. With a corn grain yield of 166 bushels per acre, which is used in GREET 2018, N_2O emissions are 0.77 g N_2O-N lower on a per bushel basis. For corn ethanol fuel, reductions in N_2O emissions are about 0.27 g N_2O-N /gallon (Table 2).

Table 2. Comparison of N_2O-N emissions estimated using existing and updated N_2O emission factors.

N_2O emissions	**With existing N_2O emission factor**	**With updated N_2O emission factor**
Per acre (kg N_2O-N /acre)	0.97	0.84
Per bushel (g N_2O-N /bu)	5.84	5.07
Per gallon (g N_2O-N /gal)	2.05	1.78

References

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