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A discussion on the paper "Global metaanalysis of the nonlinear response of soil nitrous oxide (N_2O) emissions to fertilizer nitrogen"

Shcherbak et al., 2014, PNAS

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OUTLINE

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Background

- ✓ Nitrous oxide (N_2O) is a potent greenhouse gas (GHG) and the primary stratospheric ozone-depleting substance (Ravishankara et al., 2009).

- ✓ N_2O emissions from agricultural soils, account for ～50% of global anthropogenic N_2O emissions (IPCC, 2007).

- ✓ An N_2O emission factor (EF) approach proposed by IPCC, is calculated for most national GHG inventories.The current global default EF value is 1% (IPCC, 2006).

- ✓ Results from a growing number of studies suggested that EFs are not constant but increase with N input. And some documented an exponential response of N_2O emissions to N fertilizer (McSwiney et al., 2005; Ma et al., 2010).

Methods

Study Selection

- Identifying 78 papers, covering 84 locations and 233 site-years
- Selection criteria:

  in situ flux measurements

  at least three N input levels, including a zero N control

Fig. 1. Location of study sites included in the metaanalysis (n = 84 locations).

Δ EFs

$$\begin{cases} EF_N = (ER_N - ER_0) / N & (1) \\ EF_N = EF_0 + \Delta EF \times N & (2) \end{cases}$$

$$\boxed{ER_N = ER_0 + [EF_0 + \Delta EF \times N]N} \quad (3)$$

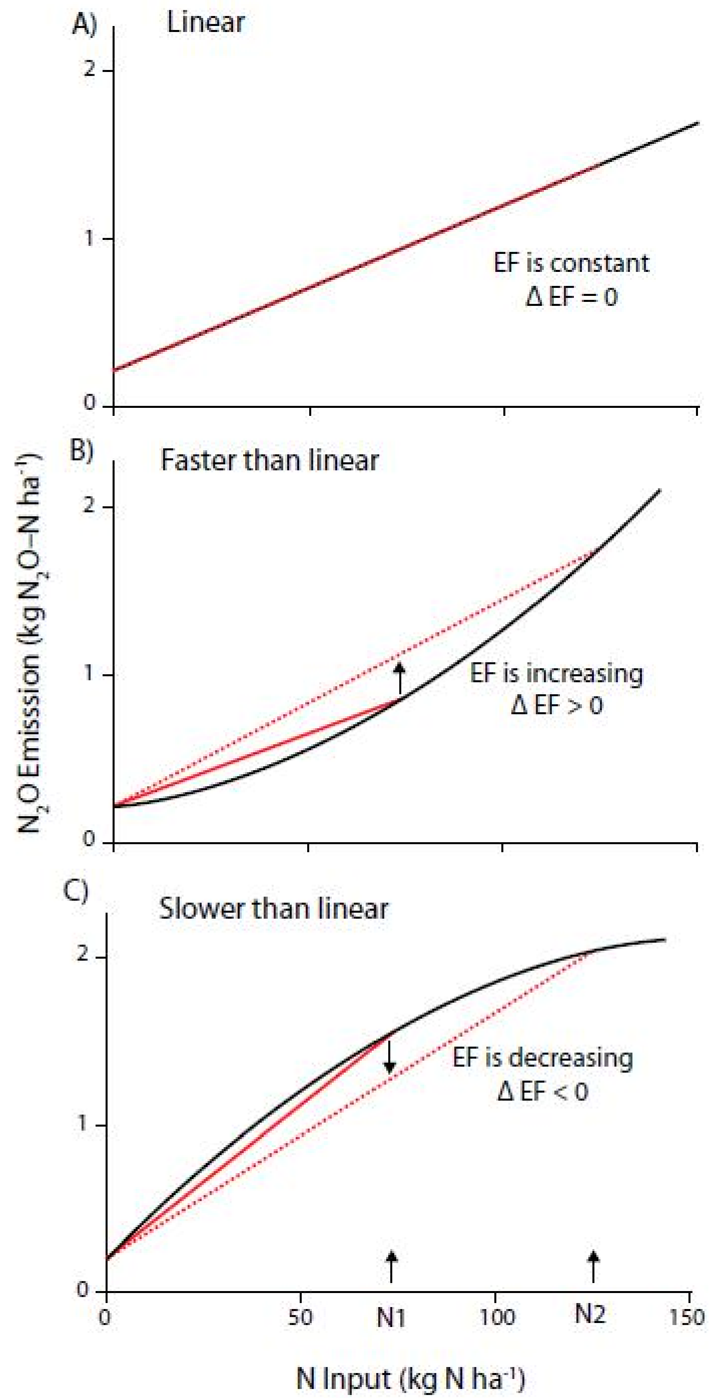

Fig. 2. Effect of N fertilizer rate on the total N_2O emissions and EFs for linear (A), faster than linear (B), and slower than linear (C) response types. The straight lines are EFs for two rates of N addition, N1 and N2; arrows between the lines denote the direction of EF change with increasing N input.

Data Analysis

- removing four outlier ΔEFs (−0.065,−0.05, 0.077, and 0.108)

- ΔEFs were divided into different categories based on:
  - crop type (N fixers, upland grain crops, rice, and perennial grass/forage)
  - fertilizer type [AN, CAN, U (urea), M (manure), and Mixed]
  - experimental factors[SOC content, soil pH (<7 and ≥7), mean annual precipitation, mean annual temperature, and lowest nonzero N-input level (0–100 and >100 $kg \cdot ha^{-1}$)]
  - sampling factors (number of fertilizer applications, total number of measurements, chamber area, number of samples per flux measurement, duration of the experiment, number of replicates, and number of input levels)

Results and Discussion

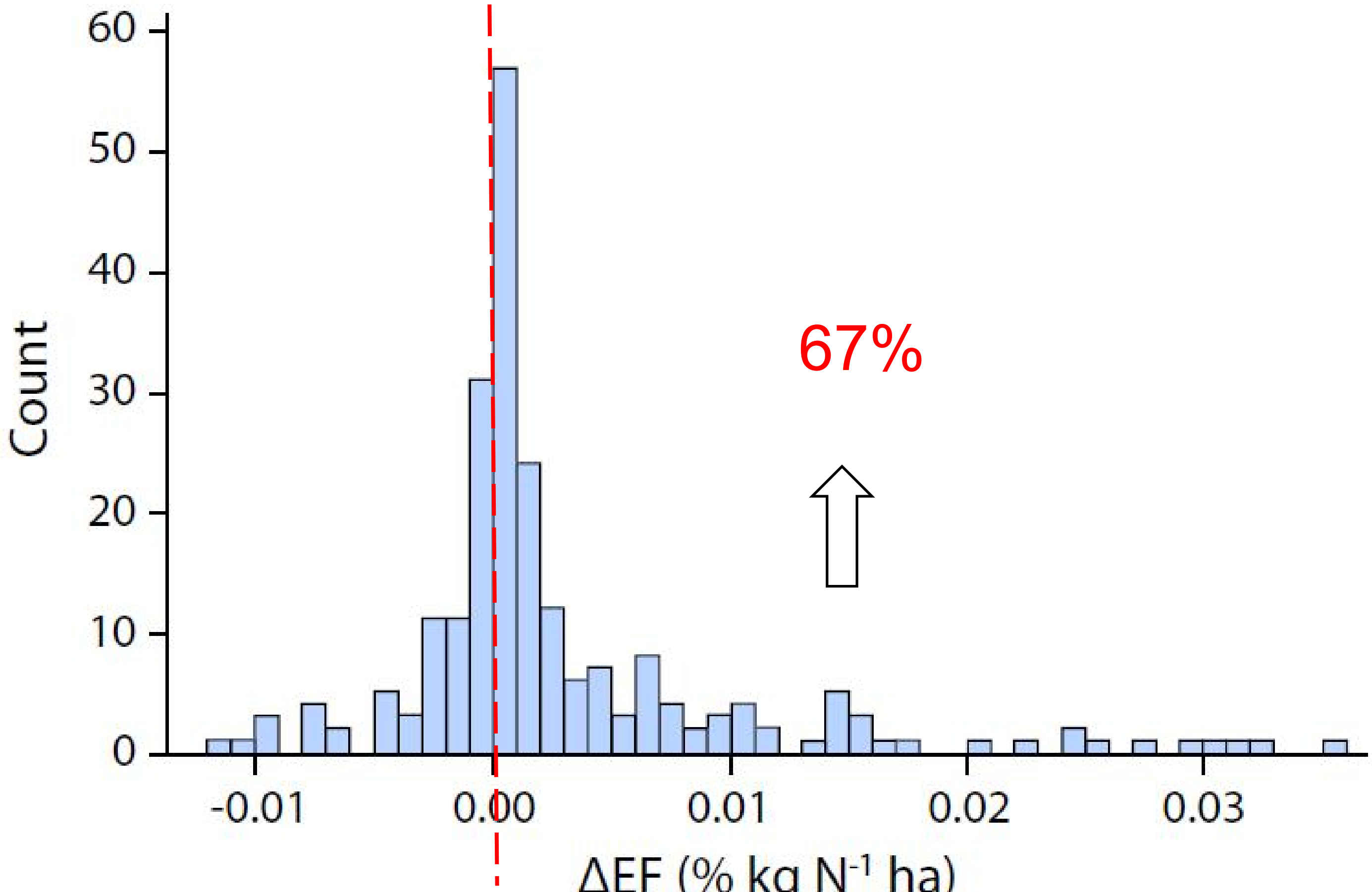

Fig.3. Histogram of emission factor change rates (Δ EFs) determined as the percent change in EF per additional kg of nitrogen fertilizer input per ha. Zero, positive, and negative Δ EFs indicate, respectively, a linear, faster than linear, and slower than linear rate of nitrous oxide (N_2O) emission increase with N input. Outlier Δ EFs (−0.065, −0.05, 0.077, and 0.108) and Δ EFs of −0.02 or less (−0.031 and −0.027) are not shown for the sake of clarity.

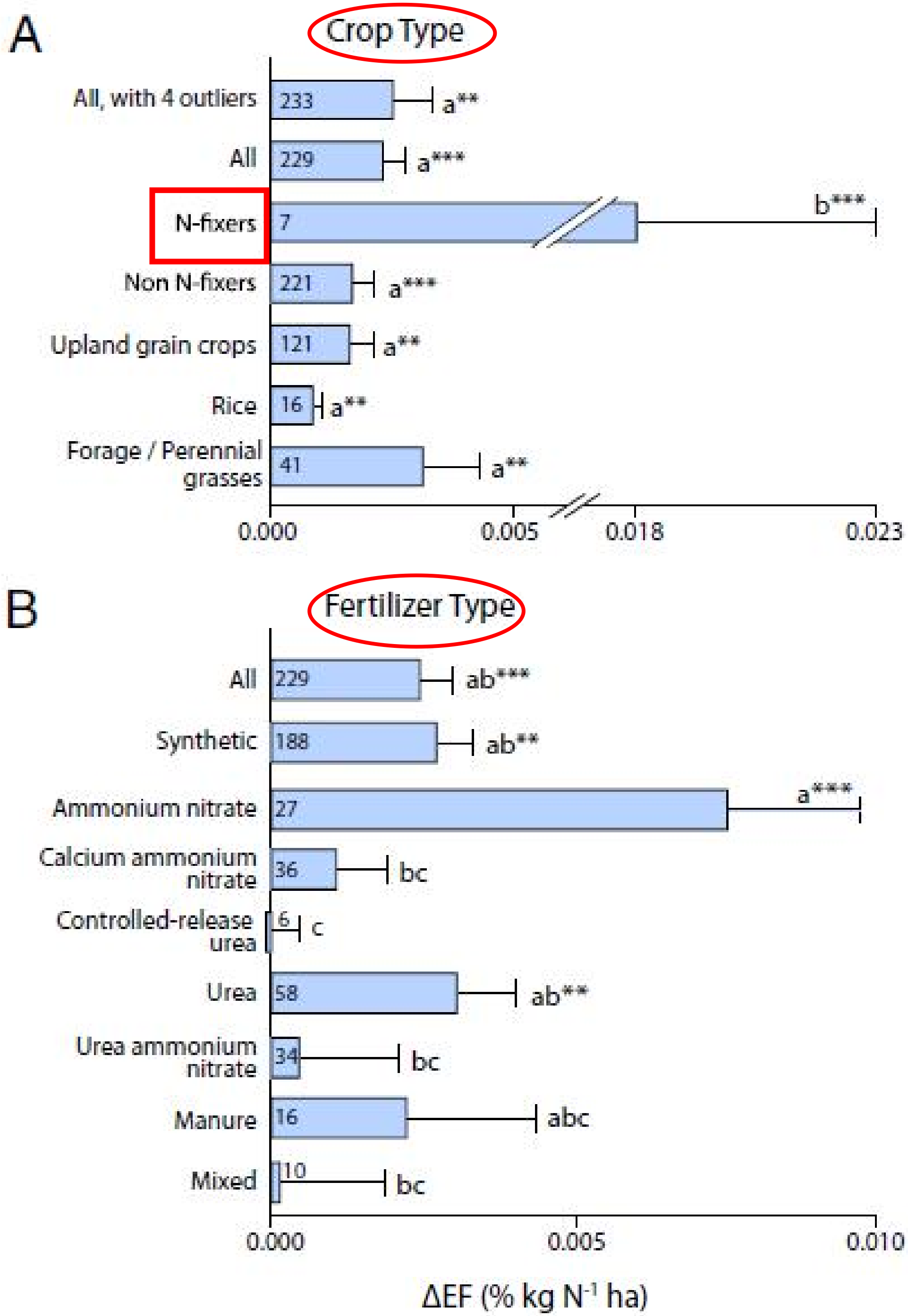

Fig.4. Δ EF by crop type (A) and fertilizer type (B). Data are presented as mean ± SEM, with n noted at the base of each bar. Asterisks indicate significant differences from zero (***P < 0.001; **P < 0.01). Different letters indicate significant differences between mean Δ EFs for groups of site-years within each category;Note the x-axis scale break in A.

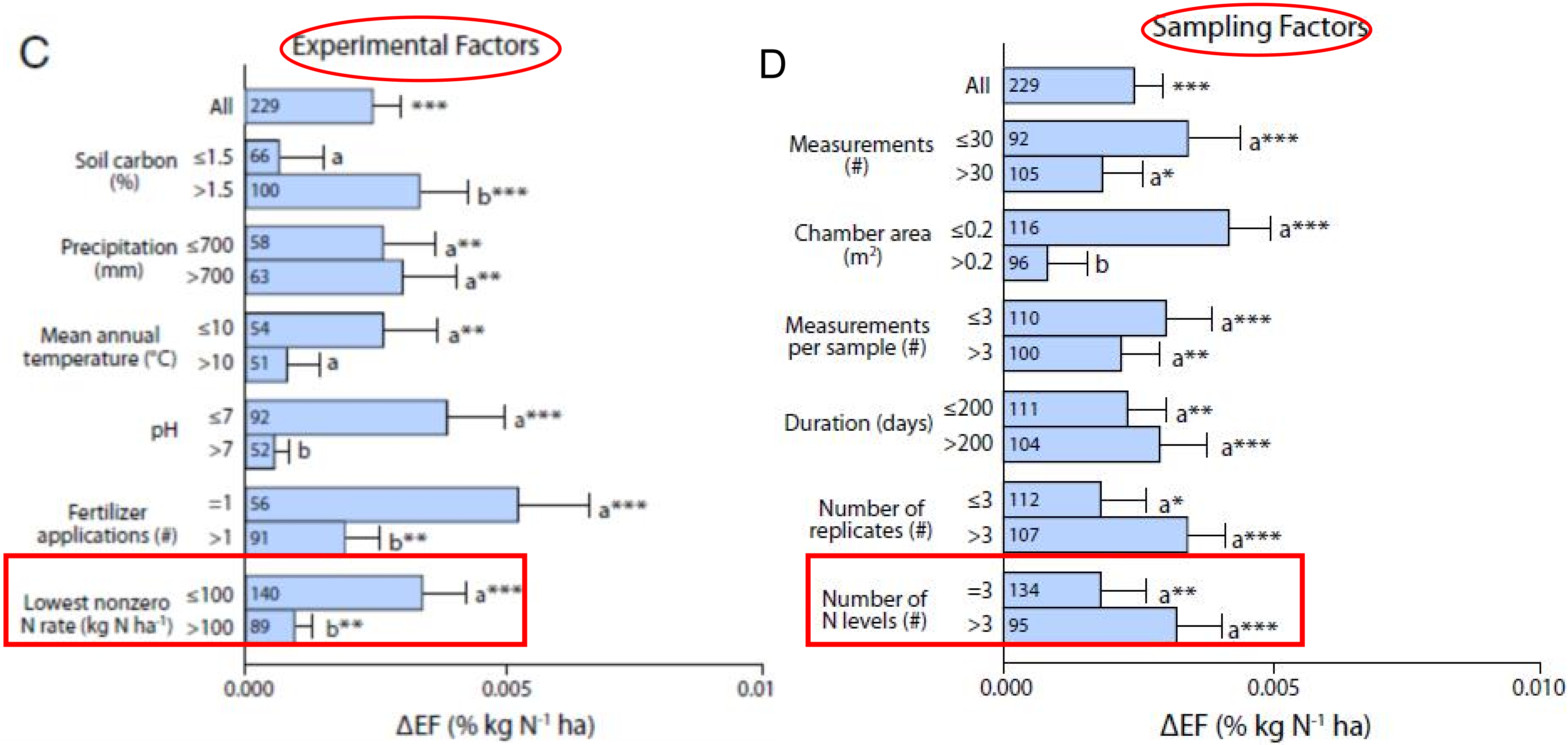

Fig.5. Bar graph of ΔEF by type of experimental factors (C) and sampling factors (D). Data are presented as mean ± SEM, with n given at the base of each bar. For experimental factors (C), different letters indicate significant pairwise differences between factors; for sampling factors (D), different letters indicate significant differences between mean ΔEFs for groups of site-years by particular factor. Asterisks indicate significant differences from zero (***$P < 0.001$; **$P < 0.01$; *$P < 0.05$).

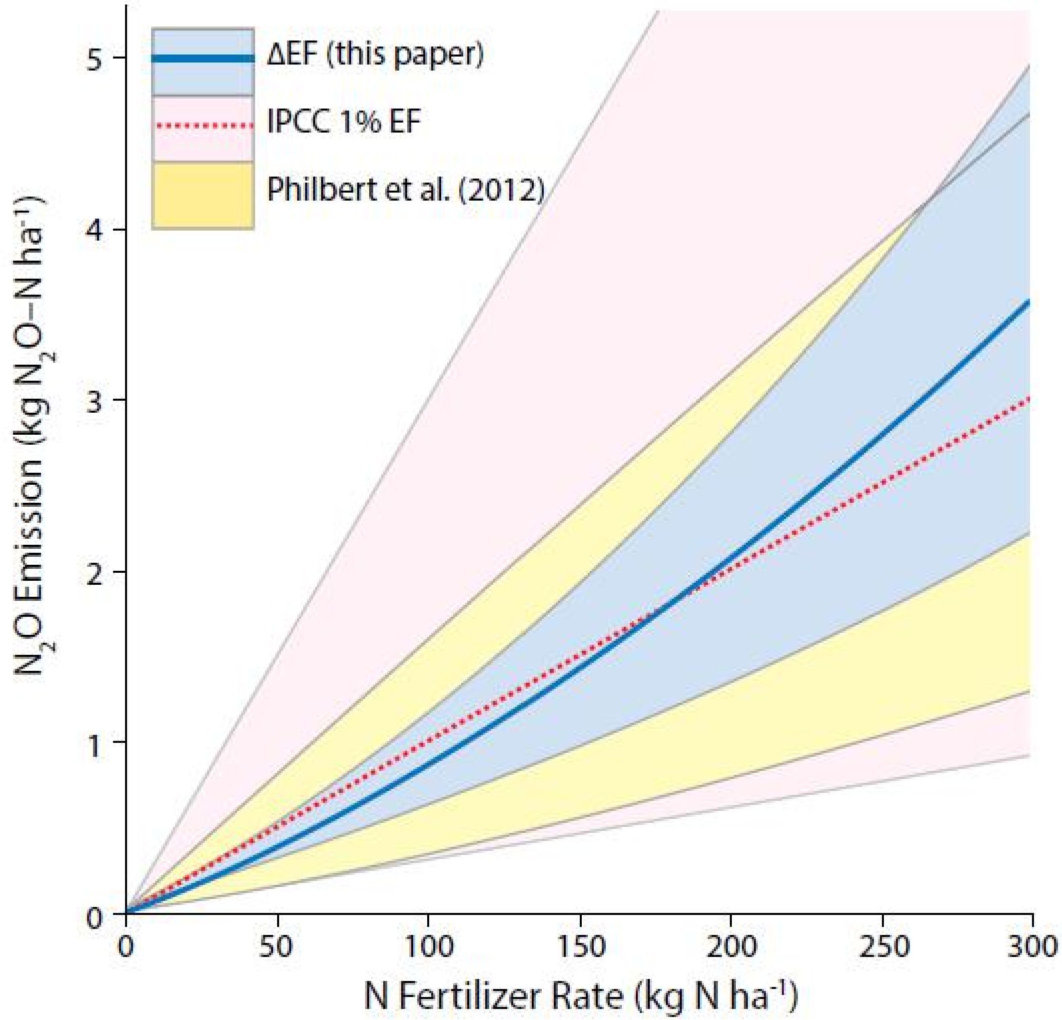

Fig. 6. Comparison of the uncertainties associated with IPCC tier 1 (1%), a range of six models from Philibert et al. (31), and the mean Δ EF model for all site-years from this metaanalysis (excluding N-fixing crops and the bare soil site-year). The 95% CI is provided for each model across a range of N fertilizer rates (0–300 kg·ha−1). The IPCC tier 1 95% CI is 0.3–3%. The Philibert et al. (31) 95% CI encompasses parameter uncertainty.

Hoben et al.'s model:

$$Emis = (4.36 + 0.025N)N \quad (4)$$

This study:

$$Emis = (6.49 + 0.0187N)N \quad (5)$$ ⇨ upland grain crops

$$Emis = (6.58 + 0.0181N)N \quad (6)$$ ⇨ all crops excluding N-fixers

Hoben JP, Gehl RJ, Millar N, Grace PR, Robertson GP (2011) Nonlinear nitrous oxide (N_2O) response to nitrogen fertilizer in on-farm corn crops of the US Midwest. Glob Change Biol 17(2):1140–1152.

IPCC 1% EF model vs. Δ EF model

$$Emis = 0.01N \qquad Emis = 0.001N(6.58 + 0.0181N)$$

Fertilization rates (kg·ha⁻¹)	the IPCC 1% EF model vs. the Δ EF model
moderate	very close
underfertilized at an N input of 50	0.5 vs. 0.37 kg N_2O-N ha^{-1} (overestimated by 25%)
overfertilized at an N input of 300	3.0 vs. 3.6 kg N_2O-N ha^{-1} (underestimated by 20%)
at an N input of 500	5.0 vs. 7.9 kg N_2O-N ha^{-1} (underestimated > 50%)

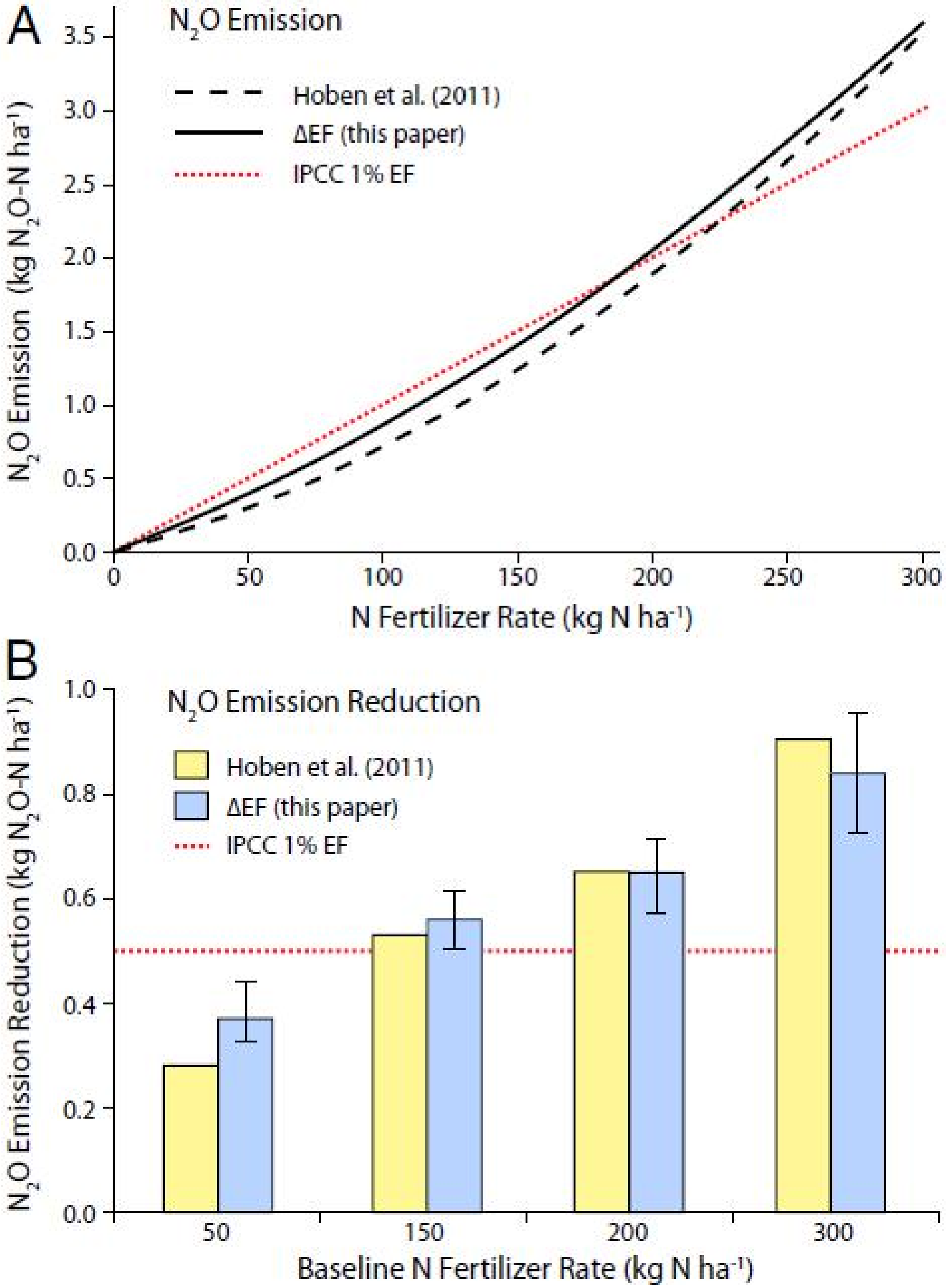

Fig. 7. (A) Comparison of N_2O emission models for N fertilizer reduction scenarios: N_2O emissions estimated by the **IPCC tier 1** (**1% linear emission: 0.01 N**) model, the **Hoben et al. (15) model** (**0.001 N[4.36 + 0.025 N]**), and the **Δ EF model** for average upland grain crop emissions from this meta-analysis (**0.001 N[6.49 + 0.0187 N]**). (B) Relative N_2O emission reductions for the three models when N fertilizer rates are **reduced by 50 kg·ha⁻¹** from four baseline N fertilization scenarios: 300, 200, 150, and 50 kg·ha⁻¹. Vertical lines denote SEs for emission estimates based on the Δ EF model.

Conclusions

- Compared with the IPCC tier 1 model, the ΔEF model can be more biologically appropriate for estimating N_2O emissions from agricultural cropland.

- For nonleguminous crops, their emissions are best characterized by the model $Emis = (6.58 + 0.0181N)N$ where N is input (kg N ha^{-1}), and Emis is N_2O emissions (g N_2O ha^{-1}).

- A significant shortcoming: few site-years with at least four nonzero N-input levels.

Thank you~