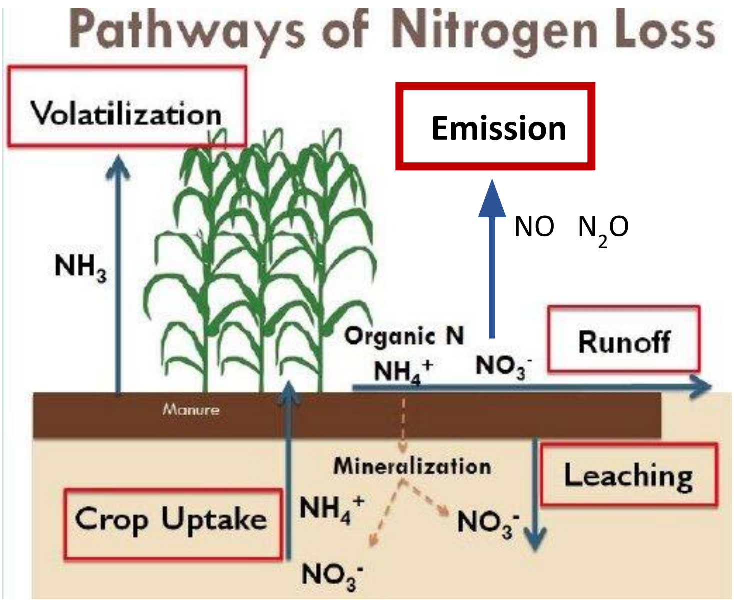
Reactive nitrogen emissions from agriculture: Model and Mesocosm experiments

Jinmu Luo[1,2]; Peter .G. Hess[2]; Steven .J. Hall[3]; Danica L. Lombardozzi[4,5]

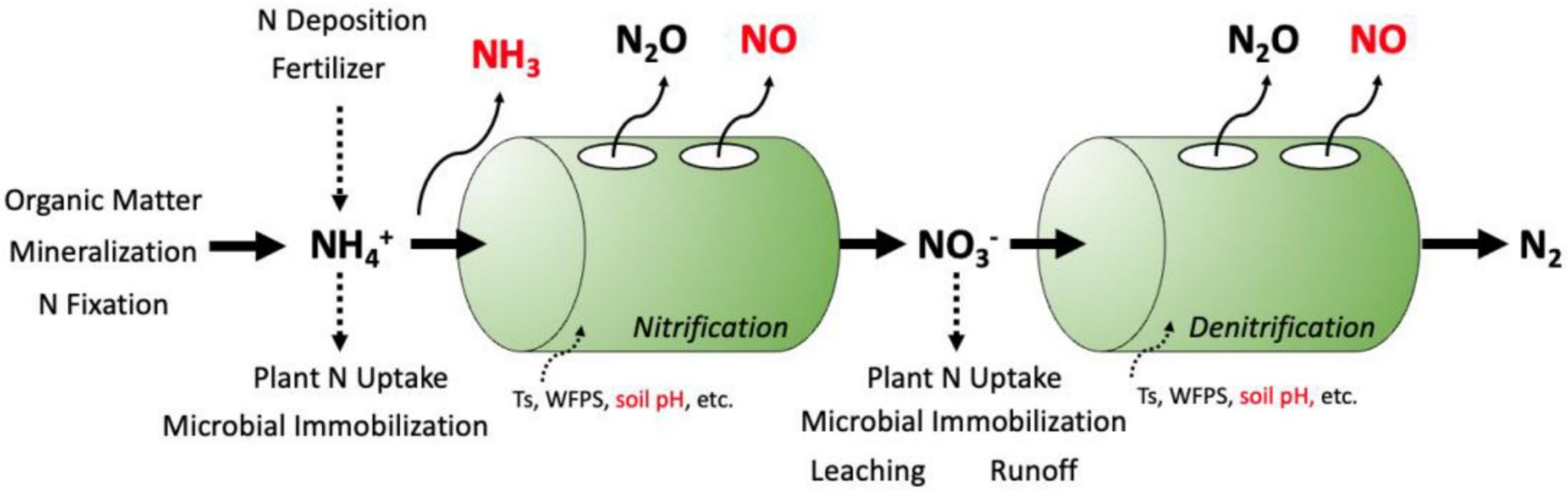
[1] Earth and Atmospheric Sciences, Cornell University;
[2] Biological and Environmental Sciences, Cornell University;
[3] Department of Plant and Agroecosystem Science, University of Wisconsin-Madison;
[4] Ecosystem Science and Sustainability, Colorado State University;
[5] National Center for Atmospheric Research.

Introduction

- NO, N_2O and NH_3 emissions are the important pathways for agricultural nitrogen loss.
- NO emissions produce O_3, which can damage plants, is an important air pollutant and a greenhouse gas.
- N_2O is the third most important greenhouse gas.
- NH_3 forms aerosols with impacts on pollution and climate.
- Statistical and regression model has limited ability to project future NH_3, NO and N_2O emissions.



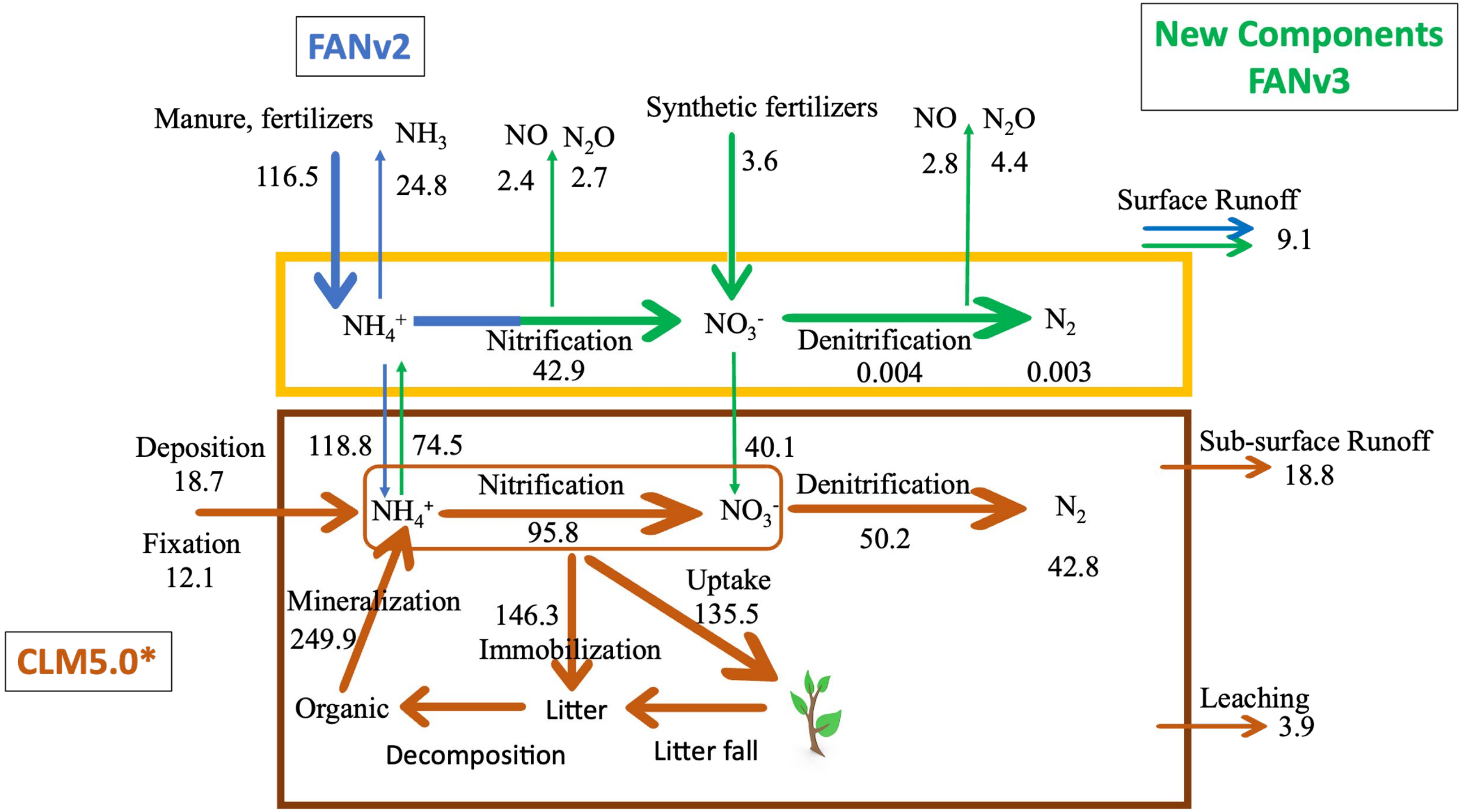
Hole-in-the-pipe model



- Nitrogen flows and emissions often parameterized through the hole-in-the-pipe model (including the CLM)
- Emissions dependent on environmental variables.
- Model does not typically include NH_3 emissions.

Parton et al ., 2001; Van Martin et al., 2023

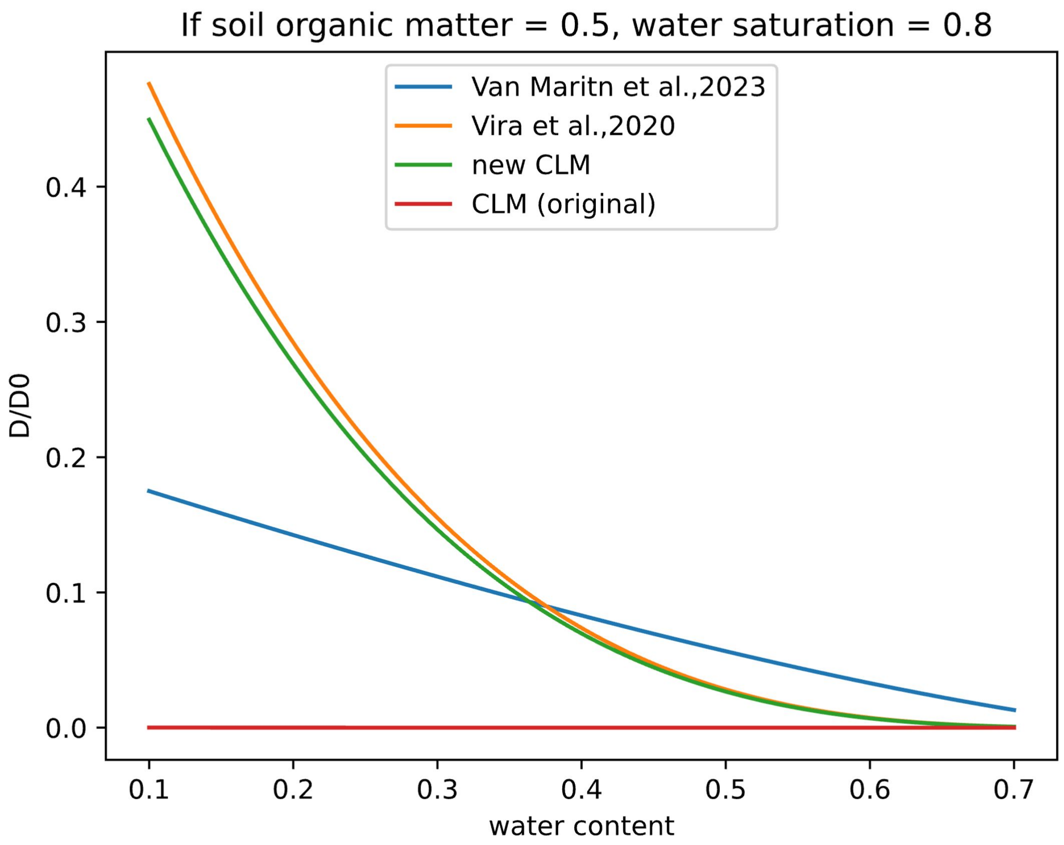
Nitrogen flows over Agricultural soil



- FANv2 diagnoses NH_3 emissions from agriculture from manure and fertilizer inputs. It explicitly models NH_3 flows and transformations in top layer of CLM. (Vira et al., 2020, 2022).

- FANv3 extends FANv2 by coupling FANv2 to the CLM5.1 and the hole-in-the-pipe model.

Soil gas diffusivity (Normalized soil gas diffusivity, tortuosity)



$$D_e = m * D_0(\theta_s - \theta)^2 \left(\frac{\theta_s - \theta}{\theta_s}\right)^{\frac{3}{b}} + (1-m)D_0\frac{(\theta_s - \theta)^{\frac{10}{3}}}{{\theta_s}^2}$$

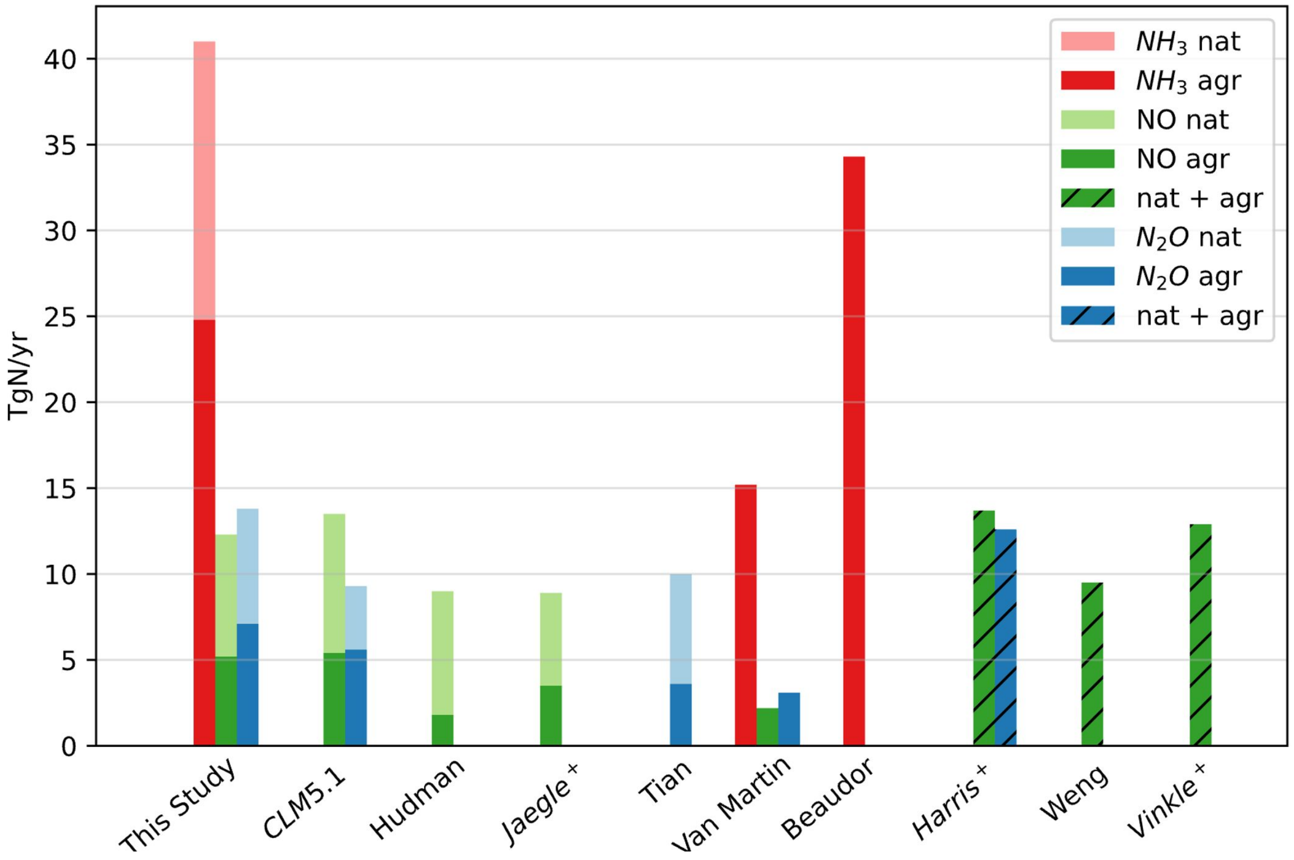
$$\frac{D_e}{D_0} = \frac{(\theta_s - \theta)^{\frac{10}{3}}}{{\theta_s}^2}$$

$$\frac{D_e}{D_0} = 0.209 * \left(\frac{\theta_s - \theta}{\theta_s}\right)^{\frac{4}{3}}$$

- N Emissions sensitively dependent on diffusivity in soil
- FANv3 corrects problem in CLM diffusivity formulation (Also impacts methane emissions)
- More N to N_2O in denitrification, increases the N_2O emission.
- A reasonable NO to N_2O ratio.

CLM-FANv3 results evaluation

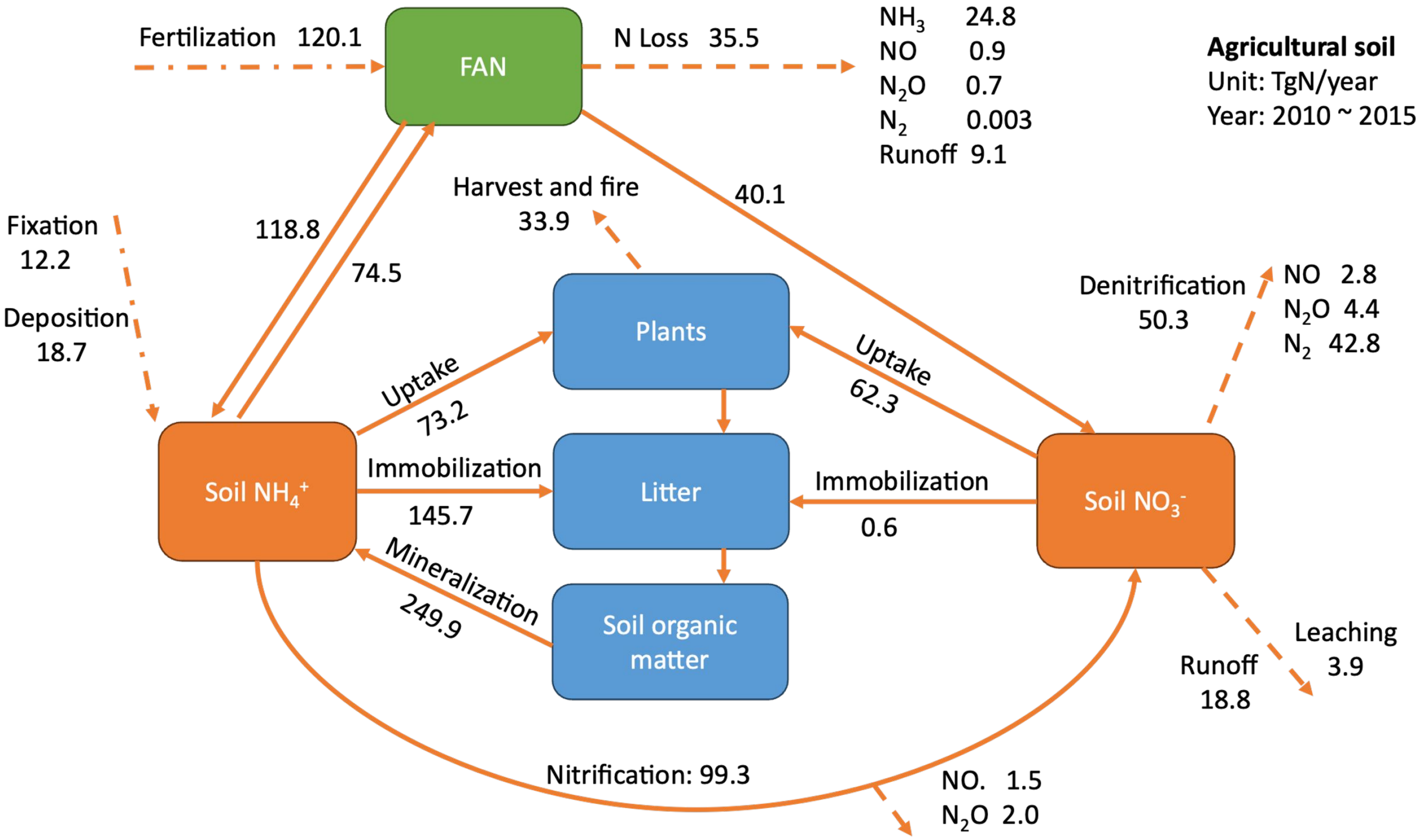
Are we getting this agreement for the wrong reason?



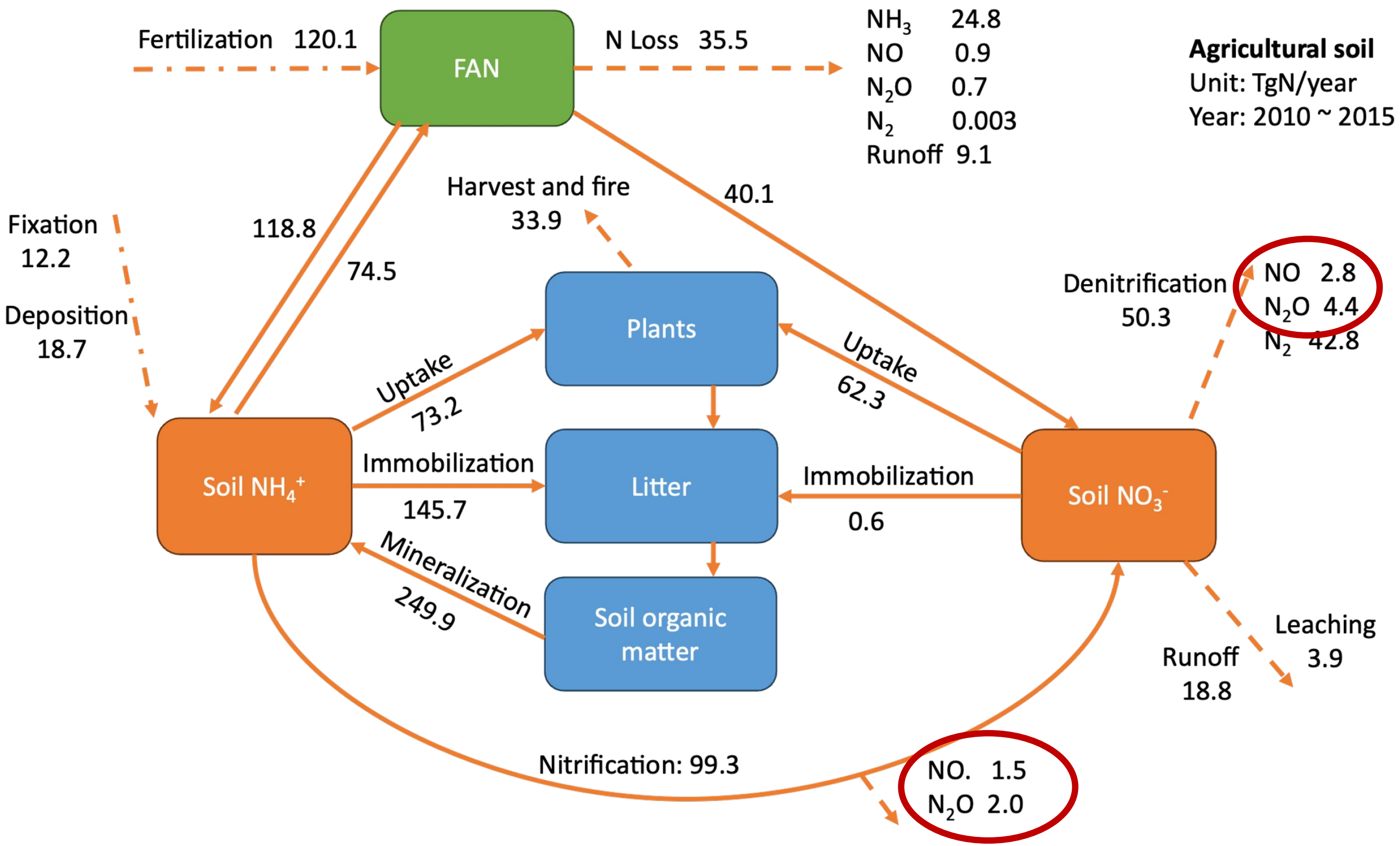
+ observation based research.

- Reactive nitrogen gas emissions simulated by CLM-FANv3 (this study) are within the range of observation-based methods and satellite estimations.
- Except for the study by Van Martin et al, we are aware of no other global biogeochemistry model that includes estimates for NH_3, N_2O and NO_x.
- NH_3 emission is an important part of budget.

Nitrogen cycle over agricultural soil



Nitrogen cycle over agricultural soil



- Site measurements suggest NO from denitrification thought to be very small, what about globally?
- How do other issues in the CLM affect the reactive nitrogen gas emissions like nitrification/denitrification, runoff fluxes etc?

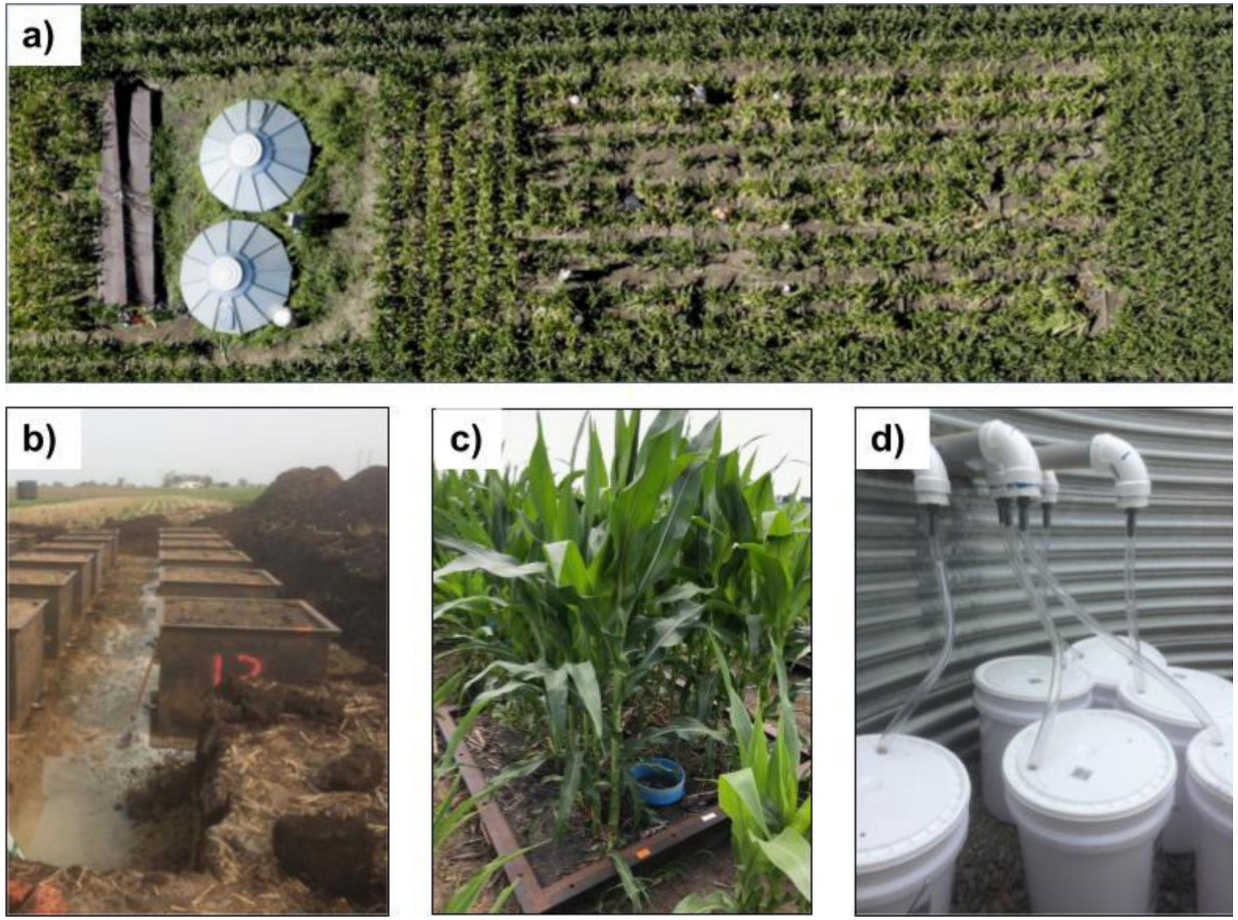
Mesocosm observations set up (one site)

What it measured.

- Fertilizer usage
- NO_x, N_2O emissions
- Harvest N
- Inorganic N runoff
- NO_3, NH_3 in soils
- Soil properties

…..

These unique observations give us a chance to further evaluate the model.



Single column CLM5.0*-FANv3

↓

Use local meteorological forcing

↓

Modify Soil properties (e.g. pH, organic content)
For either Clarion or Webster soil types

↓

Modify the fertilization amount, time and location

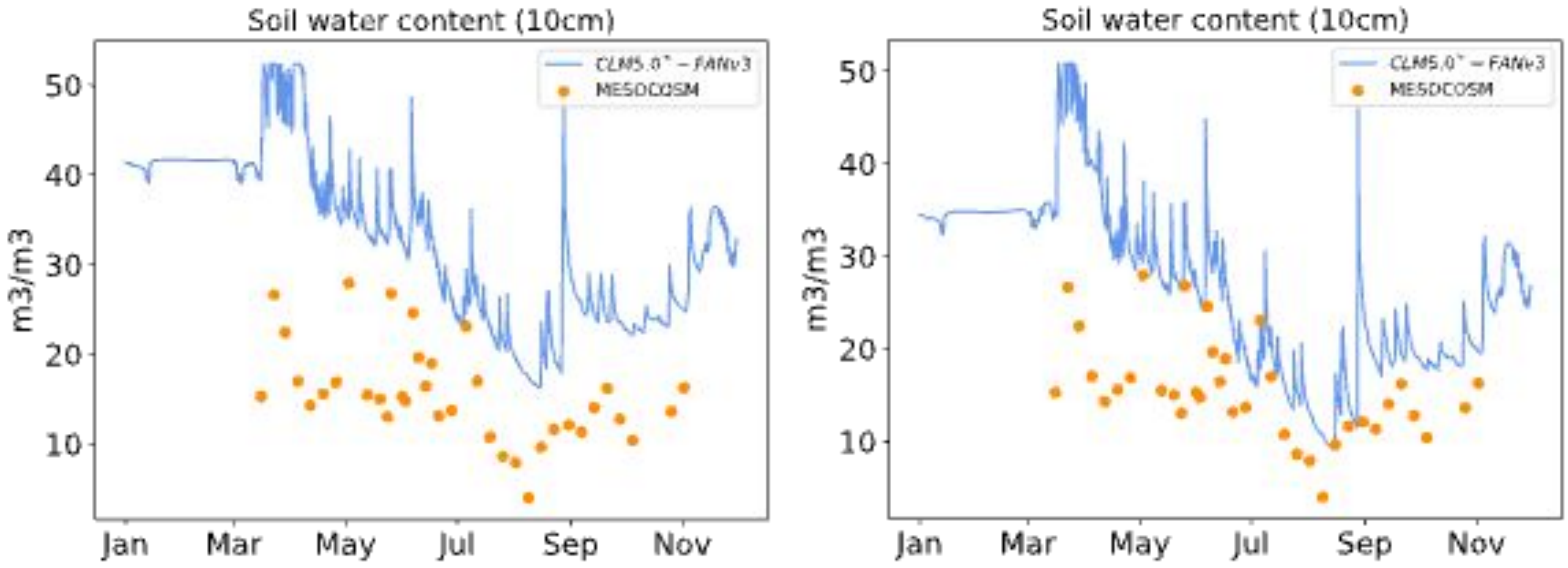
↓

Change the planting date

↓

CLM5.0*-FANv3 under mesocosm

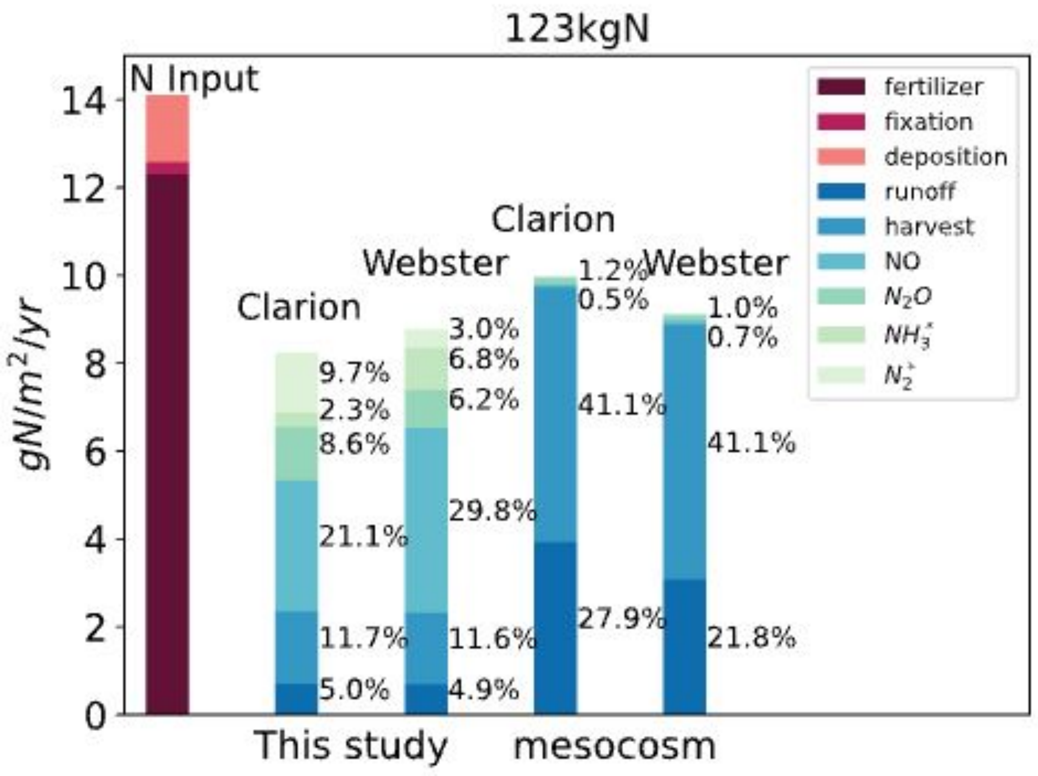
Some discrepancies



Change the soil properties.
+15% sand
-10% clay

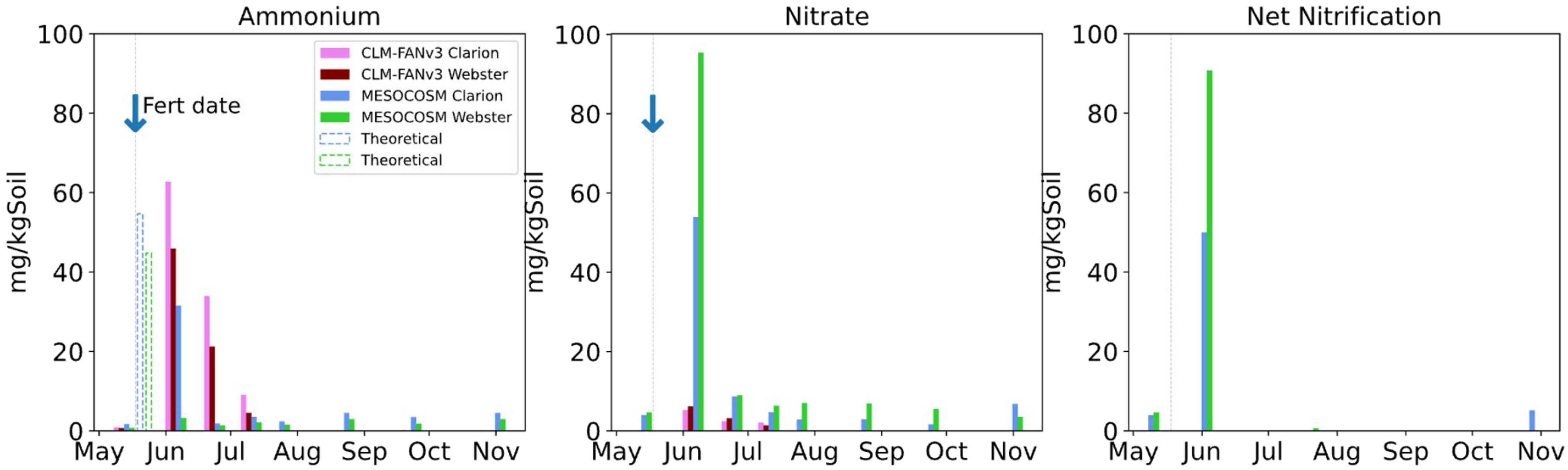
- CLM5.0*-FANv3 overestimates the soil moisture.
- Soil moisture is the critical parameter in determining the loss of N and the rates of nitrification/denitrification

Single site model results evaluation



- CLM-FANv3 simulates larger NO and N_2O emissions than mesocosm and smaller losses from runoff and harvest.

Nitrification rate is too small in the model



- Mesocosm suggests most of NH_4^+ was nitrified to NO_3^- within two weeks.
- The model can't reproduce the measured transformations between NH_4^+ and NO_3^- following fertilization.

Conclusions

- We have developed a new coupled model (CLM-FANv3) that simulates NH_3, NO and N_2O emissions, and global emissions consistent with measurements.
- Reactive N emission is dominated by NH_3 , CLM default model and most global models don't simulate NH_3 emissions. NH_3 is an important part of the nitrogen budget in agricultural soils.
- Future: Continued evaluation against mesocosm measurements and refinement of parameterizations.