CABBI
CENTER FOR ADVANCED BIOENERGY AND BIOPRODUCTS INNOVATION

MANIPULATING MICROBES TO REDUCE SOIL NITROUS OXIDE EMISSIONS FROM BIOENERGY CROPPING SYSTEMS

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ILLINOIS

U.S. DEPARTMENT OF ENERGY

DOE Bioenergy Research Centers

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SMART FARM
arpa·e
CHANGING WHAT'S POSSIBLE

ILLINOIS NREC

NSF

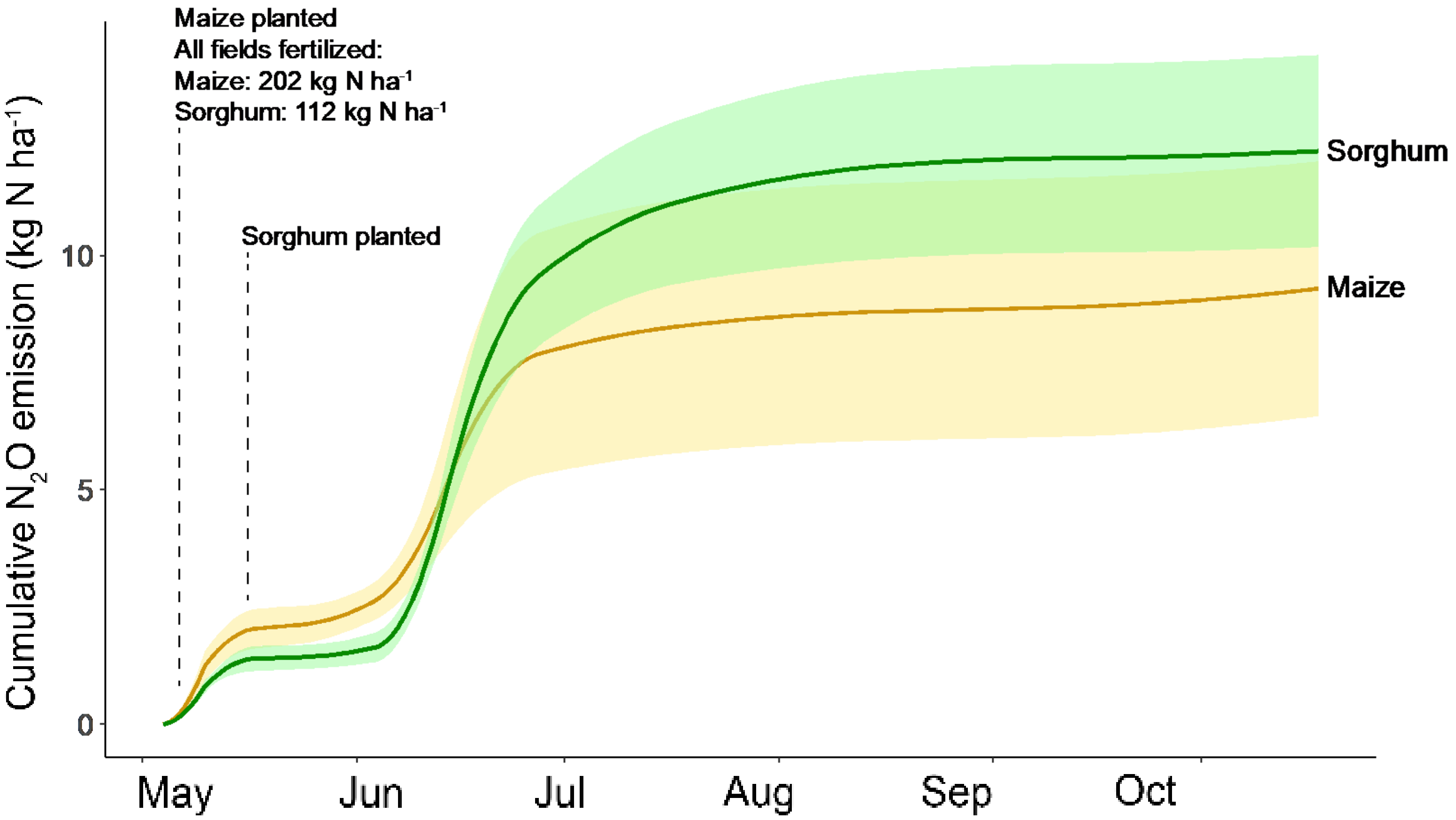
USDA National Institute of Food and Agriculture
U.S. DEPARTMENT OF AGRICULTURE

IMPROVING THE SUSTAINABILITY OF BIOMASS SORGHUM

Soil nitrous oxide (N_2O) emissions from sorghum fields are comparable to those from maize fields despite receiving half the fertilizer nitrogen (N) inputs.

Mark Burnham
Former postdoc

Allison Cook
Technician



Moore et al. 2020, *Global Change Biology-Bioenergy*

OPPORTUNITIES TO REDUCE N_2O EMISSIONS

There are many points in the soil N cycle where microbial processes can be manipulated to reduce soil N_2O emissions.

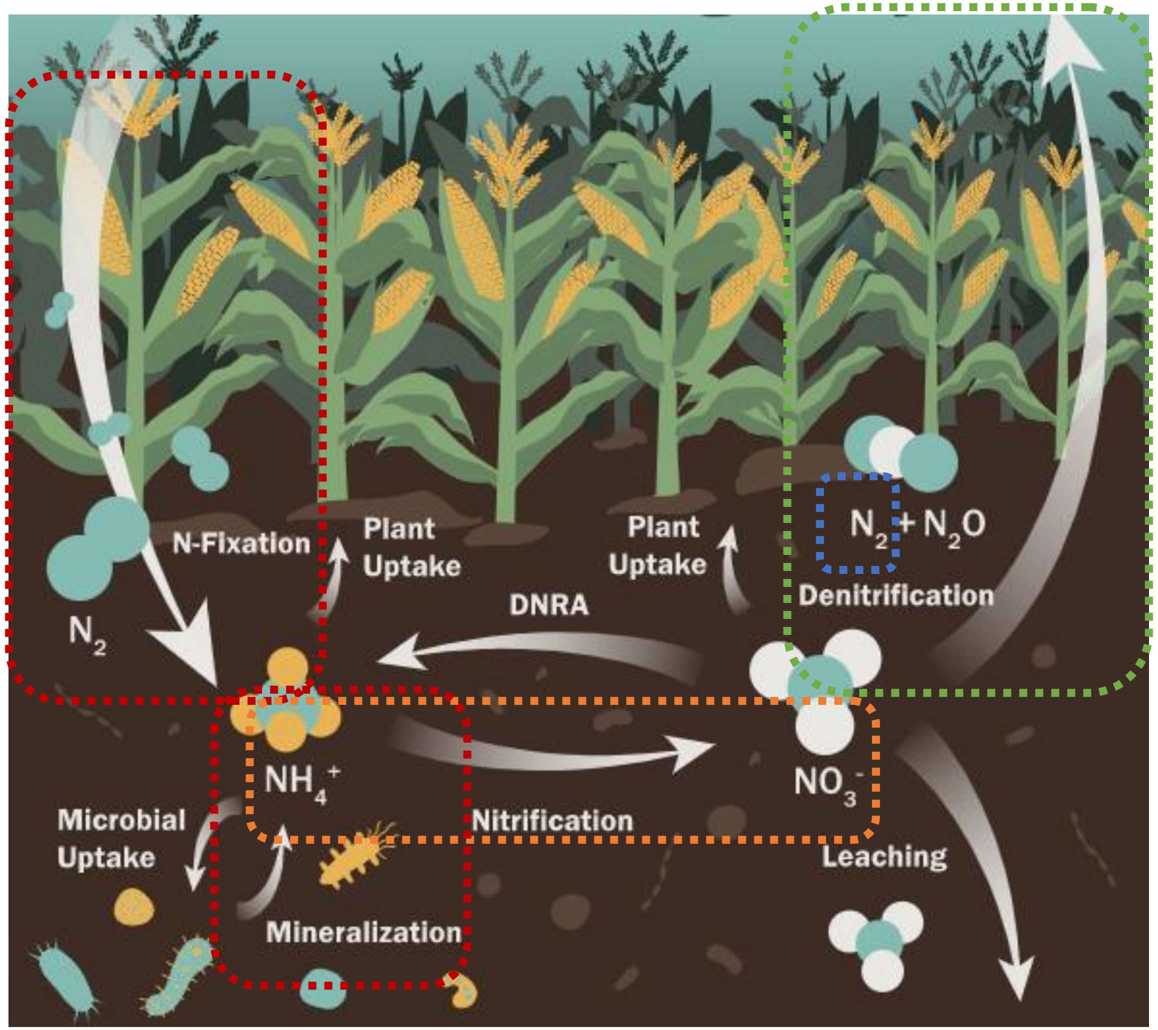


Image: Sada Egenriether, https://mail.sada-egenriether.com/

REDUCING RELIANCE ON FERTILIZER NITROGEN INPUTS

Biological N fixation can supply N from the atmosphere, and soil N mineralization can supply N from soil organic matter.

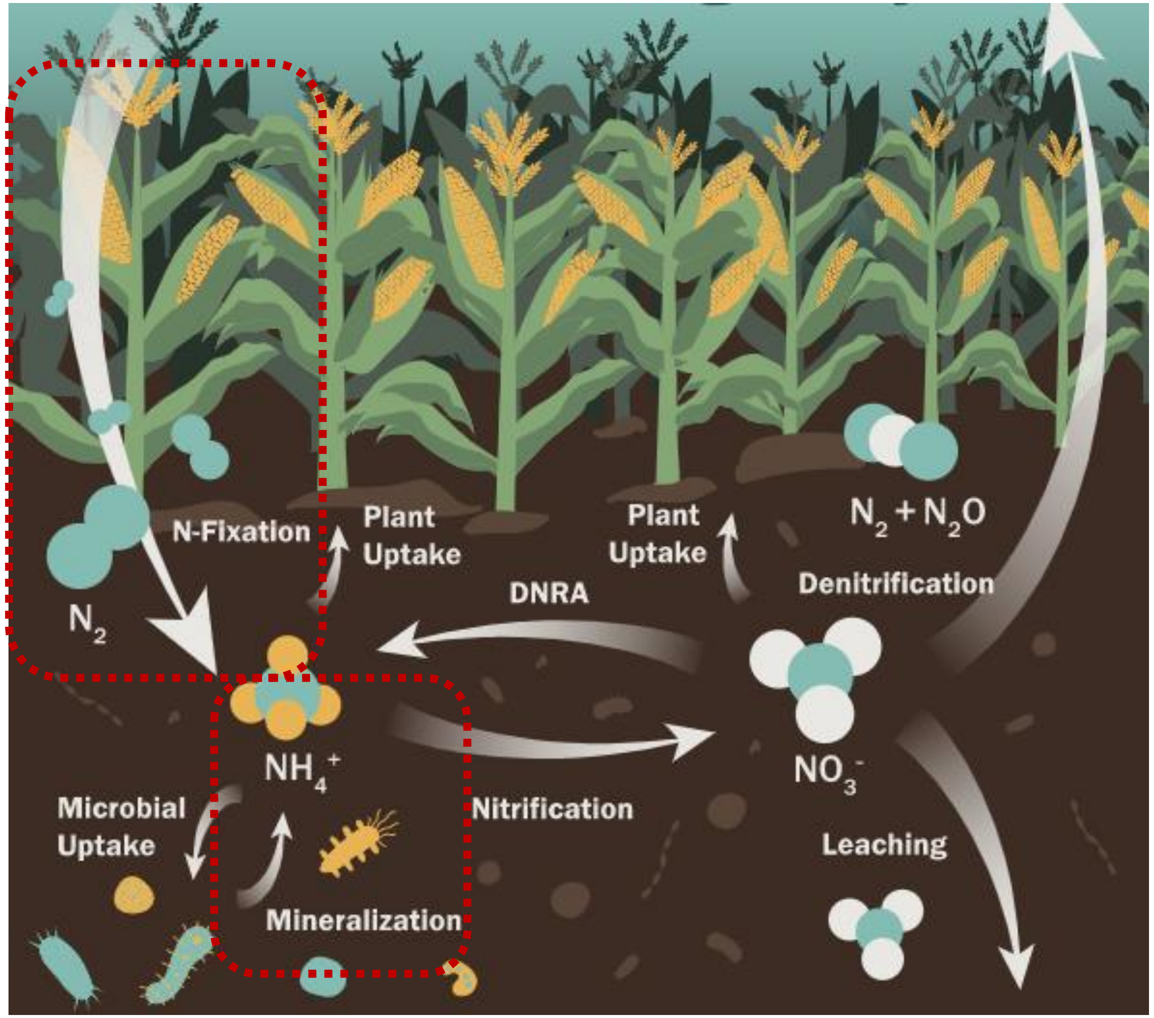
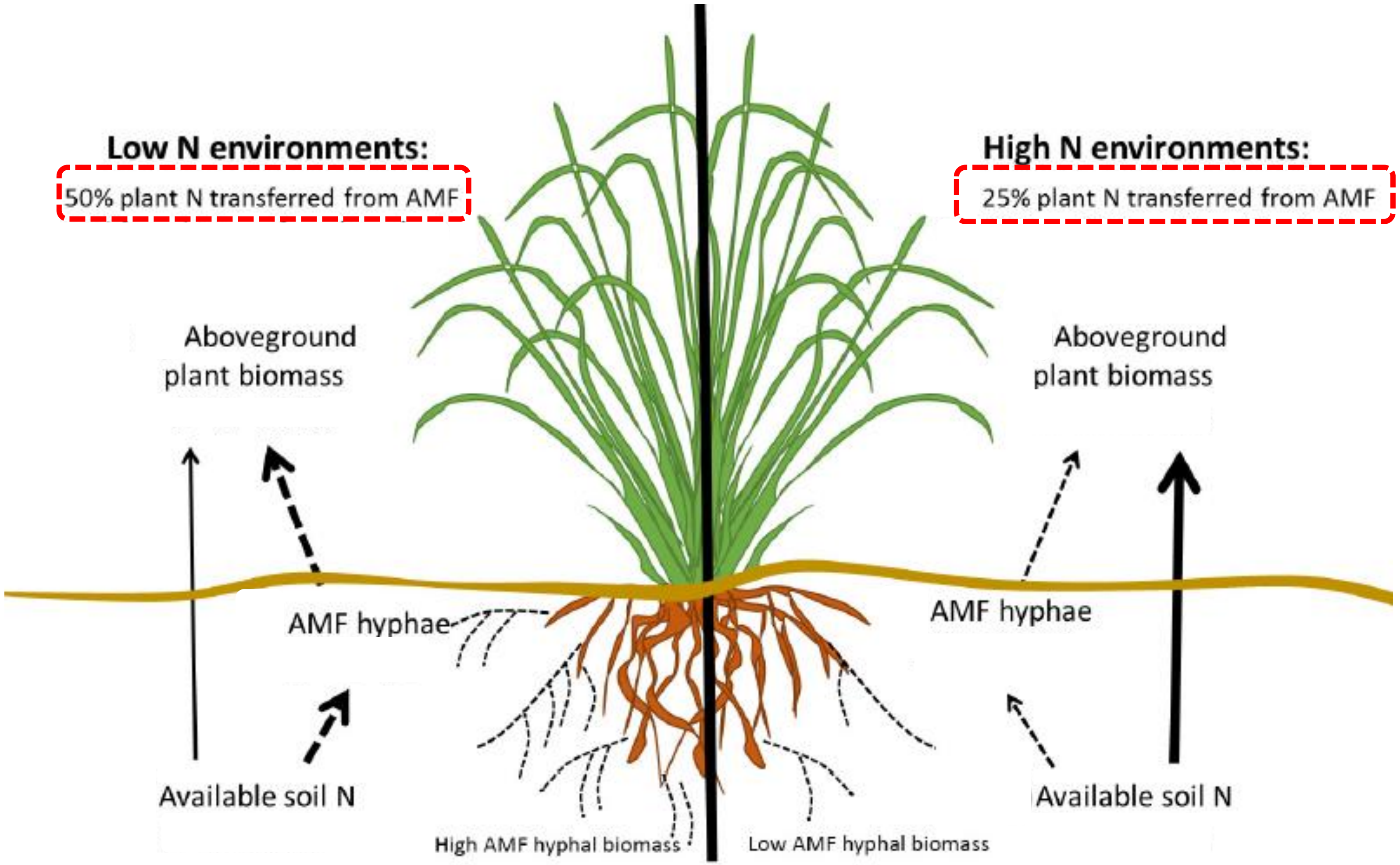


Image: Sada Egenriether, https://mail.sada-egenriether.com/

REDUCING RELIANCE ON FERTILIZER NITROGEN INPUTS

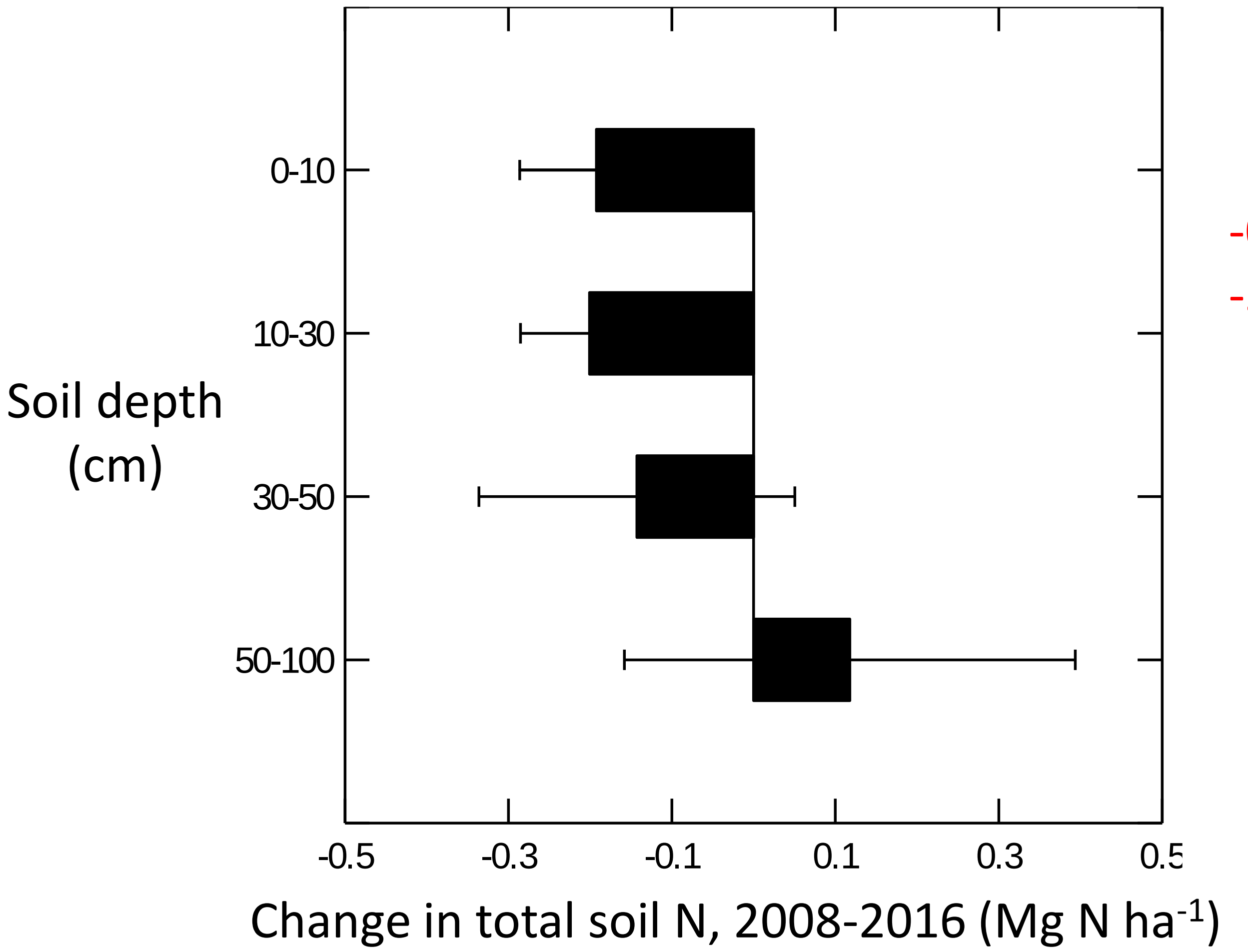
Arbuscular mycorrhizal fungi can supply soil N to plants, serving as an important N source particularly in the absence of fertilizer N inputs.



Jach-Smith and Jackson 2020, *Ecological Applications*

REDUCING RELIANCE ON FERTILIZER NITROGEN INPUTS

Total soil N content declined in surface soils (0-30 cm depth) after 8 years of unfertilized miscanthus cultivation at the University of Illinois Energy Farm, suggesting that soil N cannot be sustained as an N source in the long-term.



-0.4 Mg N ha^{-1} / 8 yr =
-52 kg N ha^{-1} yr^{-1}

Evan DeLucia

DeLucia, unpublished data

INHIBITING NITRIFICATION

Nitrification produces nitrate that is susceptible to N_2O production via denitrification, and it can also produce N_2O as a byproduct.

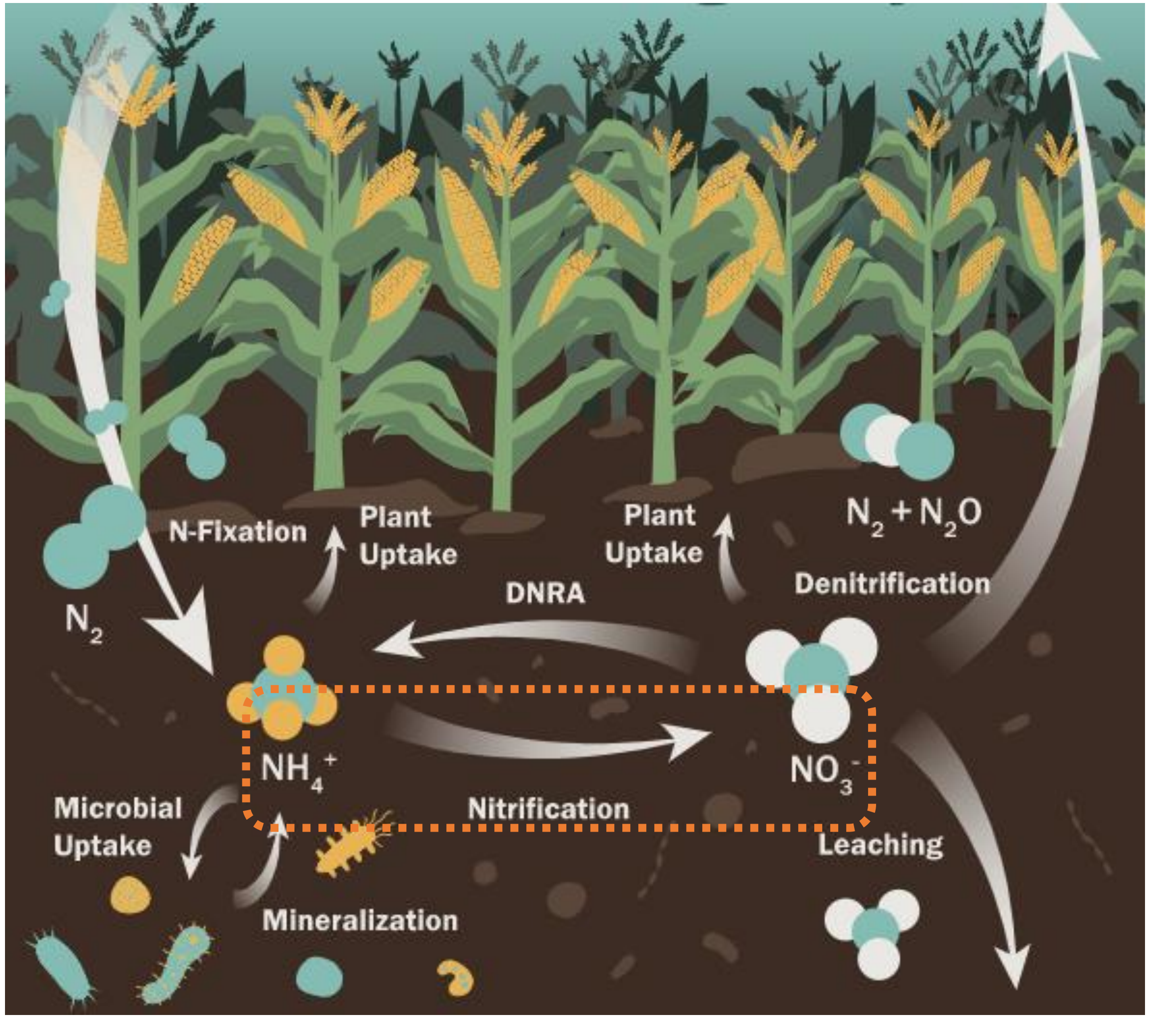
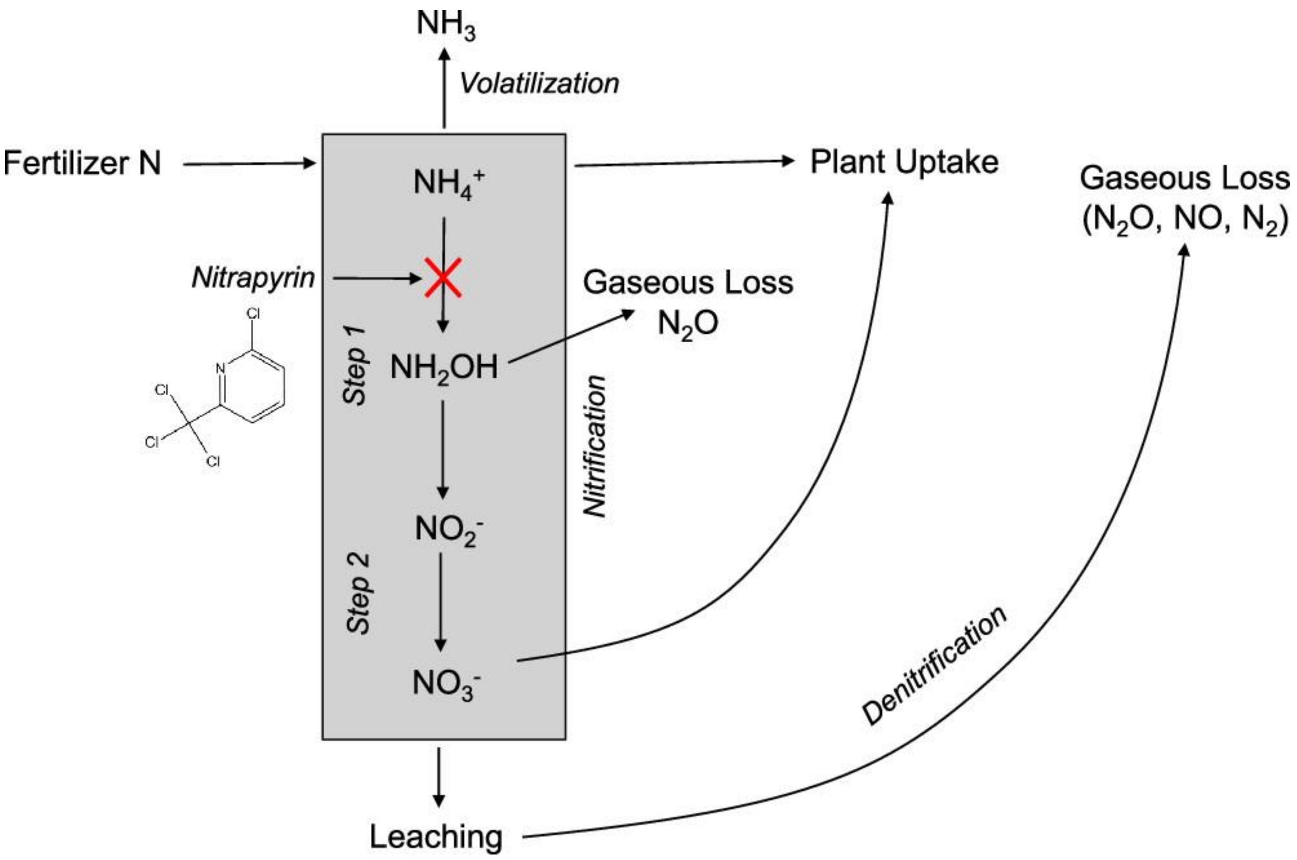


Image: Sada Egenriether, https://mail.sada-egenriether.com/

INHIBITING NITRIFICATION

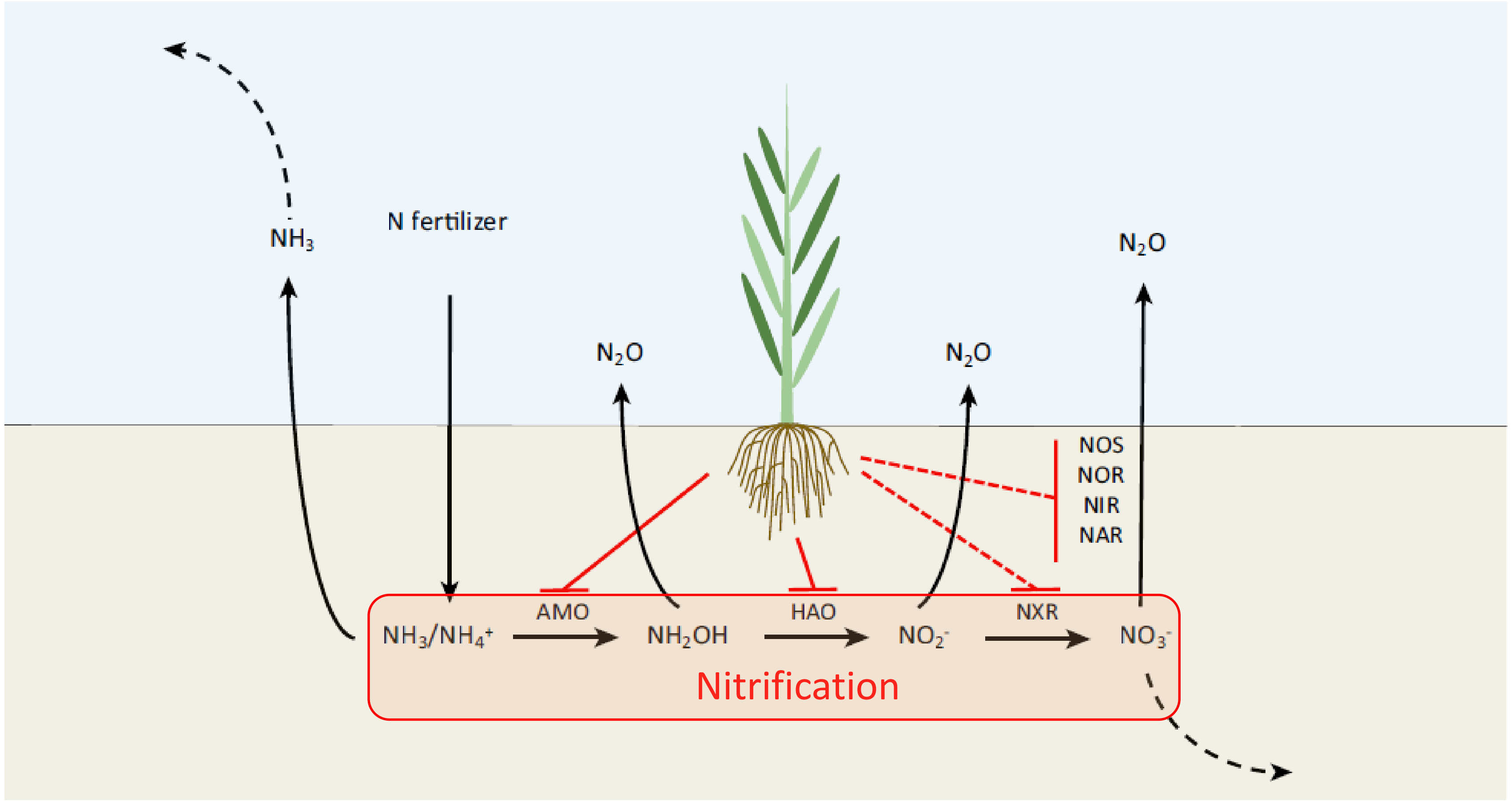
Synthetic nitrification inhibitors can effectively reduce soil N_2O emissions but the unpredictable yield benefits do not justify the cost to most farmers.



Woodward et al. 2021, *Environmental Science & Technology*

INHIBITING NITRIFICATION

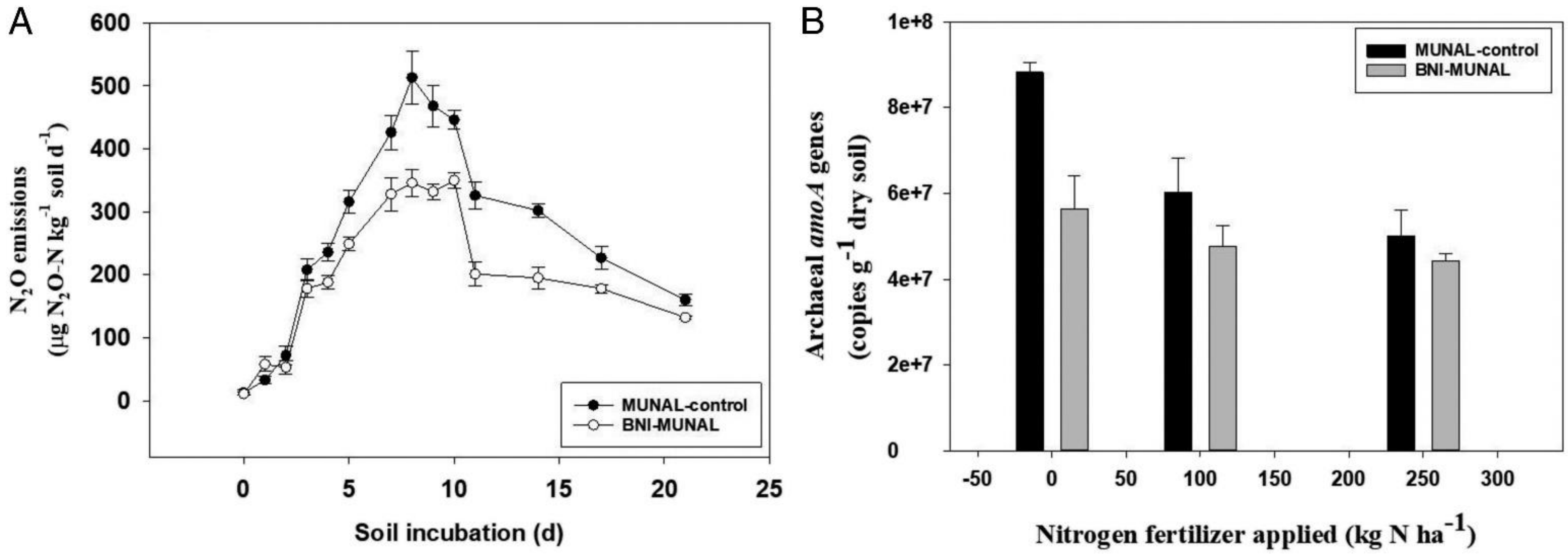
Biological nitrification inhibition (BNI) can occur via root exudates that inhibit various enzymatic steps in nitrification (and denitrification).



Coskun et al. 2017, *Trends in Plant Science*

INHIBITING NITRIFICATION

Wild grass genes encoding for biological nitrification inhibition (BNI) transferred into wheat suppressed the ammonia oxidizer community and potential soil N_2O emissions.

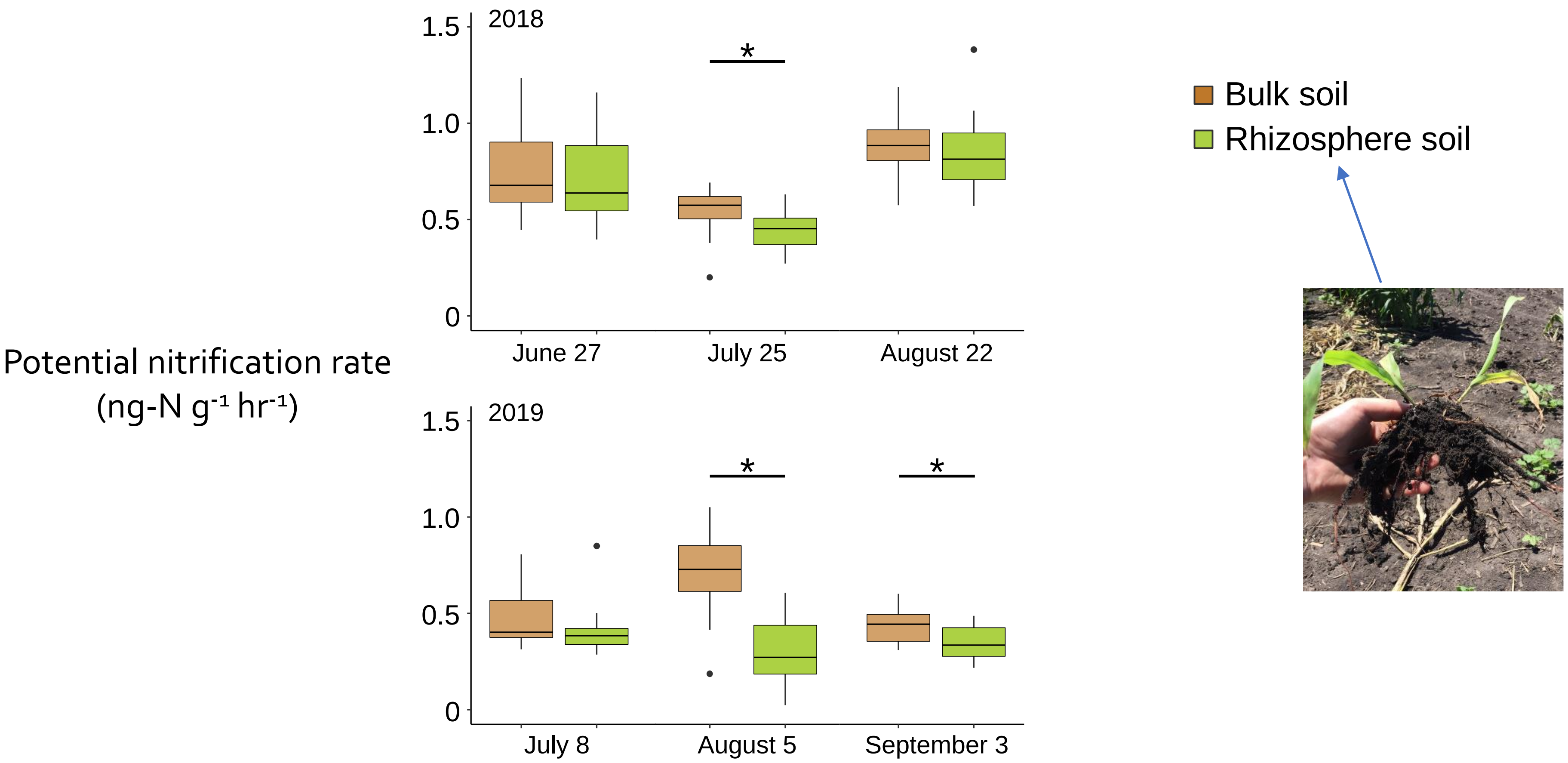


Subarrao et al. 2020, *PNAS*

INHIBITING NITRIFICATION

We detected biological nitrification inhibition in biomass sorghum fields only in the mid-growing season, estimated from the difference in potential nitrification rates between bulk and rhizosphere soil.

Mark Burnham
Former postdoc

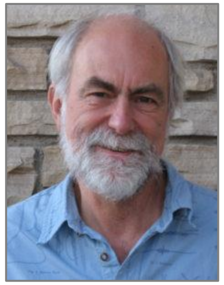


Burnham et al. 2022, *Global Change Biology - Bioenergy*

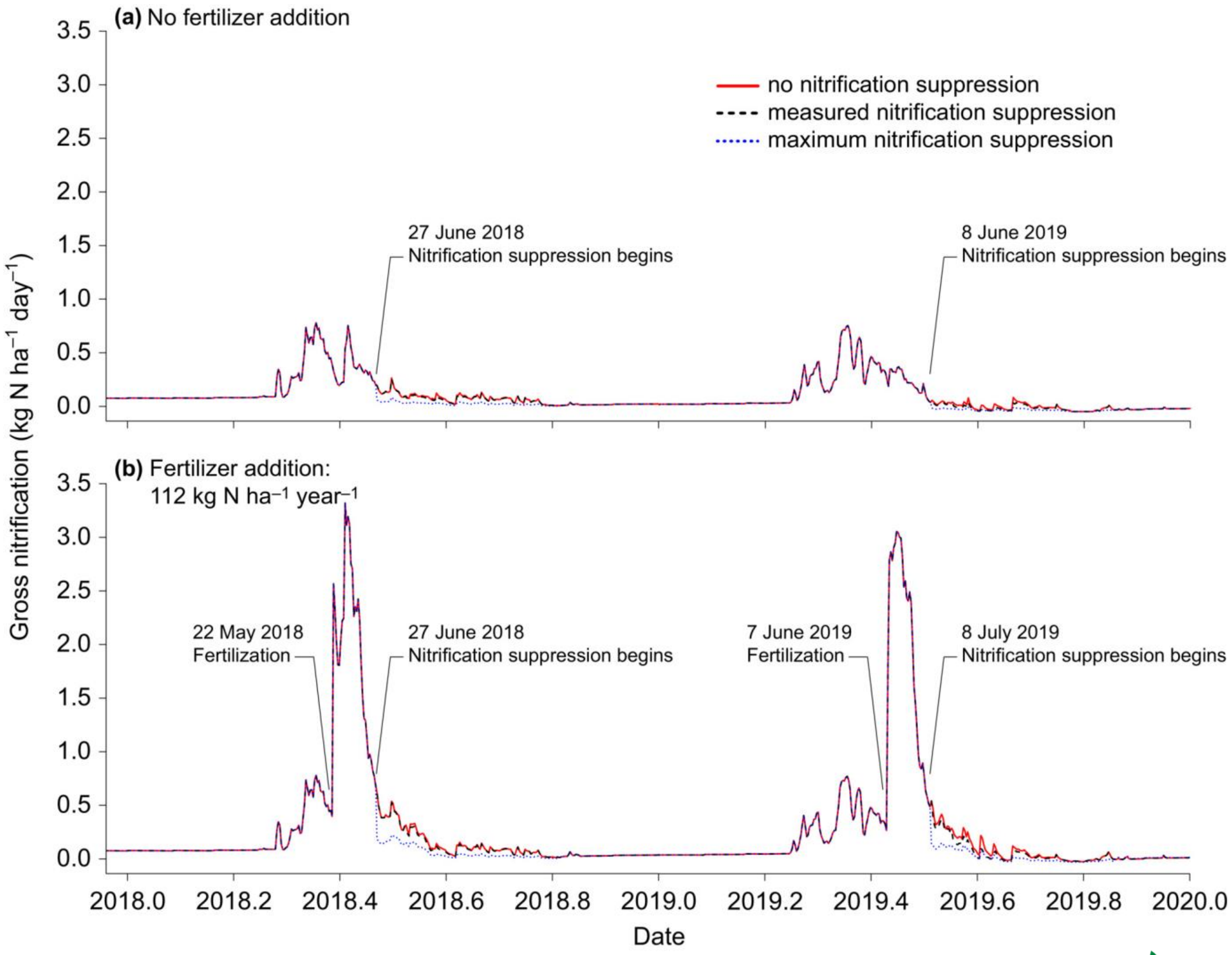
INHIBITING NITRIFICATION

DayCent model simulations suggest that BNI would have little effect on cumulative annual nitrification rates and soil N_2O emissions at the Energy Farm due to the onset of BNI after peak nitrification.

Melannie Hartman



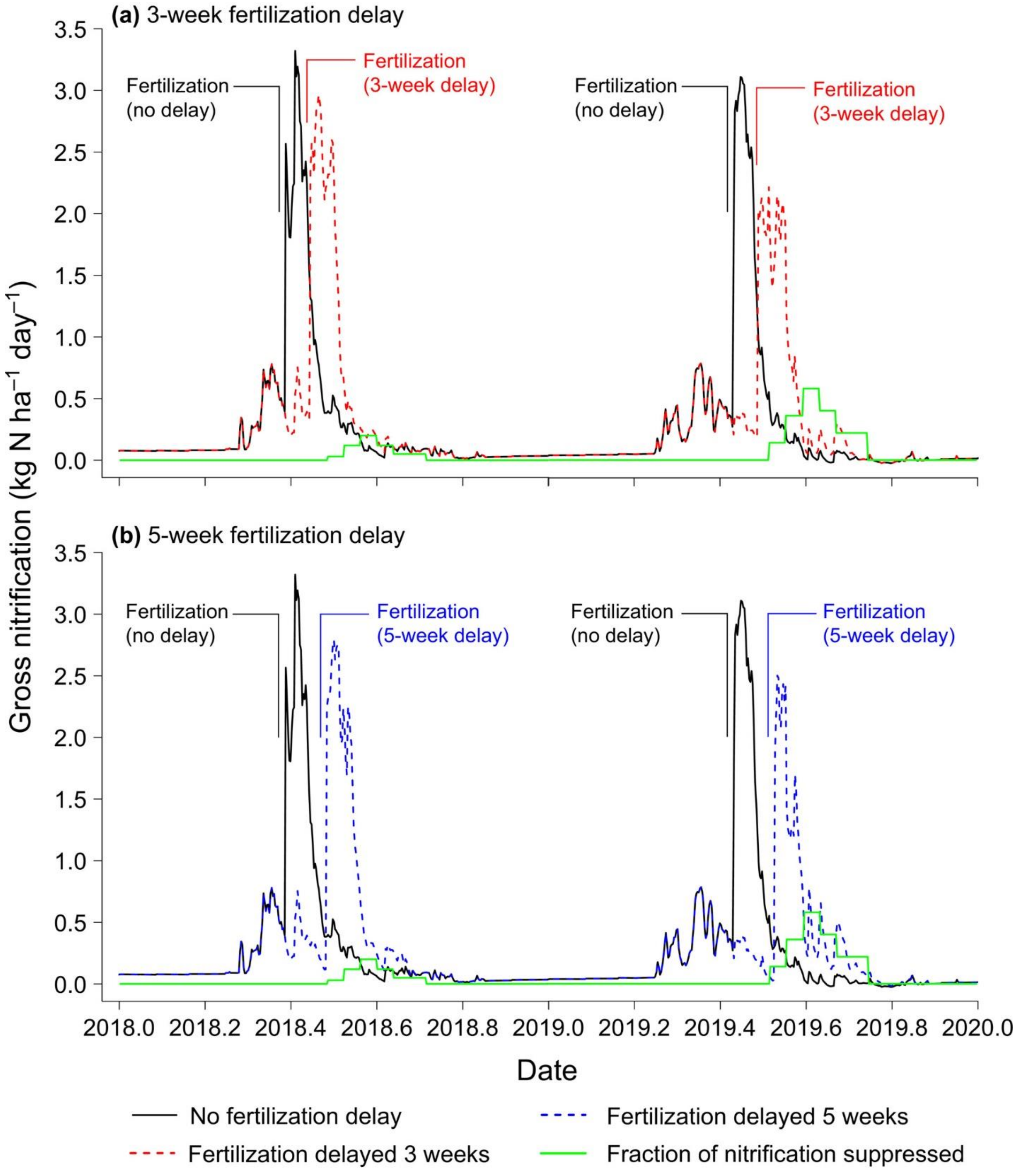
Bill Parton



Hartman et al. 2022, *Ecosphere*

INHIBITING NITRIFICATION

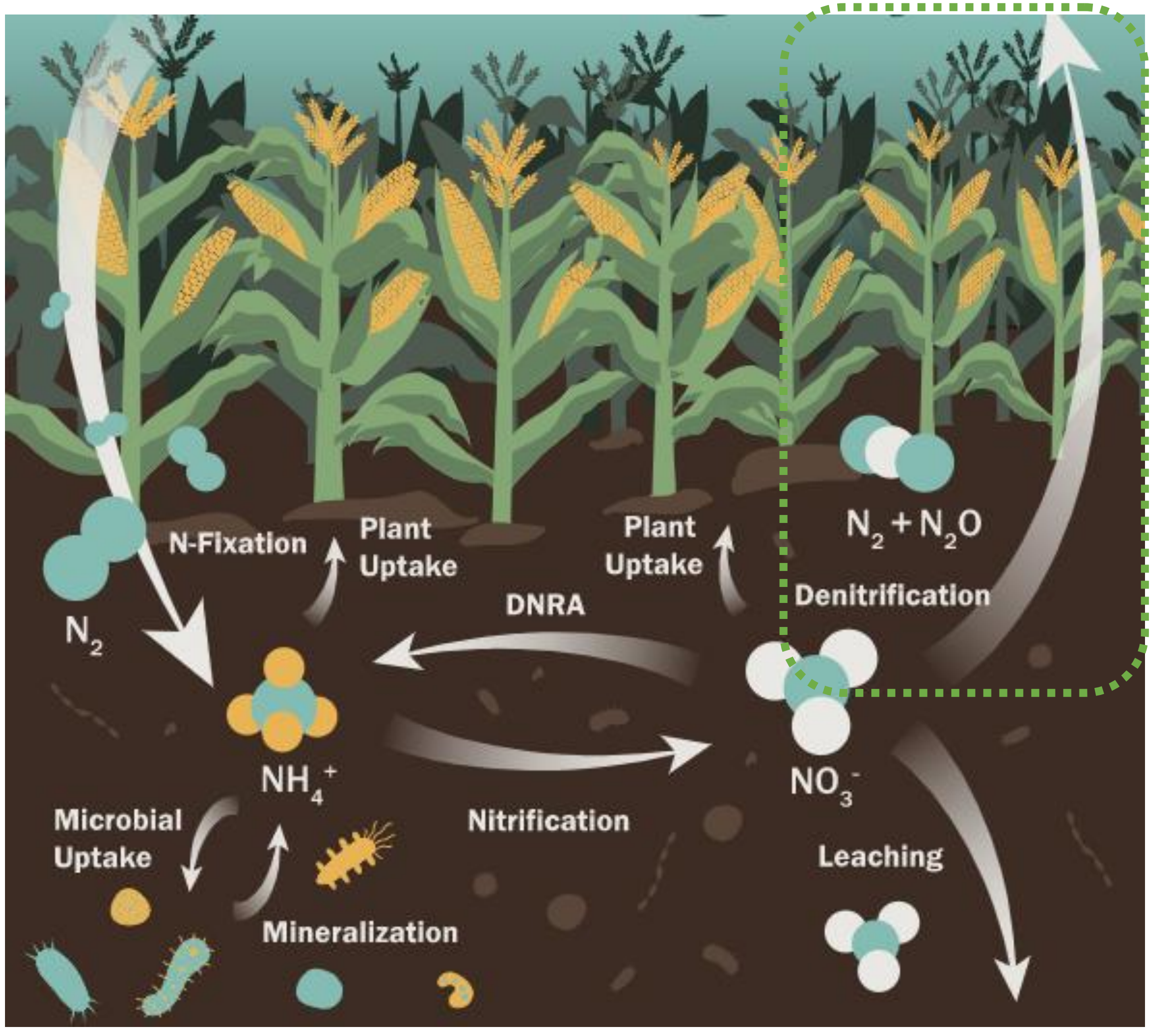
Delaying fertilization to synchronize N inputs with the onset of BNI would reduce nitrification rates, but increases in denitrification-derived N_2O emissions would compensate for decreases in nitrification-derived N_2O emissions.



Hartman et al. 2022, *Ecosphere*

SUPPRESSING DENITRIFICATION

Denitrification reduces nitrate to gaseous end-products of nitrous oxide and dinitrogen.



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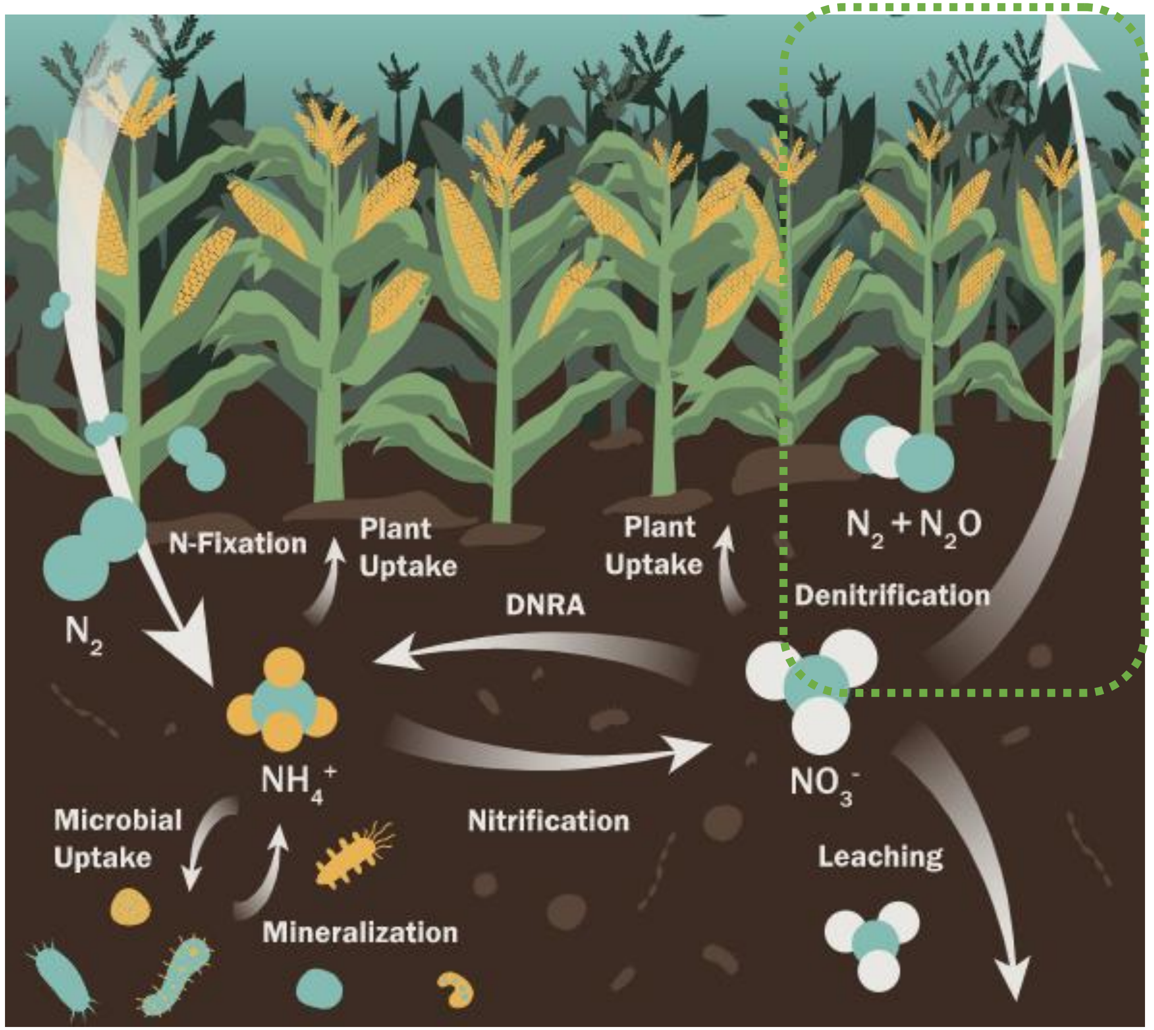
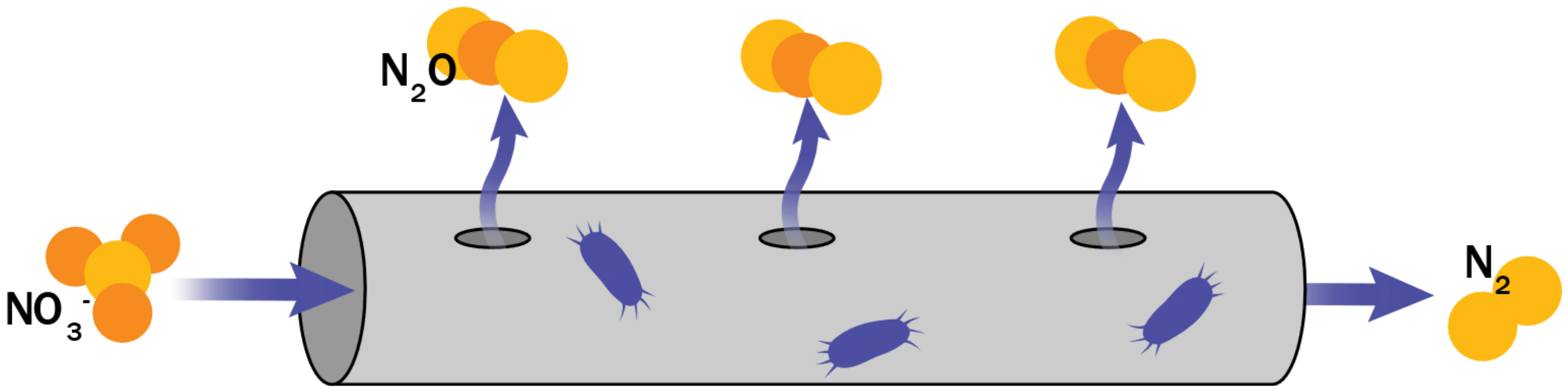


Image: Sada Egenriether, https://mail.sada-egenriether.com/

SUPPRESSING DENITRIFICATION

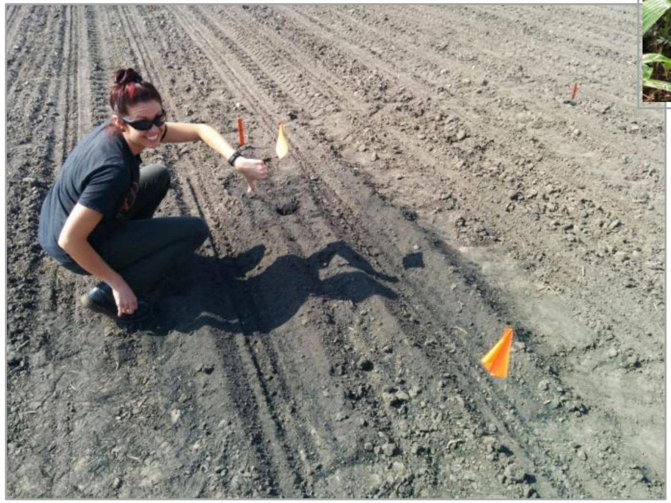
The “hole-in-the-pipe” model suggests that denitrification-derived N_2O emissions can be decreased by **suppressing overall rates of denitrification** and/or reducing the leakiness of the denitrification process.



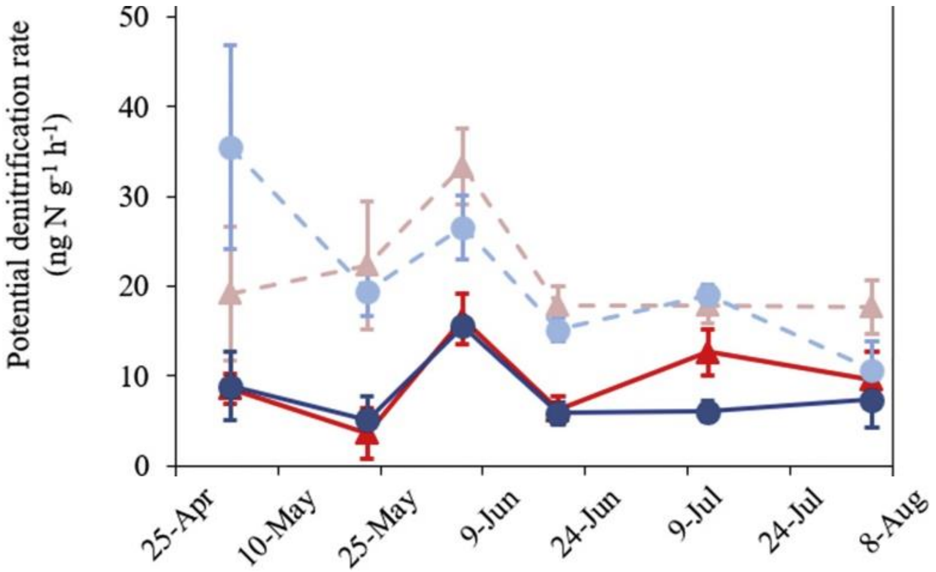
Firestone and Davidson 1989, *Exchange of Trace Gases Between Terrestrial Ecosystems and the Atmosphere*

SUPPRESSING DENITRIFICATION

Biochar suppresses denitrification potential.



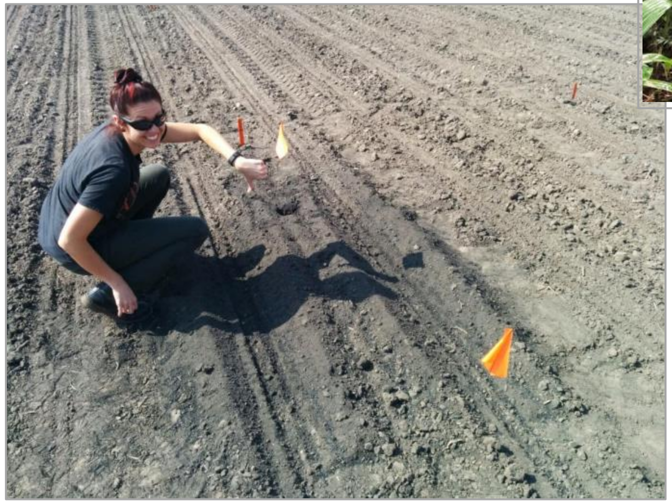
Joseph Edwards
BS 2017, PhD 2022



Edwards et al. 2018, Soil Biology & Biochemistry

SUPPRESSING DENITRIFICATION

Biochar suppresses denitrification potential, but it also stimulates nitrification in fertilized soils.



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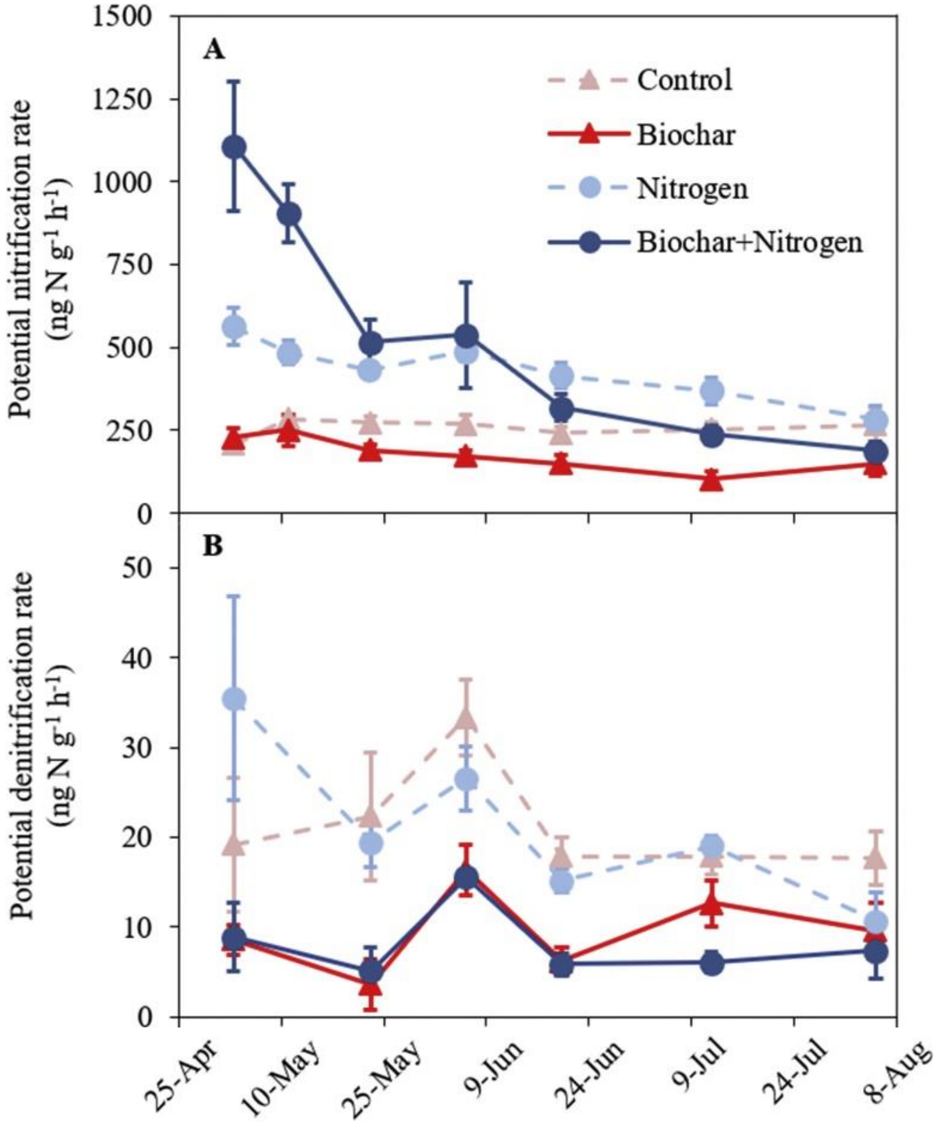
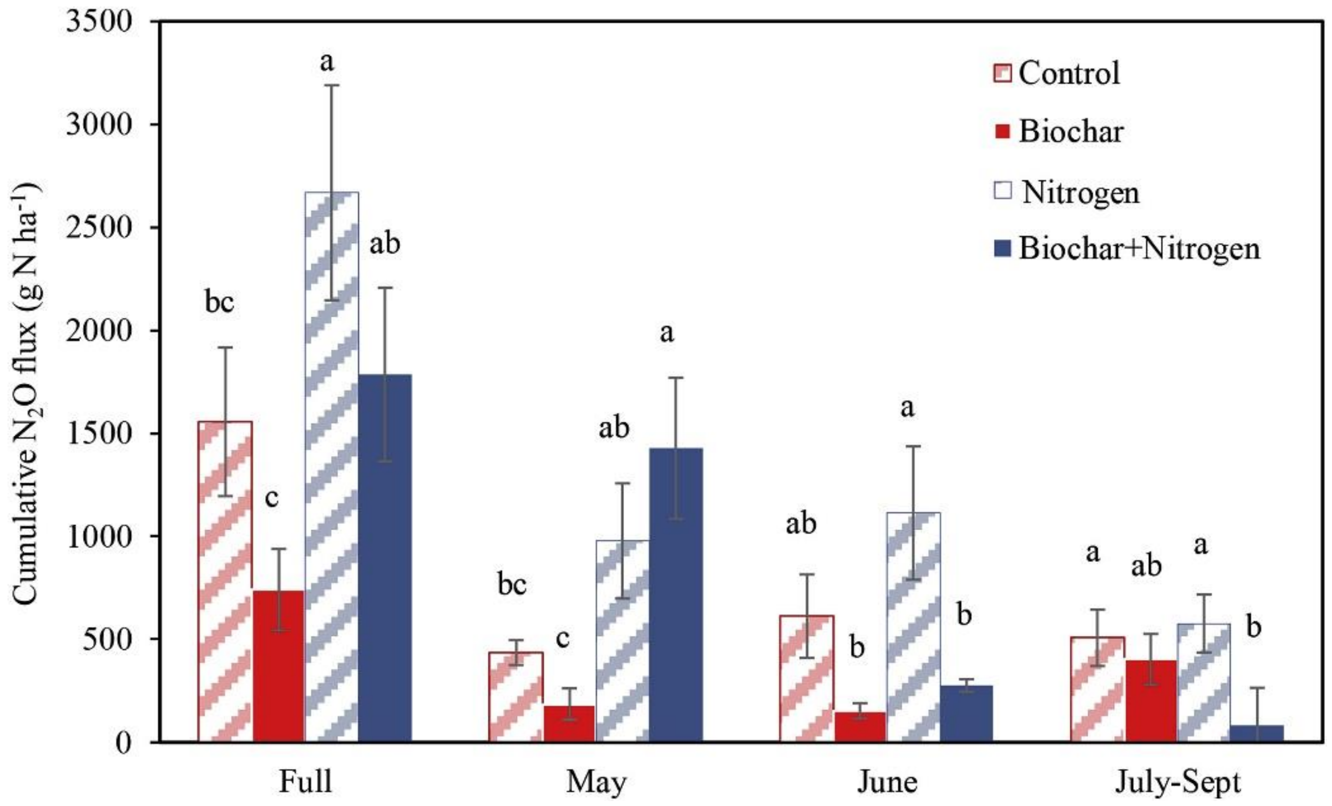


Edwards et al. 2018, Soil Biology & Biochemistry

SUPPRESSING DENITRIFICATION

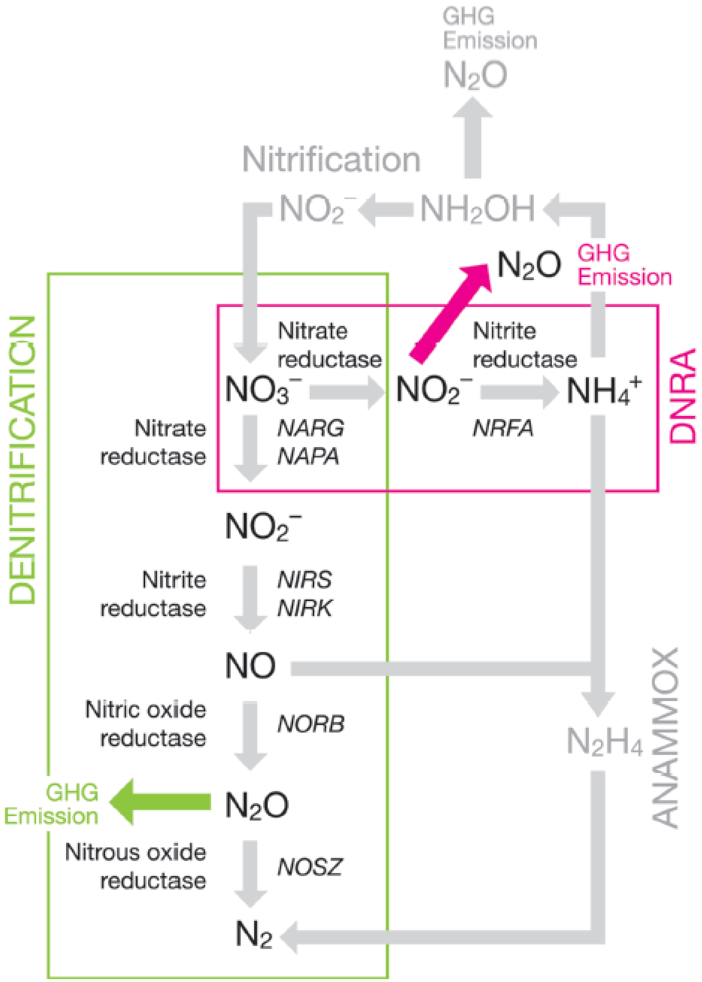
Biochar decreased cumulative growing season N_2O emissions, but when combined with N fertilization, it increased N_2O emissions in the early growing season when nitrification peaks.



Edwards et al. 2018, Soil Biology & Biochemistry

SUPPRESSING DENITRIFICATION

Dissimilatory nitrate reduction to ammonium (DNRA) is an anaerobic microbial process that returns inorganic N from nitrate to ammonium, contributing to N retention in the soil.



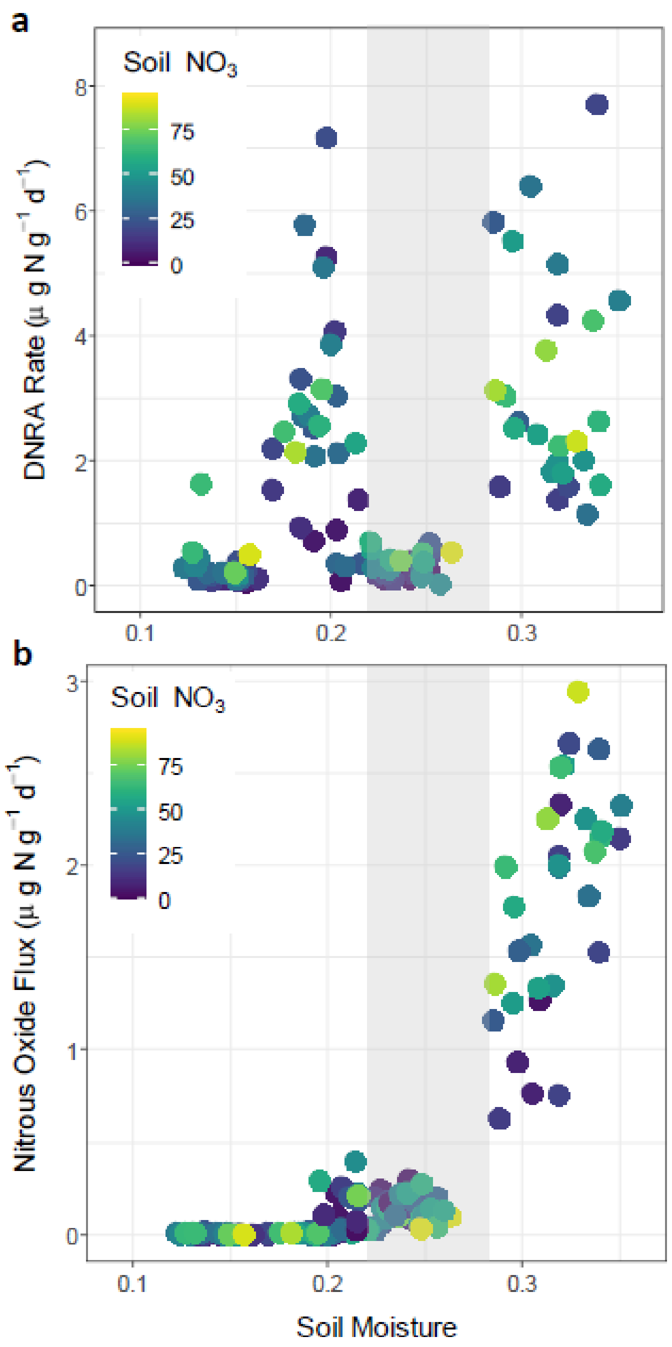
Giles et al. 2012, *Frontiers in Microbiology*

SUPPRESSING DENITRIFICATION

The diversity in harboring *nrfA* leads to DNRA function at both high and low soil moisture, suggesting potential to enhance DNRA to directly compete with denitrification or to suppress denitrification by depleting the soil nitrate pool.

Sada Egenriether
PhD 2021

Angela Kent



Egenriether et al., in prep

ENHANCING N_2O REDUCTION

Nitrous oxide reduction completes the N cycle by returning reactive N back to the inert form of N_2.

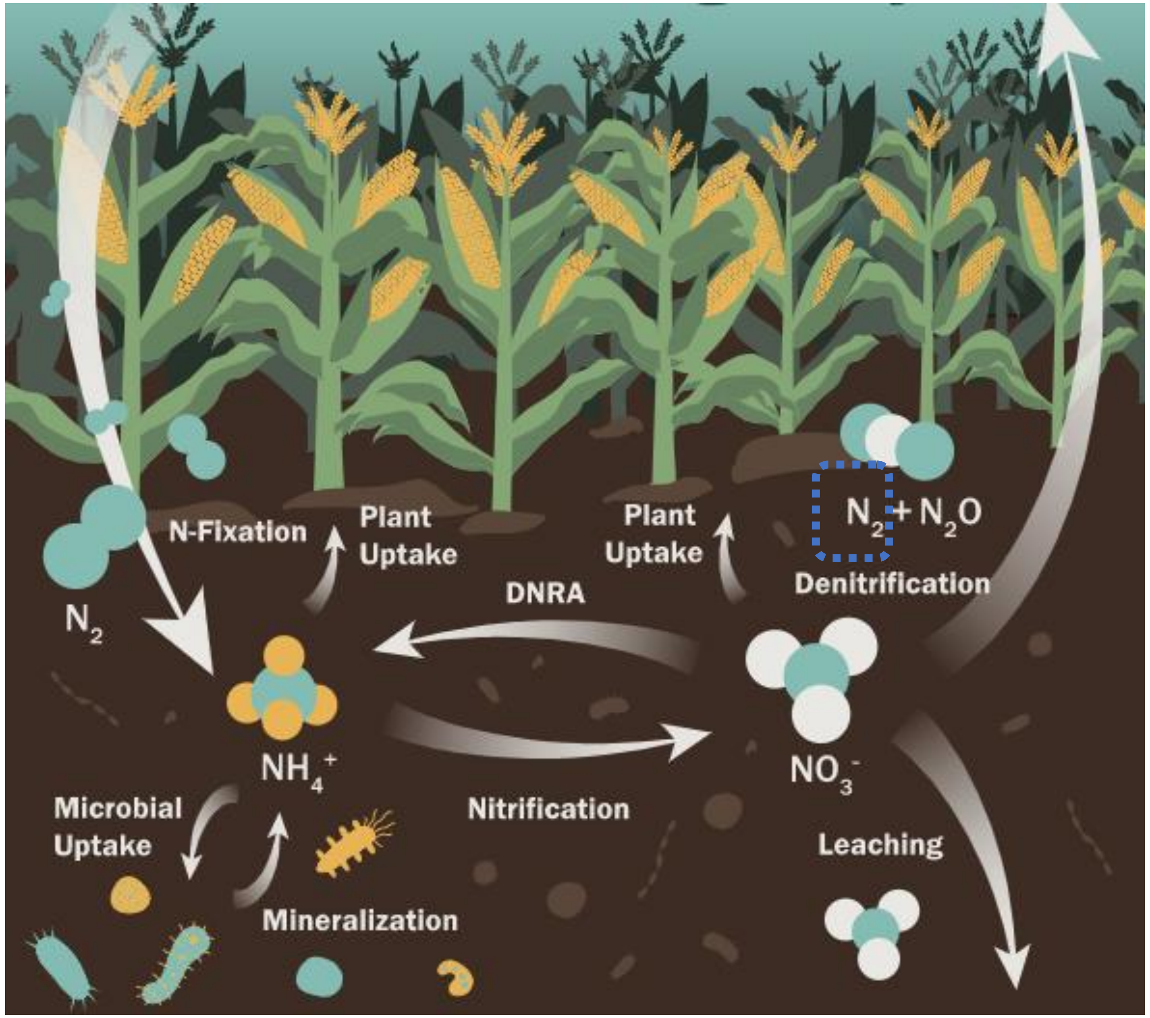
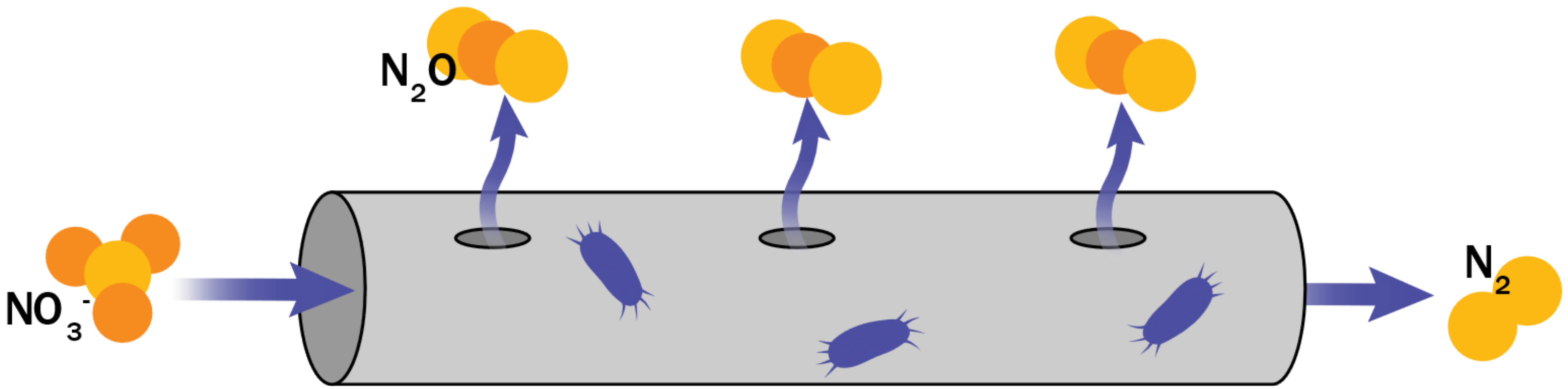


Image: Sada Egenriether, https://mail.sada-egenriether.com/

ENHANCING N_2O REDUCTION

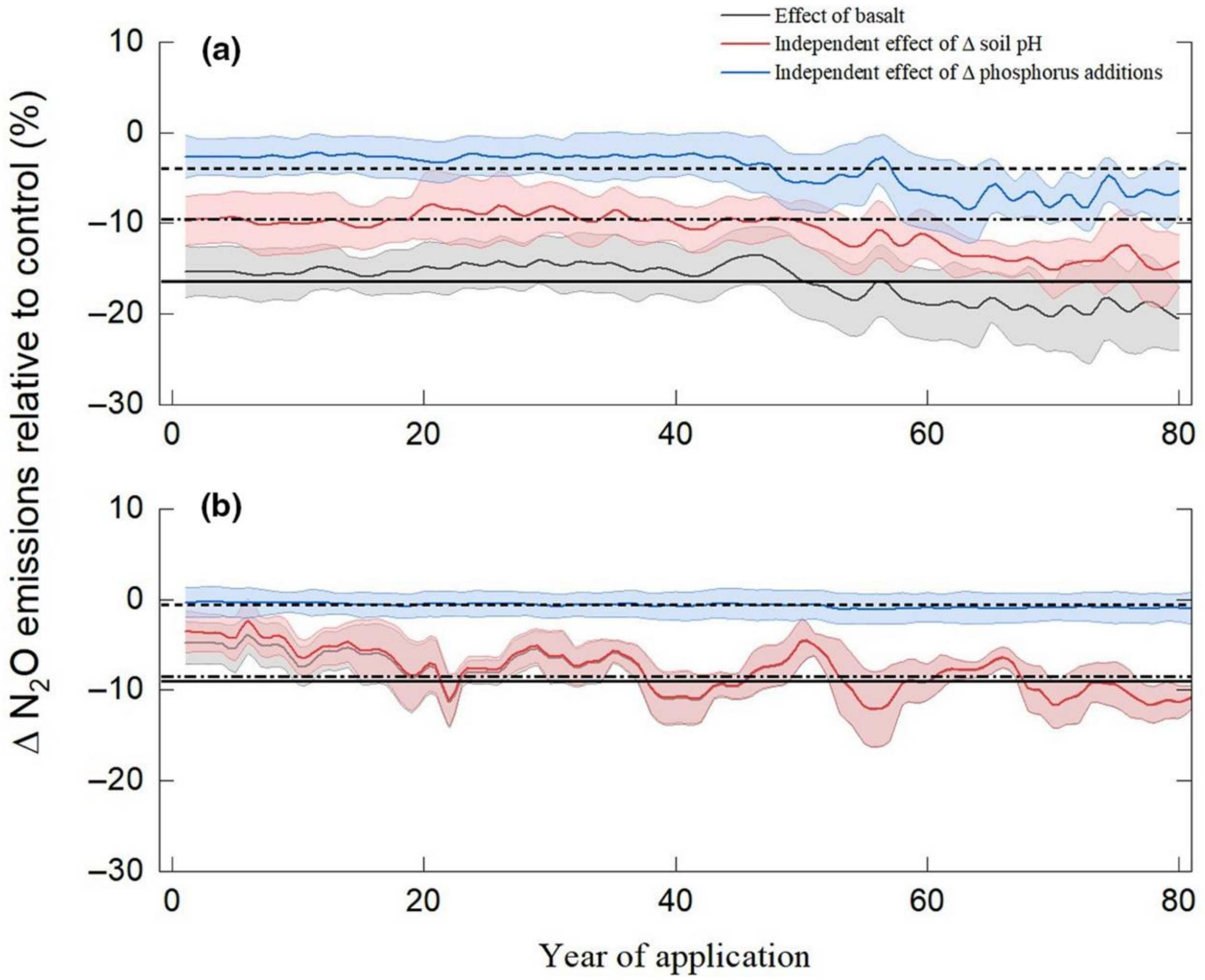
The "hole-in-the-pipe" model suggests that denitrification-derived N_2O emissions can be decreased by suppressing overall rates of denitrification and/or **reducing the leakiness of the denitrification process**.



Firestone and Davidson 1989, *Exchange of Trace Gases Between Terrestrial Ecosystems and the Atmosphere*

ENHANCING N_2O REDUCTION

Increased soil pH from basalt amendments can enhance the activity of the N_2O reductase enzyme, NosZ.



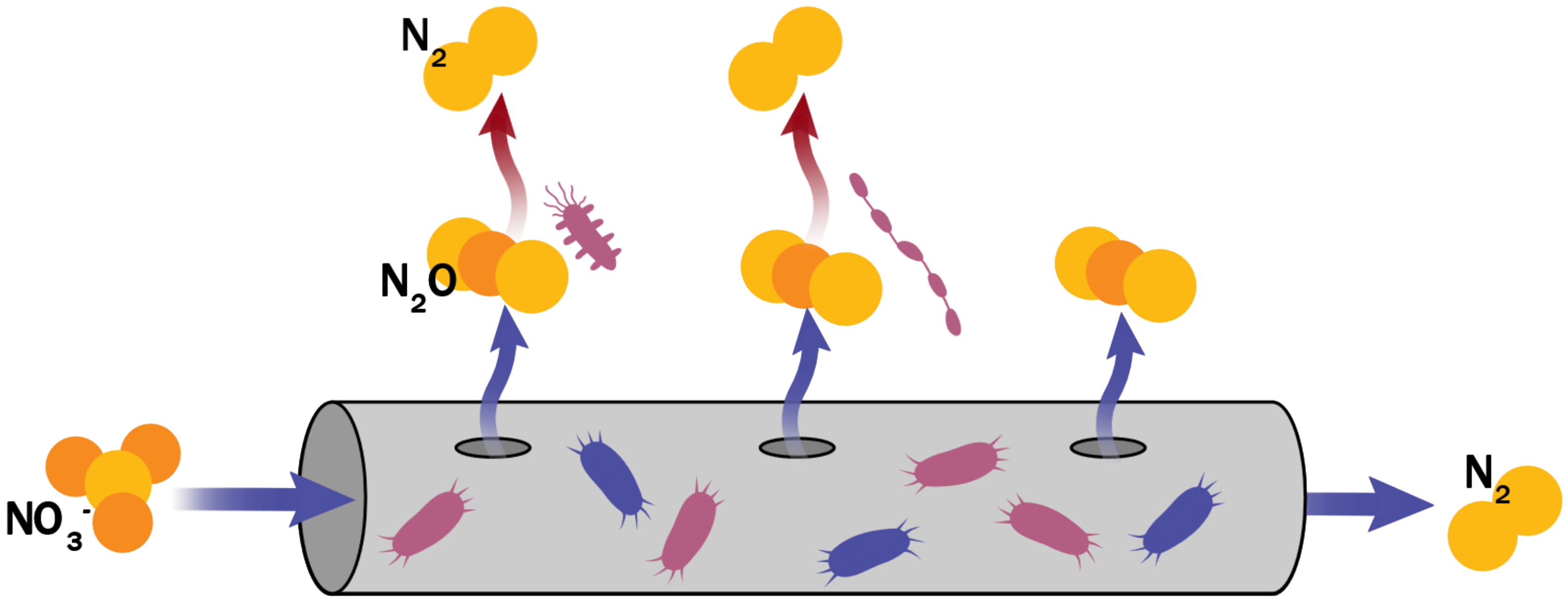
Elena Blanc-Betes

Evan DeLucia

Blanc-Betes et al. 2020, *Global Change Biology - Bioenergy*

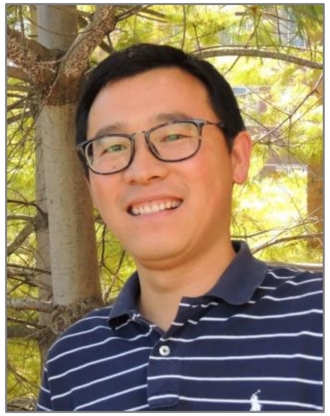
ENHANCING N_2O REDUCTION

The relatively recent discovery of Clade II NosZ which has more functional diversity than Clade I NosZ expands the environmental contexts in which N_2O reduction can occur, beyond denitrification.

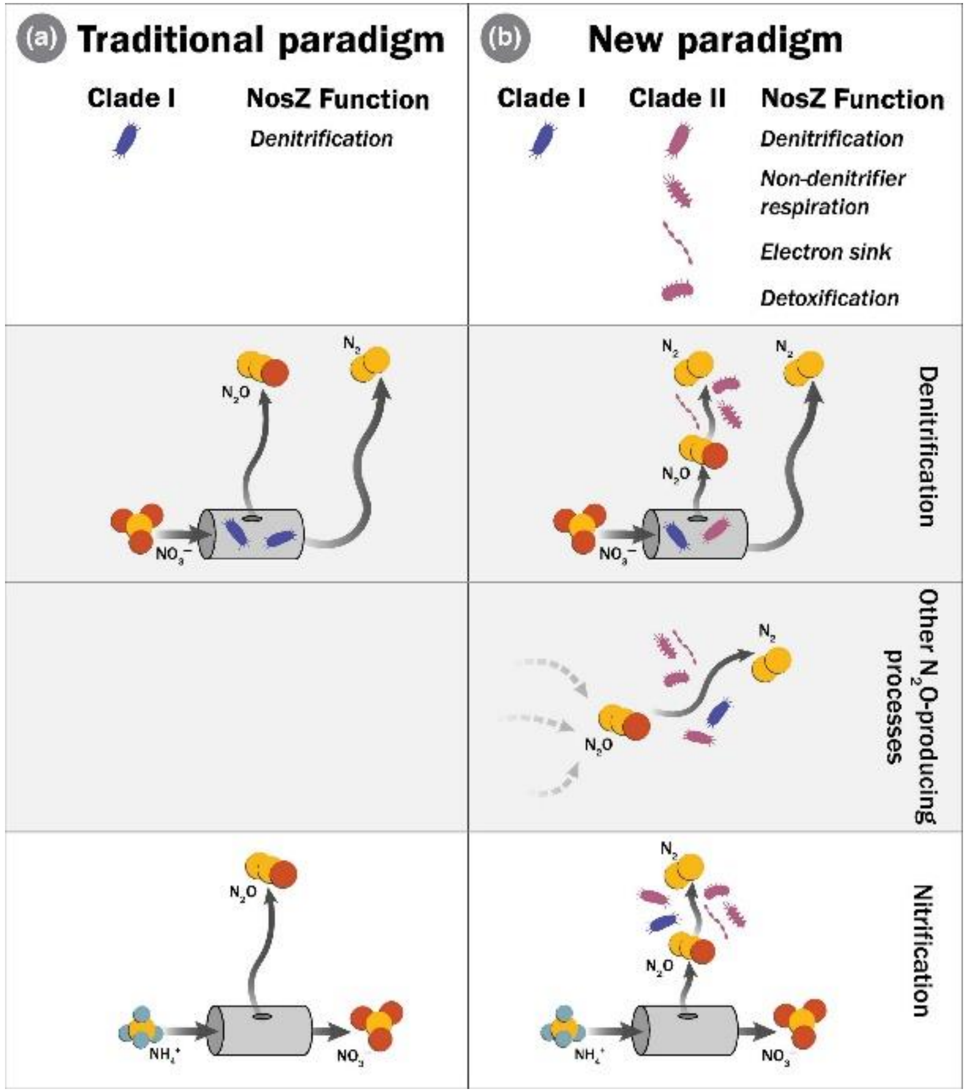


ENHANCING N_2O REDUCTION

Clade II N_2O reducers are generally more abundant in soil than Clade I N_2O reducers, but we still have poor understanding of conditions controlling Clade II NosZ function.



Jun Shan
Former Visiting Scientist



Shan et al. 2021, *Global Change Biology*

OPPORTUNITIES TO REDUCE N_2O EMISSIONS

The major challenges include accounting for long-term sustainability, considering effectiveness in the environment, and isolating microbes with the desired functional capabilities.

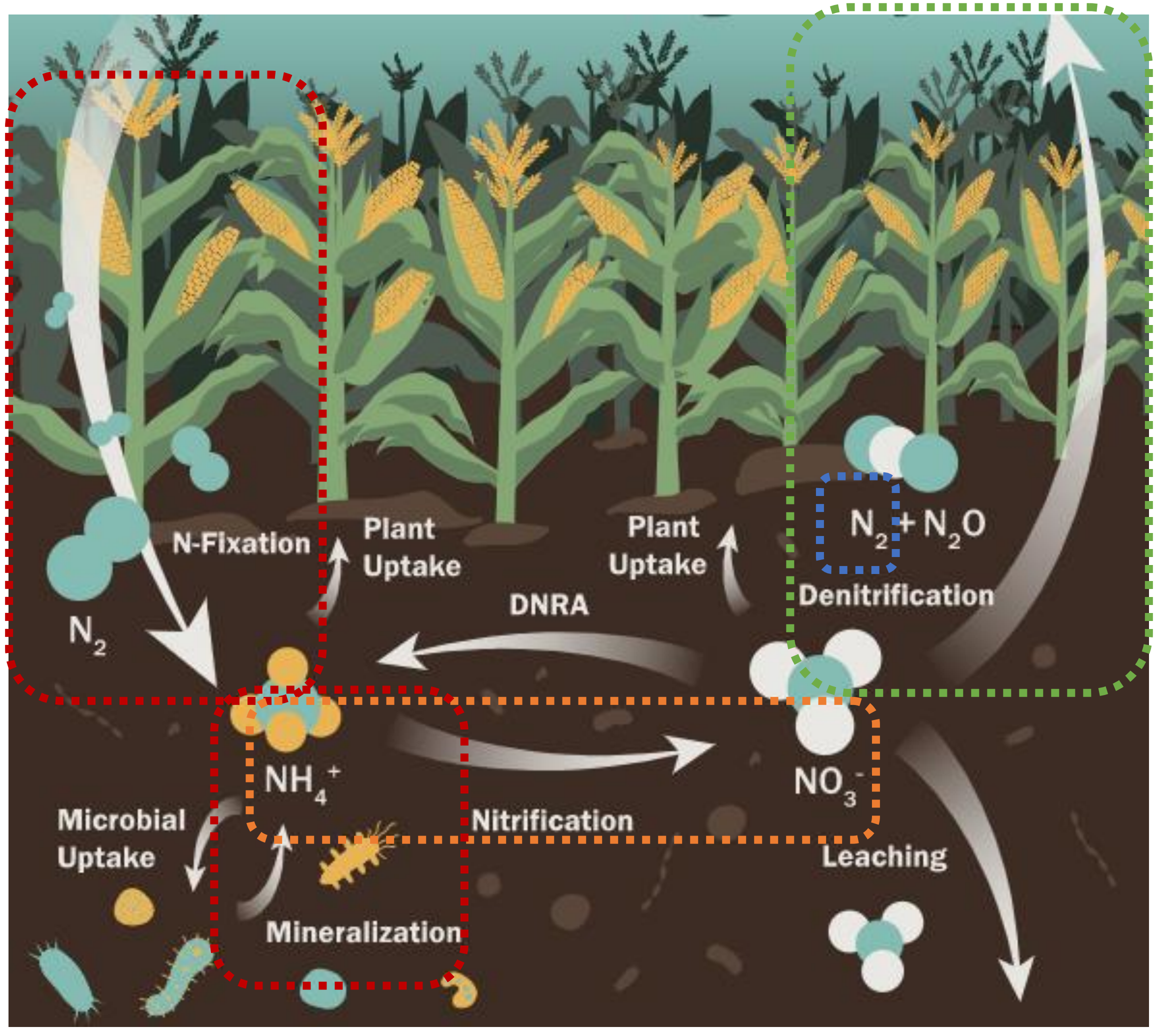


Image: Sada Egenriether, https://mail.sada-egenriether.com/

A CAUTIONARY ENDING

High spatial variation in soil N_2O emissions challenges our ability to evaluate the effectiveness of any technologies.

Zhang, Eddy, et al., Submitted to *Nature Geoscience*