# Understanding the devious nitrogen cycle: Are we there yet?

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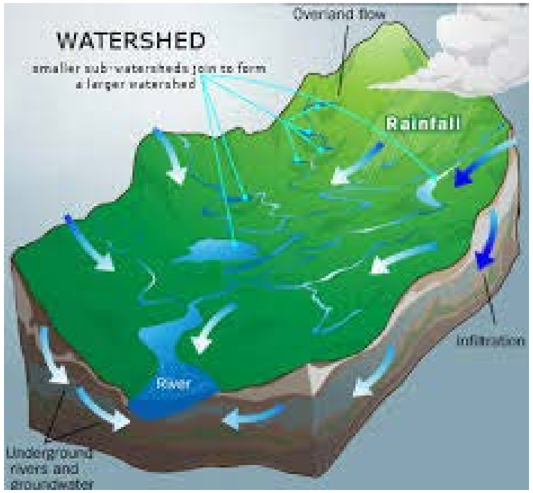
# Overview of this talk

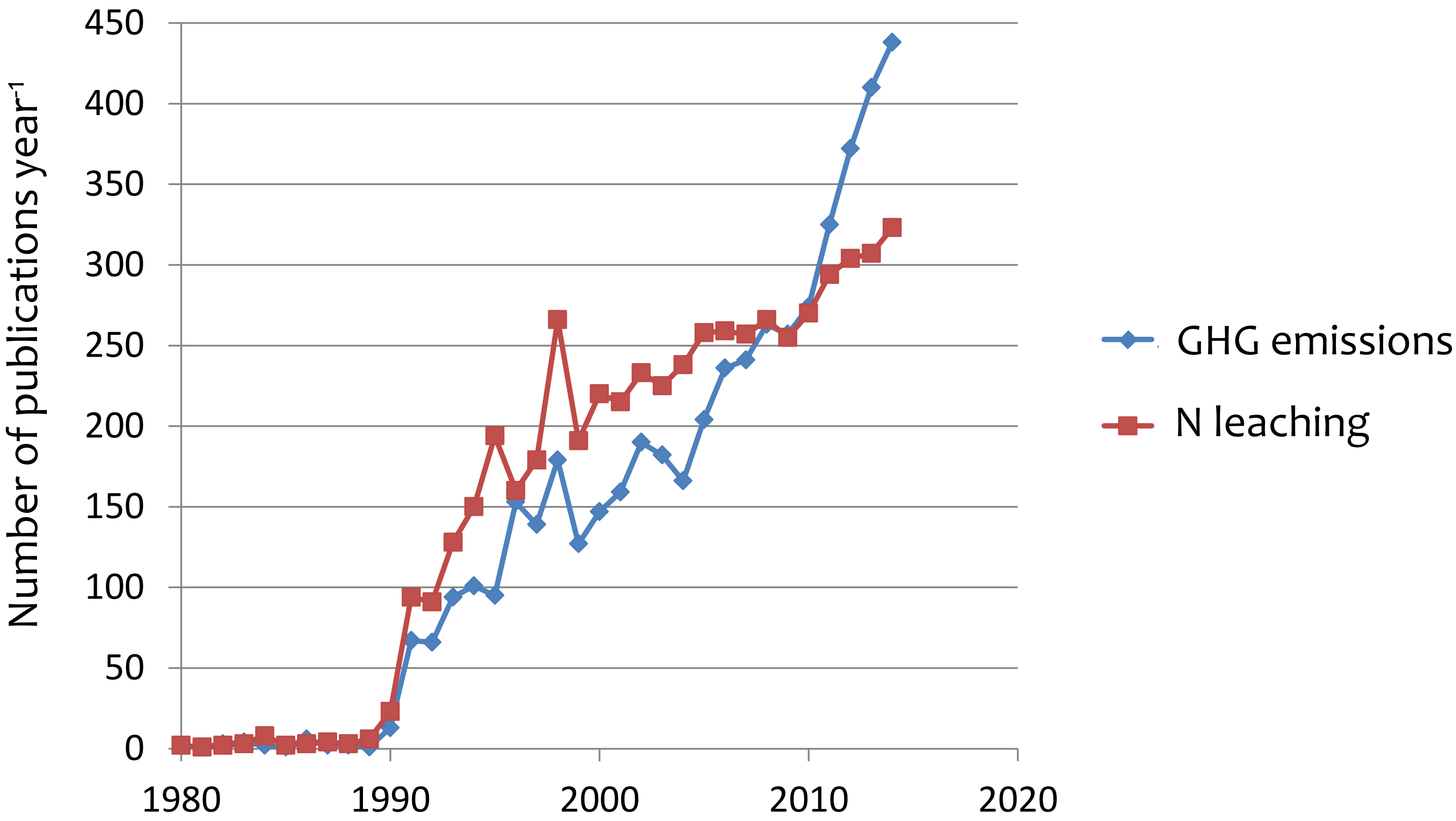
- Coming to grips with the true nature of the nitrogen problem
- Discoveries that have changed our view of N cycling
  - N saturation as a conceptual framework
  - The role of plant-microbial collaborations in driving N/C cycles
  - Microbial communities and N loss/conservation pathways
- The way forward

# The changing scale of the nitrogen problem

1970's: Groundwater contamination → 1980's: Watershed budgets → 1990's Global budgets




# Research on the fate of fertilizer N: nitrate leaching and nitrous oxide losses




Web of science: 1900-present

# Watershed studies documented the flow of N from agricultural lands

- …watersheds with more agricultural land had consistently higher loads of N, K, Ca, Mg, and Cl in streamflow and had NO3-N loads 1.5 to 4.4 times higher than loads from the less agricultural watersheds. (Lowrance et al. 1985, Ecology)
- Tracking total N flows for an entire year to calculate N mass balance documented "massive flows of N, especially from anthropogenic sources". (Kesner et al. 1989, Landscape Ecology)

Issues in Ecology

# Technical Report

*Ecological Applications*, 7(3), 1997, pp. 737–750


## HUMAN ALTERATION OF THE GLOBAL NITROGEN CYCLE: SOURCES AND CONSEQUENCES

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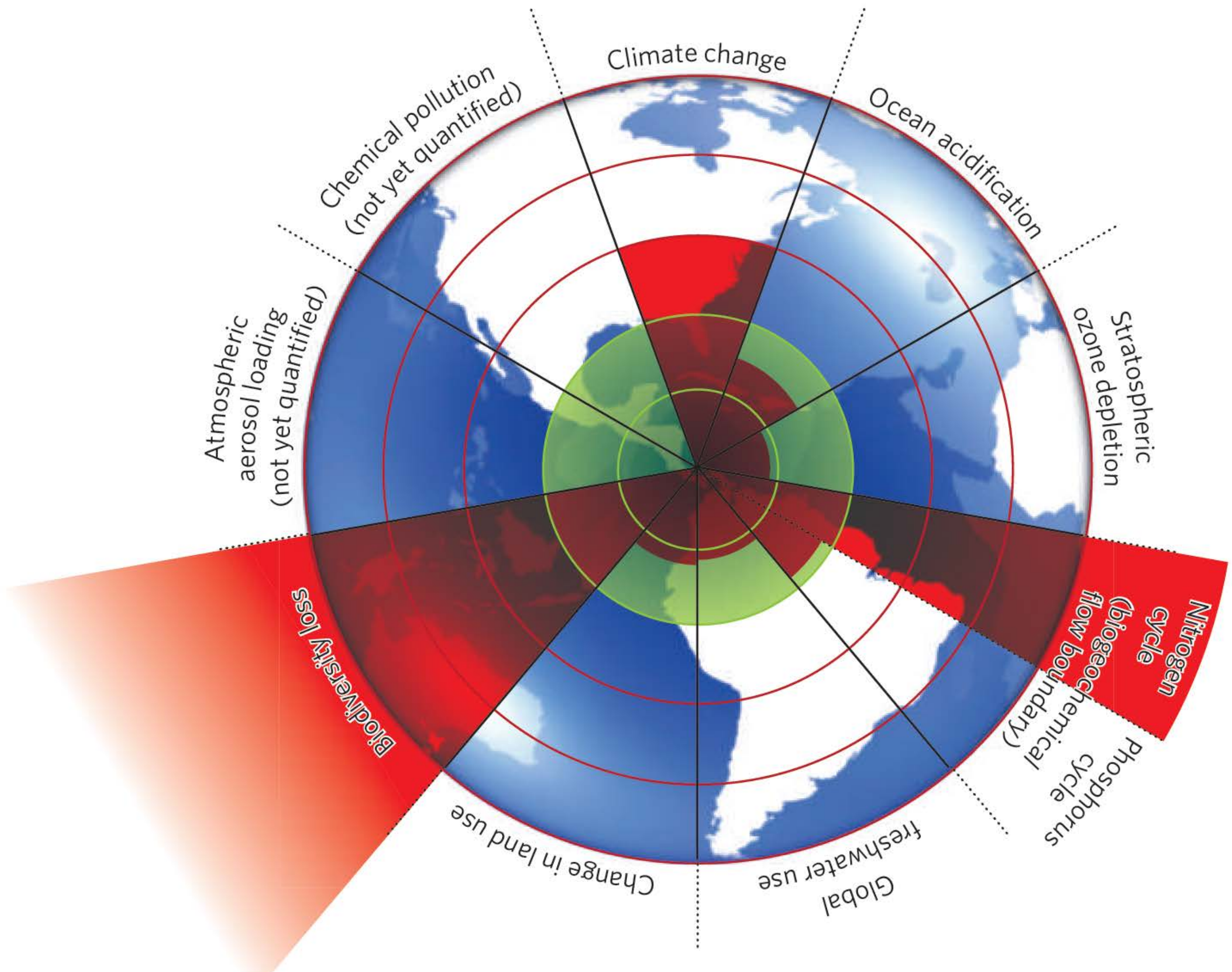
(2,200 citations)

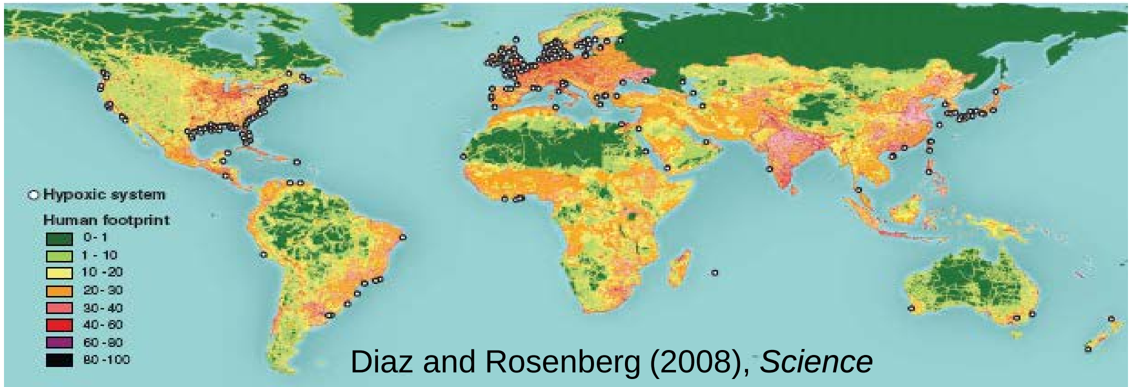
# How much global change is acceptable?




Rockstrom et al., 2009, Nature; 1113 citations

# The persistent problem of agricultural N losses

- About half the N applied a fertilizer is lost to the environment
- Reactive N in the biosphere has doubled
- Agriculture accounts for 75% of all anthropogenic N
- Increased GHG emissions; N deposition → species losses and ecosystem changes
- Eutrophication of freshwater resources and near shore hypoxic zones:  More than 400 world wide



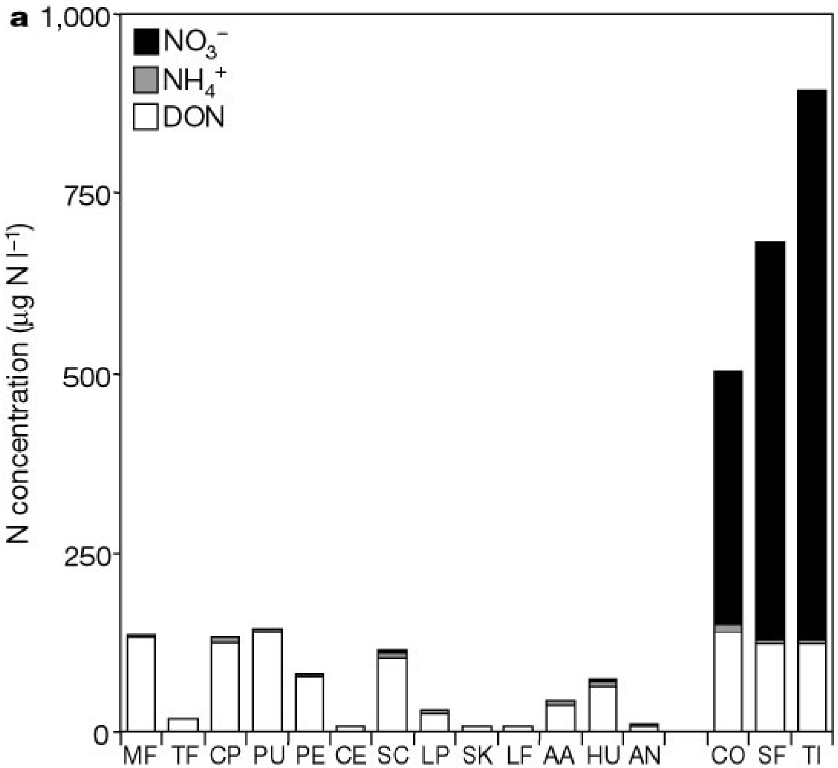
Diaz and Rosenberg (2008), *Science*

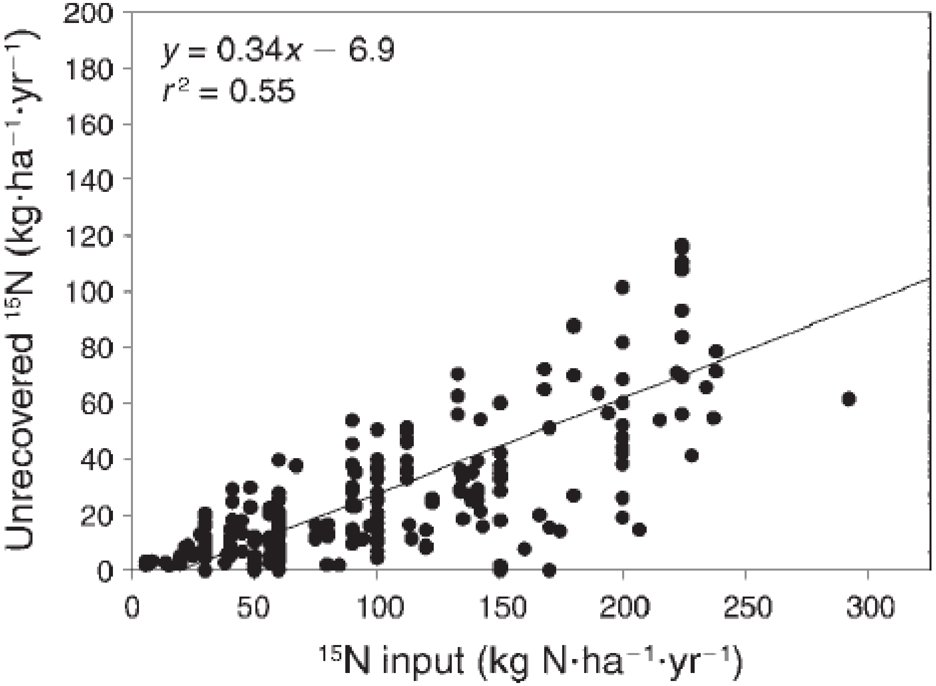
# Discoveries that have changed our view of N cycling

- N saturation as a conceptual framework

- N saturation: N influx exceeds the capacity of the ecosystem to assimilate or store N in internal reservoirs which can be accessed by plants or microorganisms

# N losses are a symptom of N saturation




Perakis and Hedin 2002 Nature; Gardner and Drinkwater 2009, Ecological Appl.

# Symptoms of N saturation

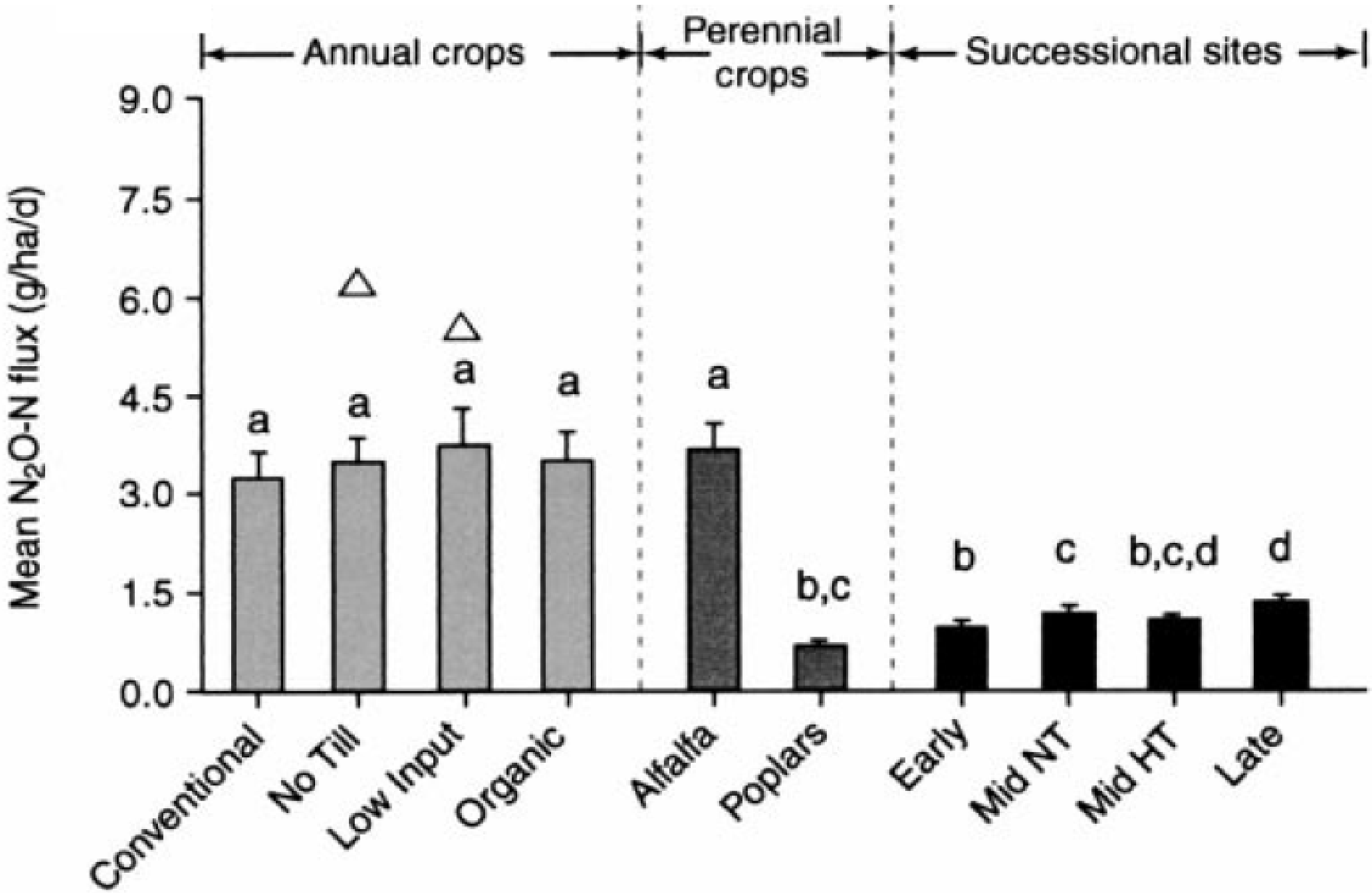
- Increased rates of nitrification & soil acidification
- Increased leaching losses of DOC, DON, $NO_3^-$, & cations
- Greater proportion of N is lost as nitrate
- Increased $N_2O$ production from denitrification(?)

# N saturation hypothesis

- Developed to explain differences in N loss & retention across forest ecosystems
- Provides an organizing framework for understanding how N cycling in natural systems interacts with other elemental cycles
- Highlights the tight coupling between N and C cycling
- Predicts ecosystem response to N pollution (anthropogenic N additions)

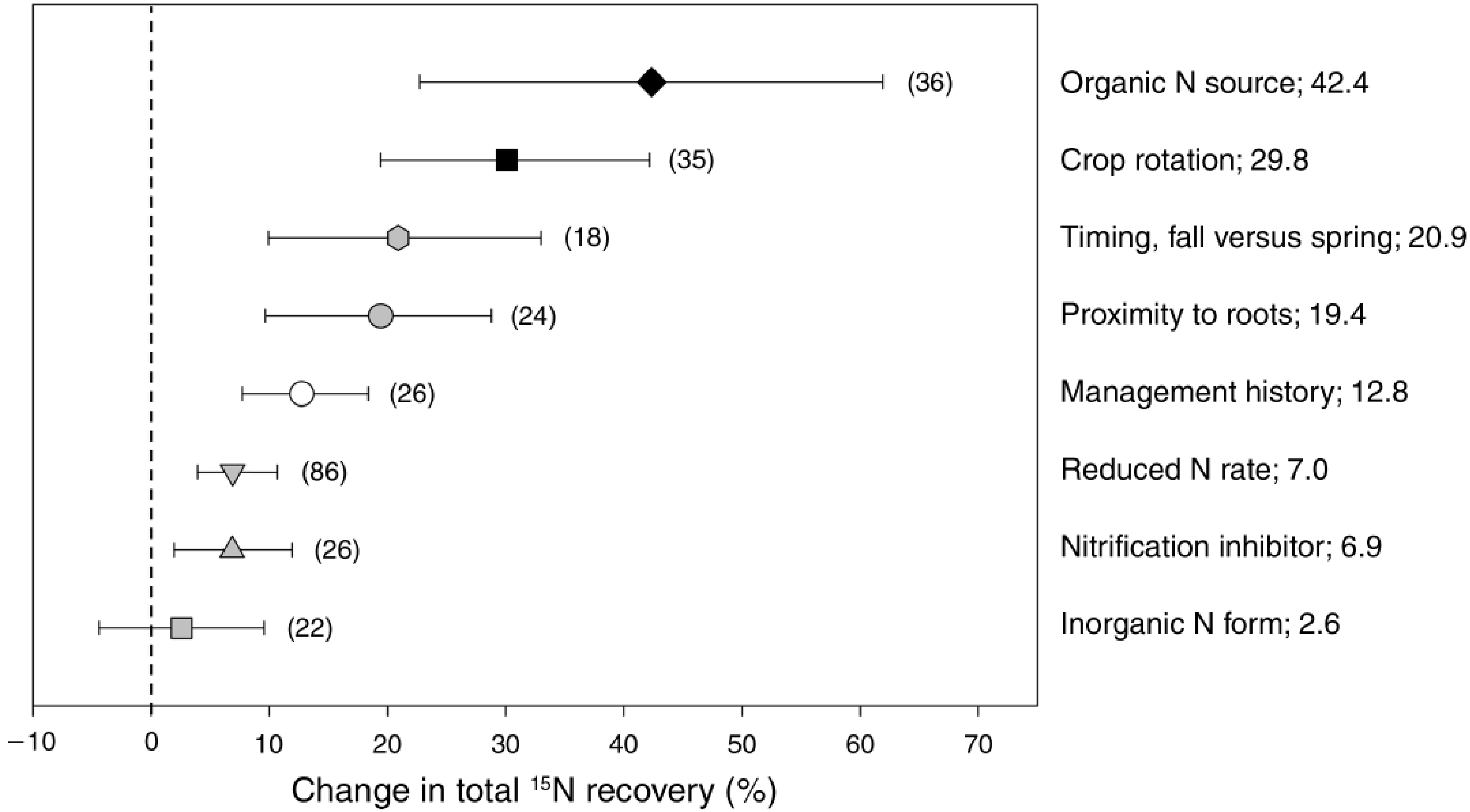
Aber et al. 1989,1998; Fenn et al. 1998; Perakis and Hedin 2002

# KBS-LTER: N losses across ecosystems



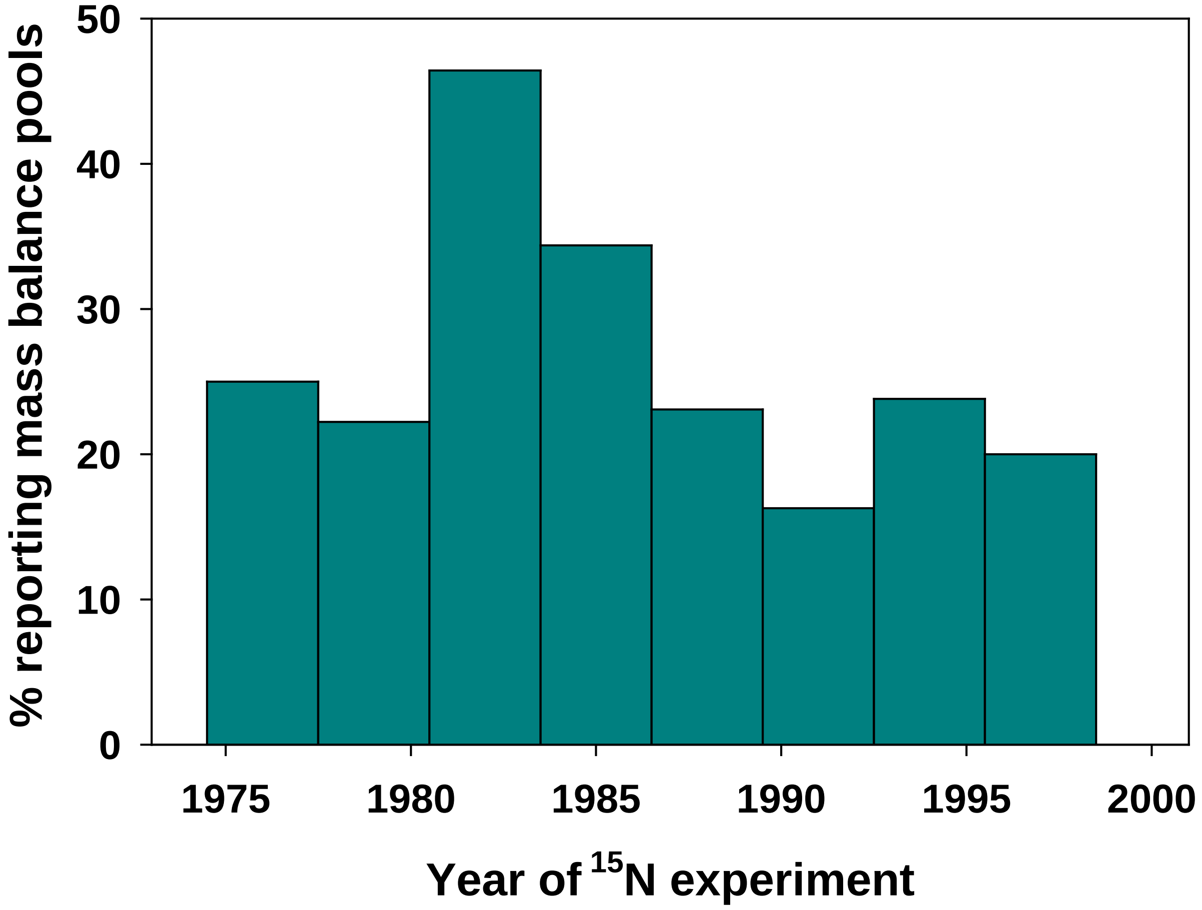

Robertson et al. 2000, Science, (550)

# Strategies that re-couple C and N have the greatest impact on N recovery



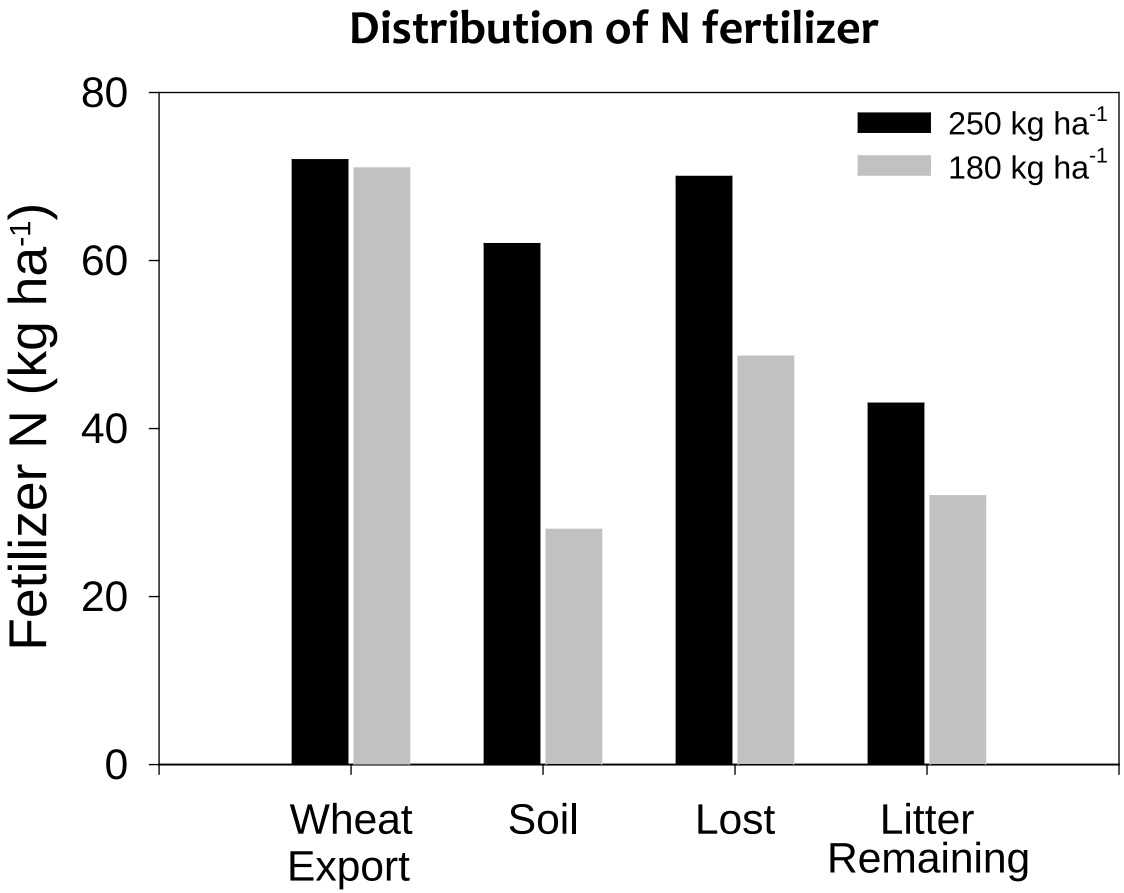

Based on 217 field-scale $^{15}N$ studies, Gardner and Drinkwater 2009, Ecol. Applications

# $^{15}N$ Research in Grain Agroecosystems



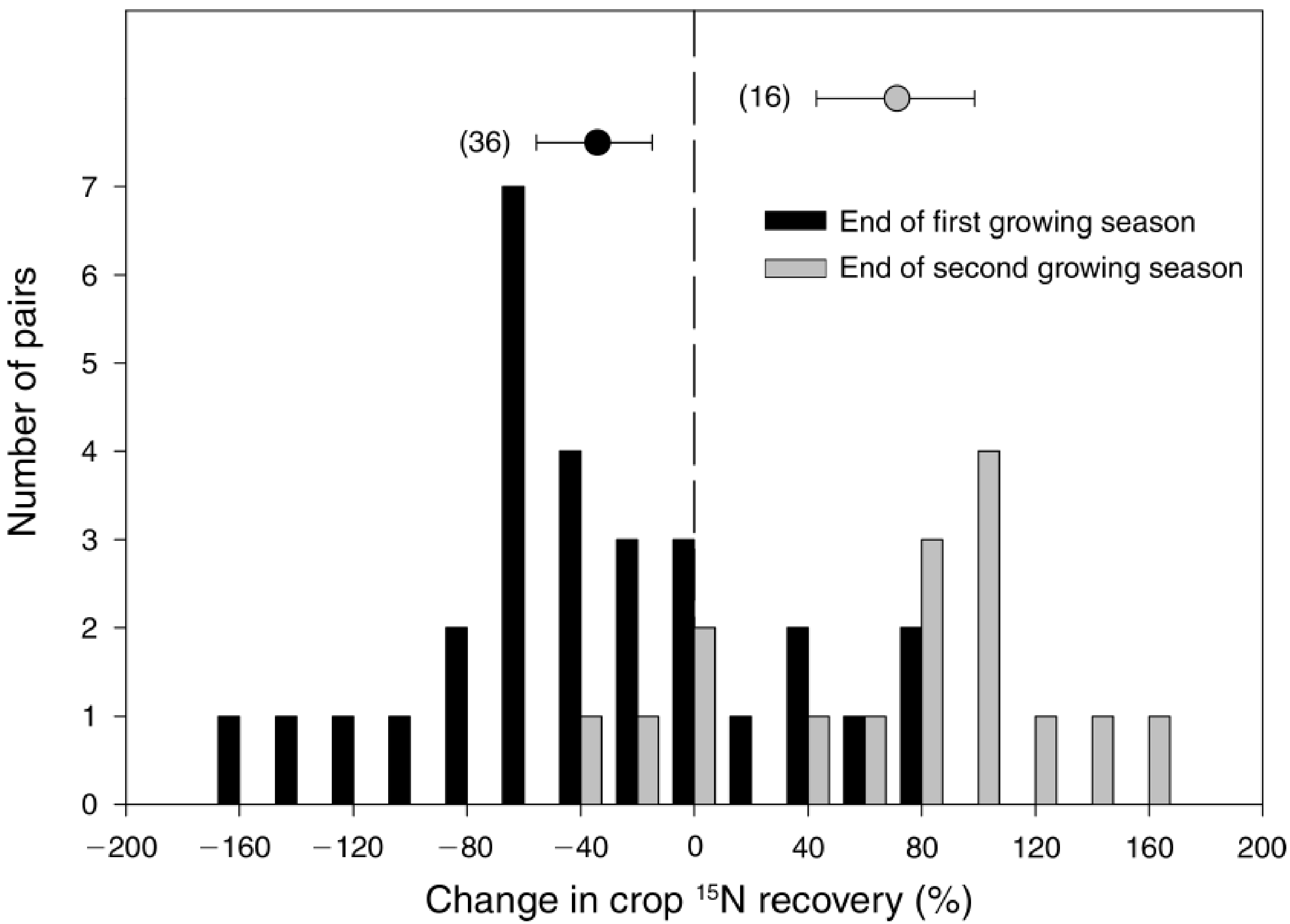

Gardner and Drinkwater, 2009

# Fate of fertilizer N: How does improved FUE alter N flows?

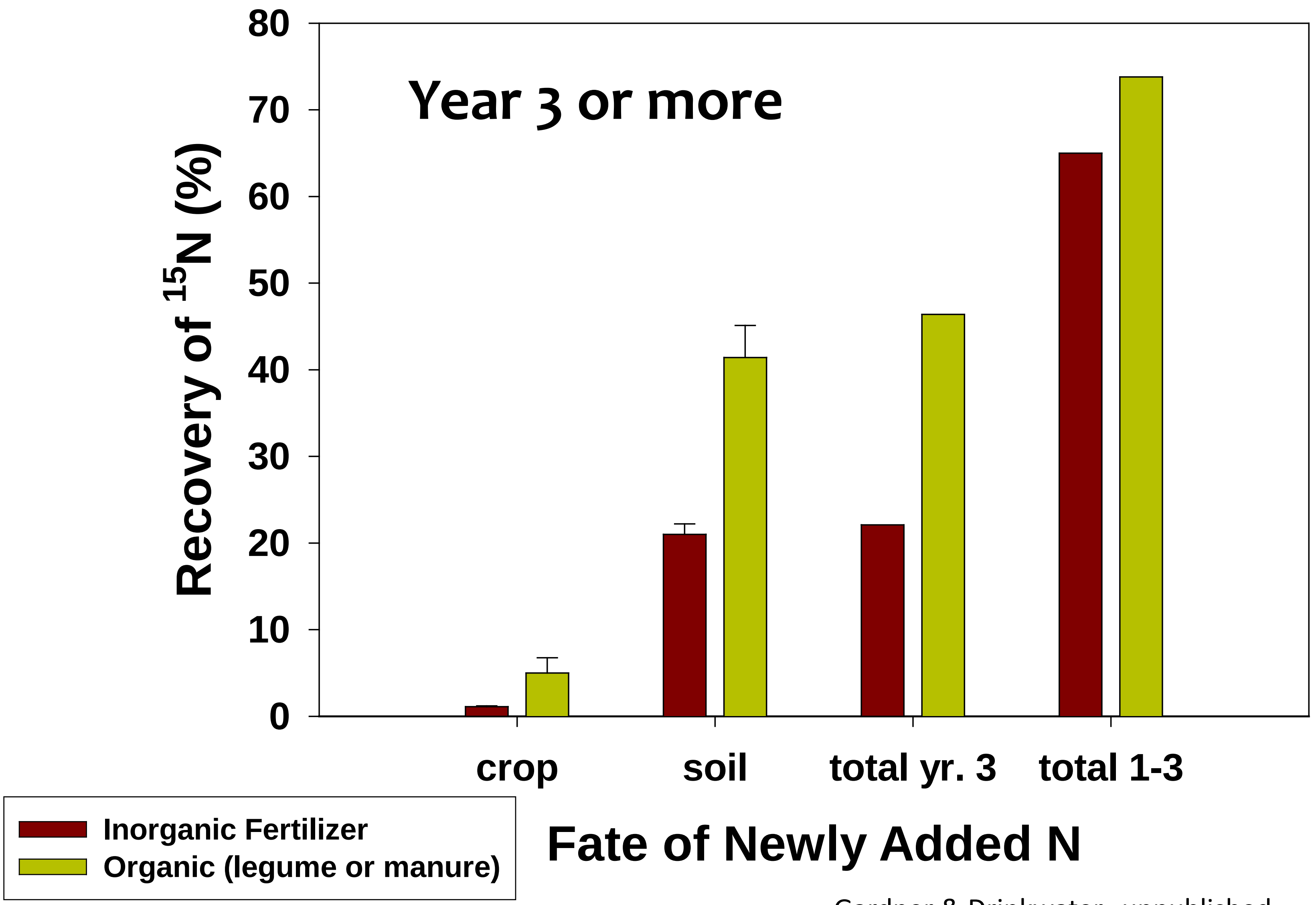



Drinkwater and Snapp, 2007 based on data from Matson et al. 1998 and Ortiz-Monasterio, pers. comm.

# Fertilizer vs legume-derived N



# Recovery of $^{15}N$




Gardner & Drinkwater, unpublished

# Five-year N mass balances for two fields in 110 farms

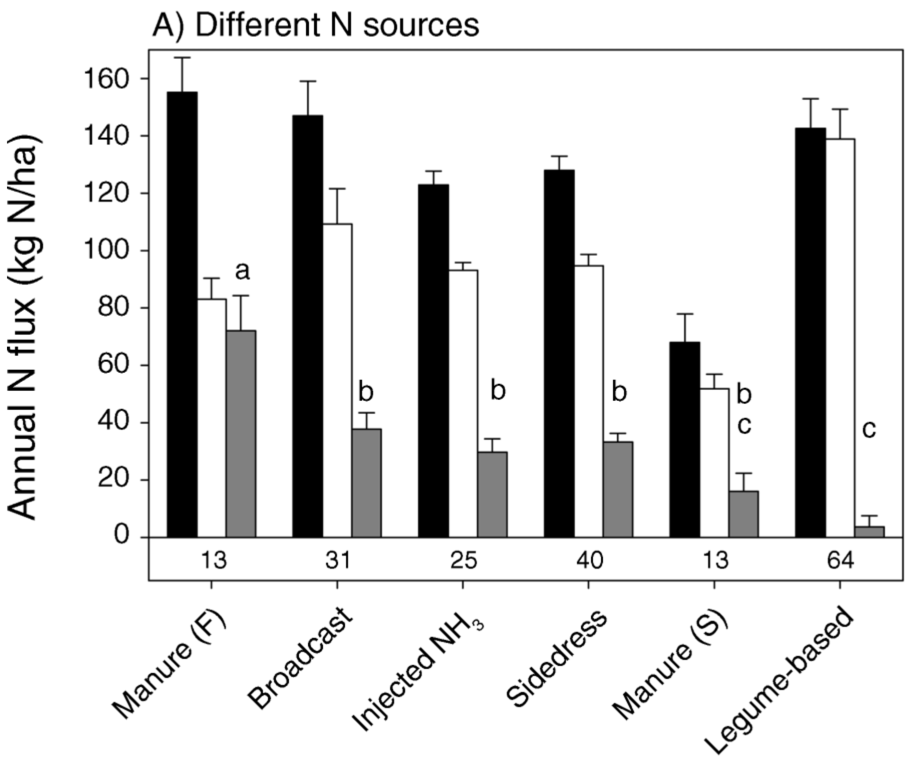
**Grain Field**


**N Input - N Export = N balance**

1) N surplus = potential for N loss
2) N deficit = potential for mining of soil N pools

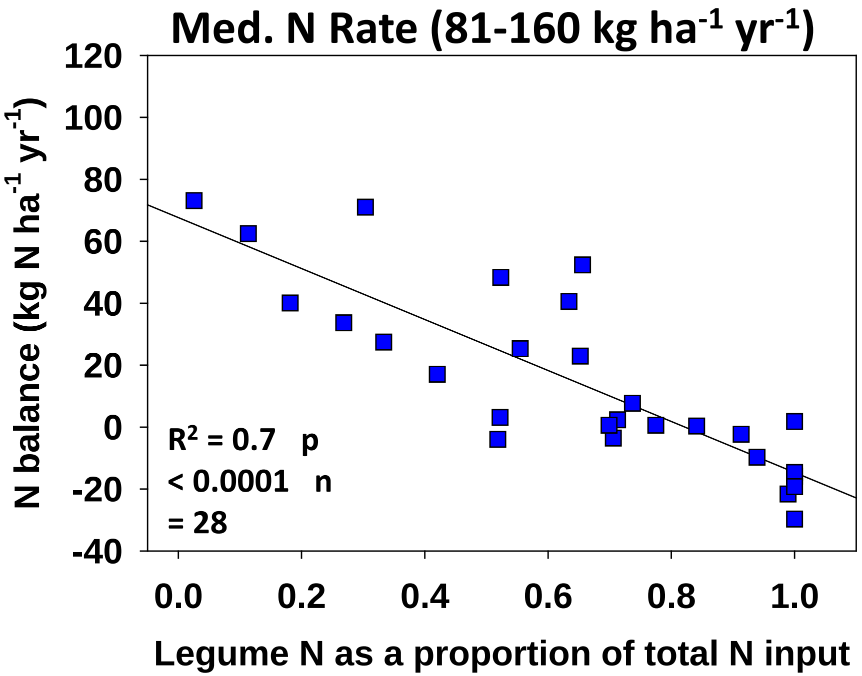
Blesh & Drinkwater, Ecol. Applications. 2013

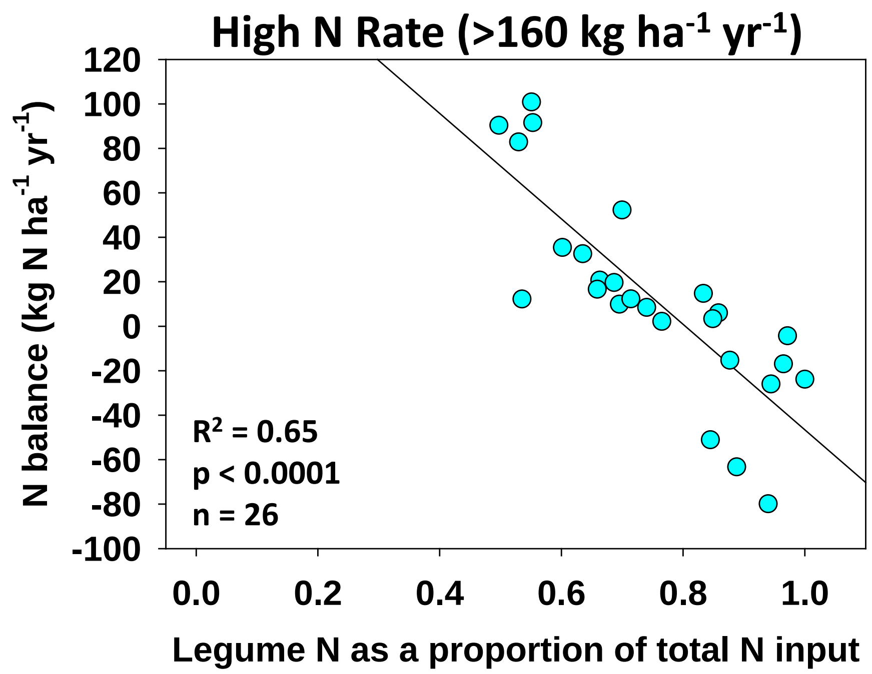
# N surpluses were lowest in diversified, legume-based rotations




Blesh & Drinkwater, Ecol. Applications. 2013

# Increased reliance on legume N correlates with improved N balance

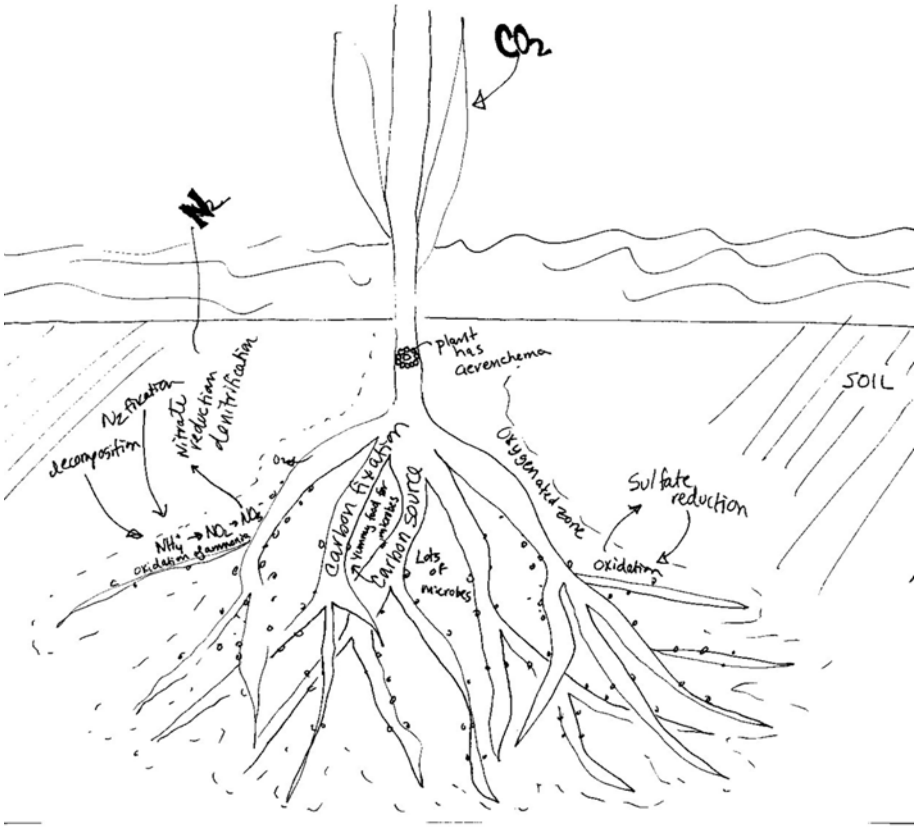


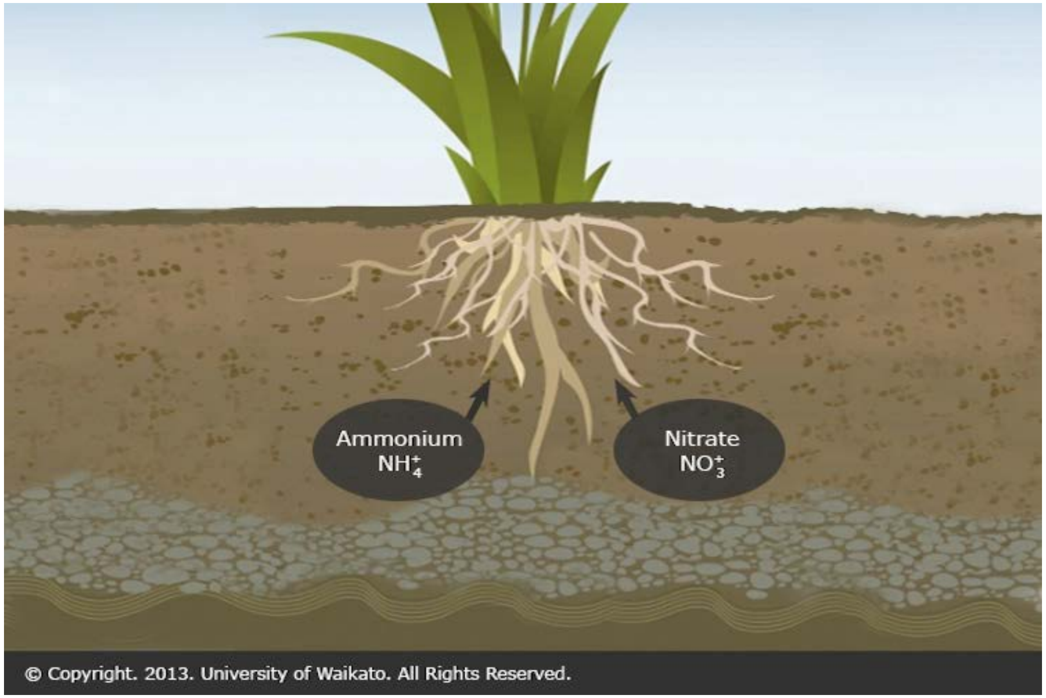

Blesh & Drinkwater, Ecol. Applications. 2013

# Discoveries that have changed our view of N cycling

- N saturation as a conceptual framework
- The role of plant-microbial collaborations in driving N/C cycles



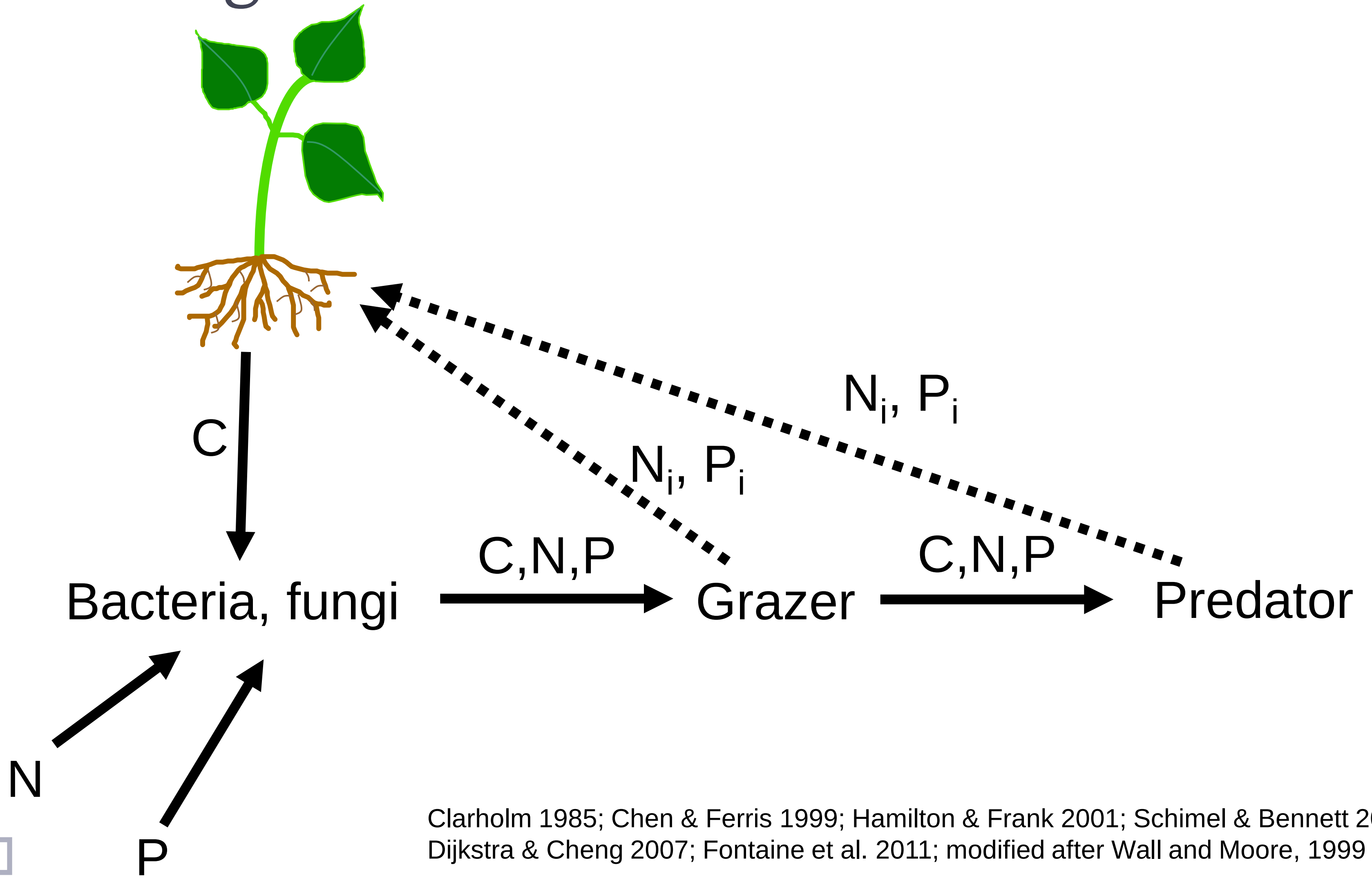
# The traditional view of decomposition as a microbial process, separate from plant uptake

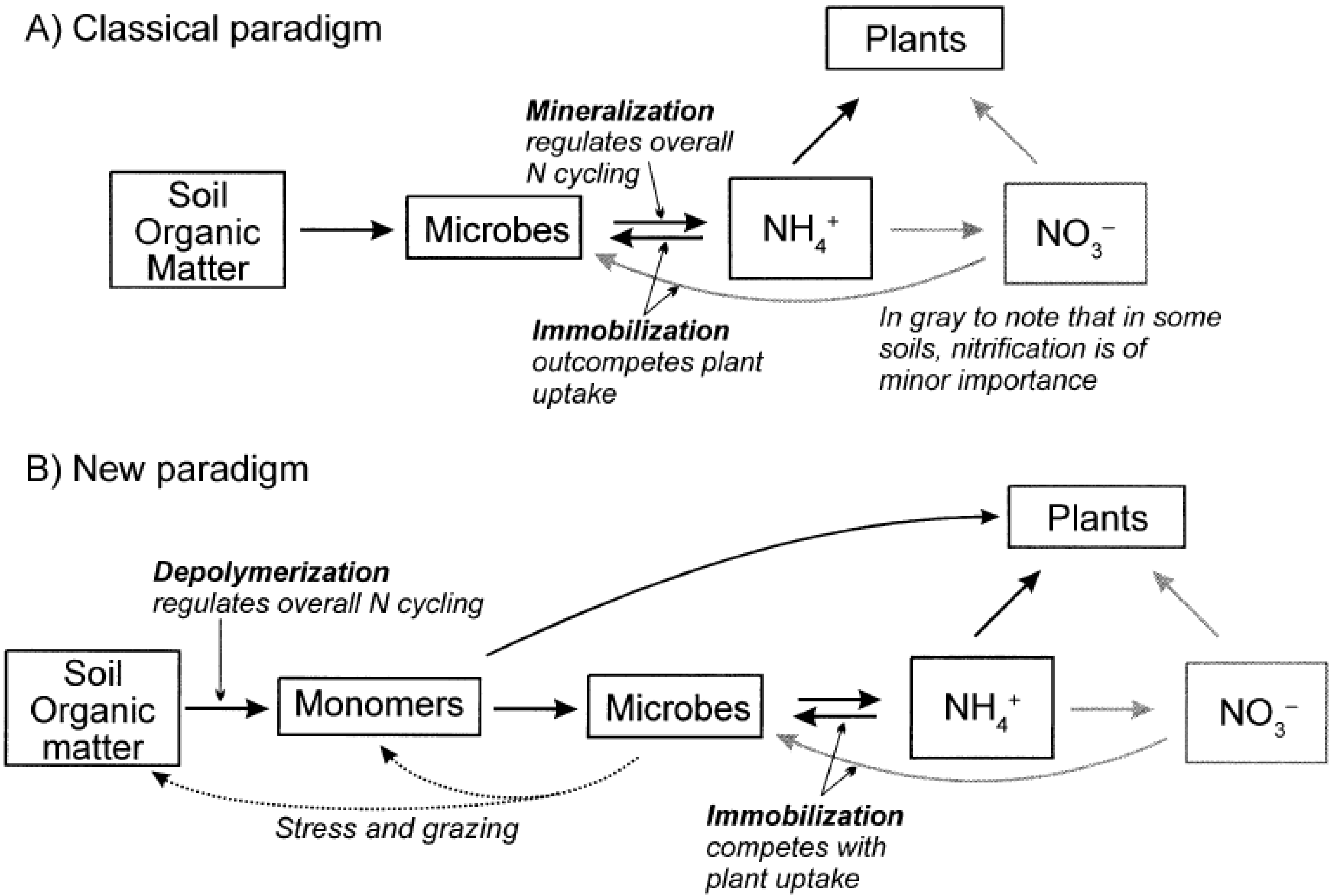

Nitrogen uptake by plants

http://www.sciencelearn.org.nz

# Plant-microbial collaboration and decomposition exchange of C for nutrients



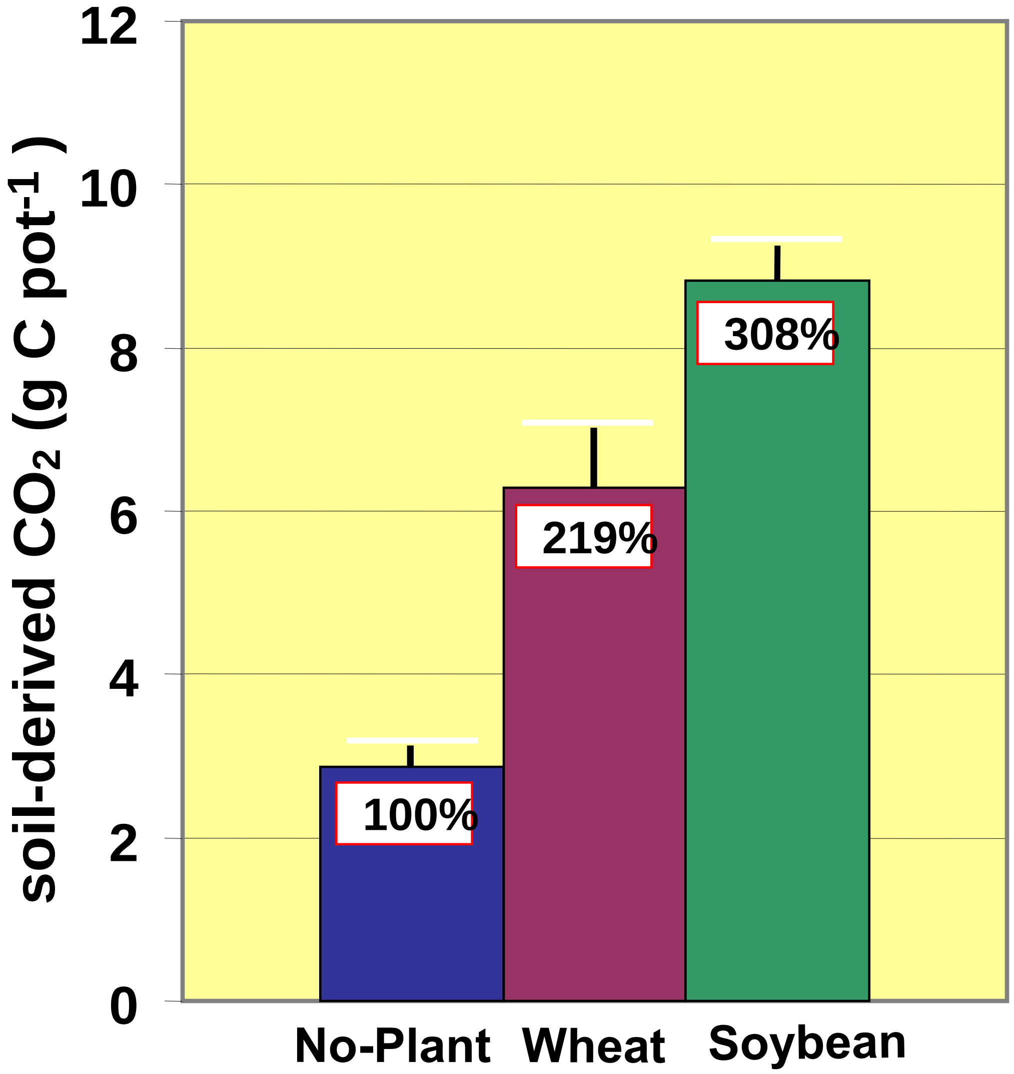

Clarholm 1985; Chen & Ferris 1999; Hamilton & Frank 2001; Schimel & Bennett 2004; Dijkstra & Cheng 2007; Fontaine et al. 2011; modified after Wall and Moore, 1999




Schimel and Bennett, 2004, Ecology ; 655

# The rate of SOM decomposition stimulated by plants varies across crop species

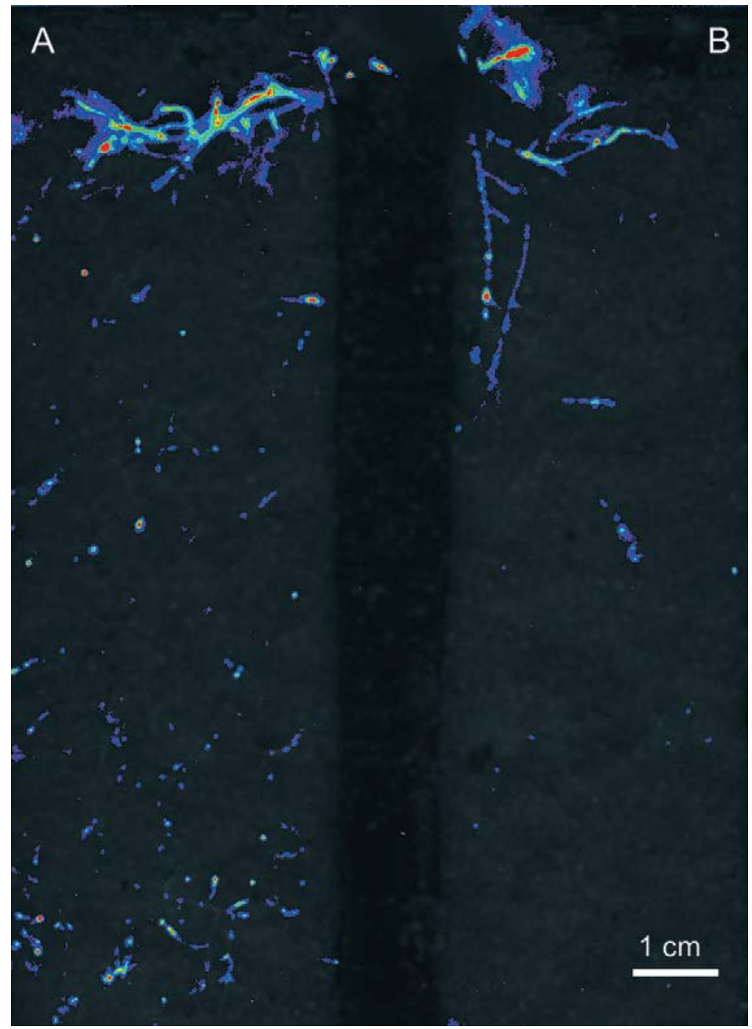
Rhizosphere priming effect was 119% for wheat, and 208% for soybeans.




Cheng et al. 2004

# Plants can alter root exudation to gain access to N reserves

Pot study: Root exudation increased under N limiting conditions




-N +N

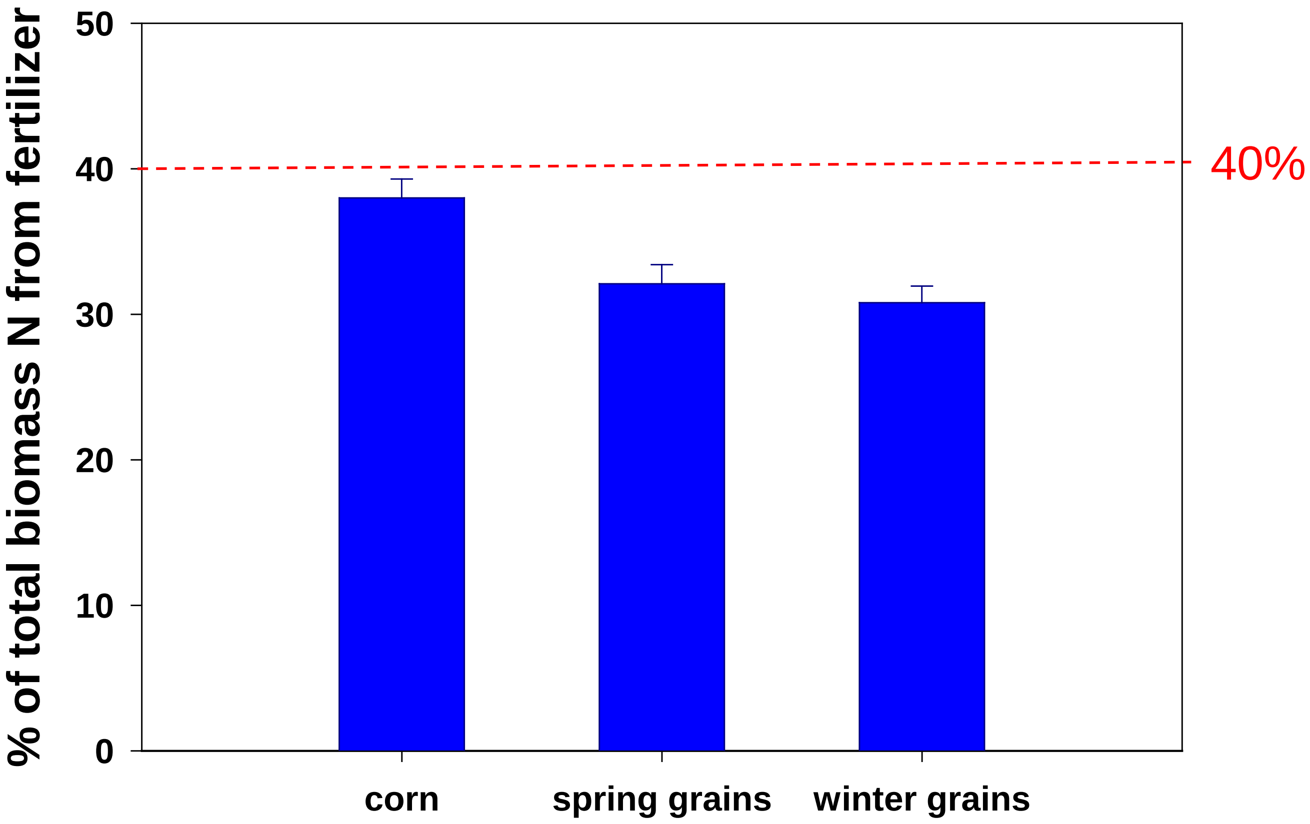
Paterson et al. 2006

# The rhizosphere

- Site of intense plant-microbial interactions that govern C and N cycles in terrestrial ecosystems
- N mineralization, N fixation and assimilation by heterotrophic microbes, (de)nitrification
- Compared to bulk soil, the rates of these processes are greatly increased in the rhizosphere
- Clearly, plants play a substantial, indirect role in governing soil N and C transformations  once thought to be solely under microbial control

Herman et al., 2006; Kuzyakov and Xu, 2013; Cheng et al. 2014

# Fertilizer N accounts for <40% of total plant N




Based on data from 217 field-scale $^{15}N$ experiments; Gardner and Drinkwater 2009, Ecol. Applications

# Rice cultivars and their associated AOB alter N cycling

**Improved traditional**

- Able to use either $NH_4$ or $NO_3$
- Rhizoplane is dominated by heterotrophs
- Most abundant AOB is *Nitrosopira*
- Nitrification is reduced

**Modern hybrid**

- Greater efficiency with $NH_4$ application
- Roots leak more $O_2$
- AOB dominated by *Nitrosomonas sp.*
- Higher rate of nitrification

**Cultivar differences → rhizosphere community→ N cycling, NUE**

Briones et al., 2002, 2003

# Discoveries that have changed our view of N cycling

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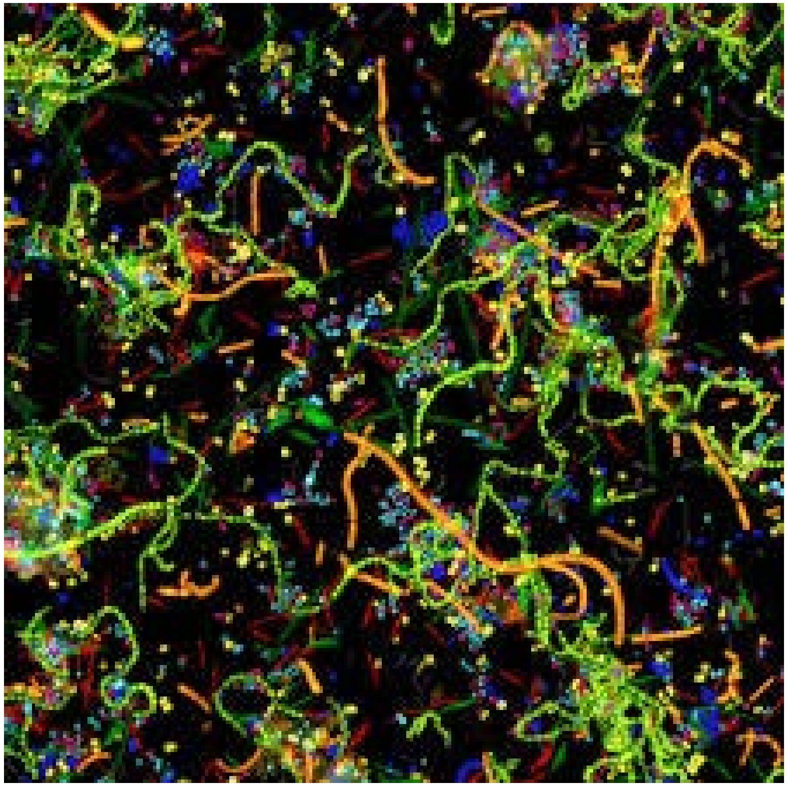
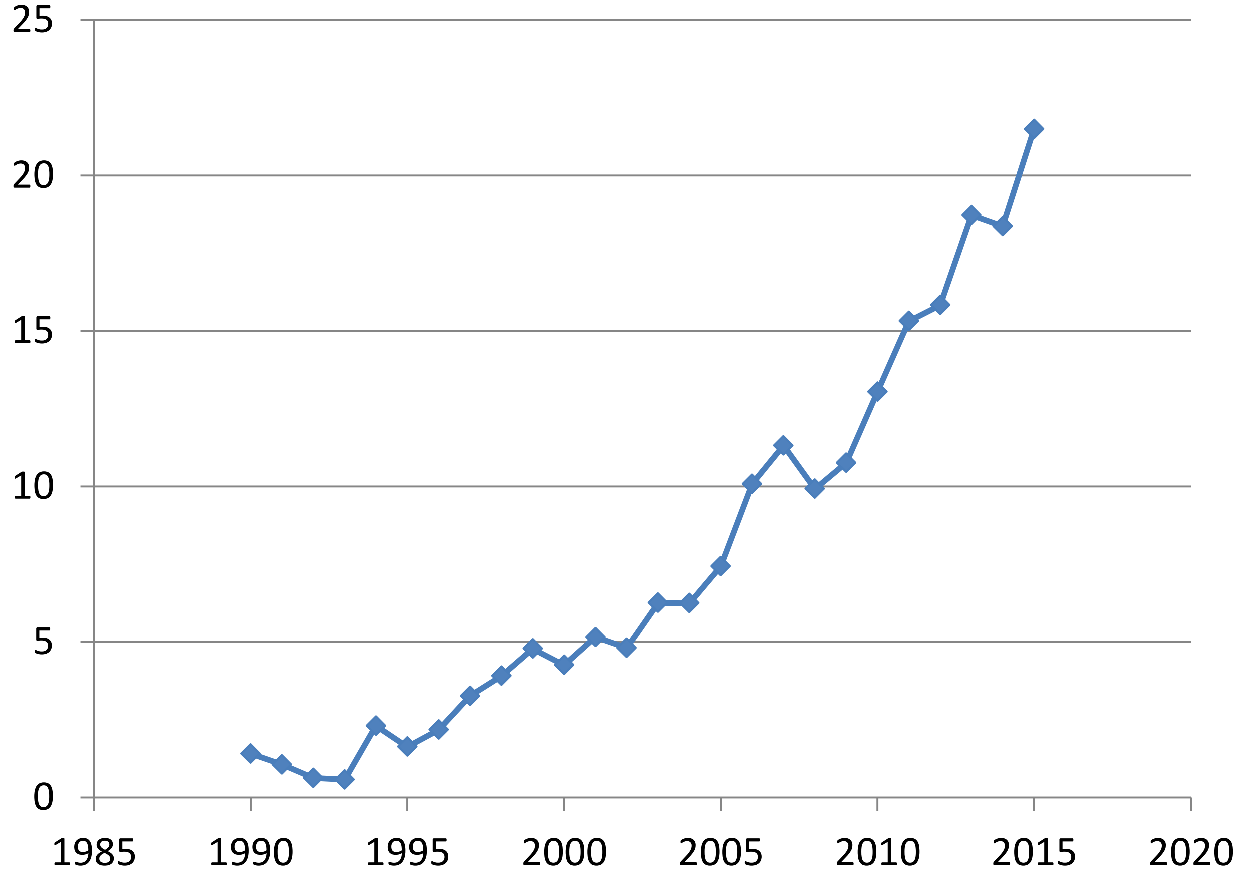
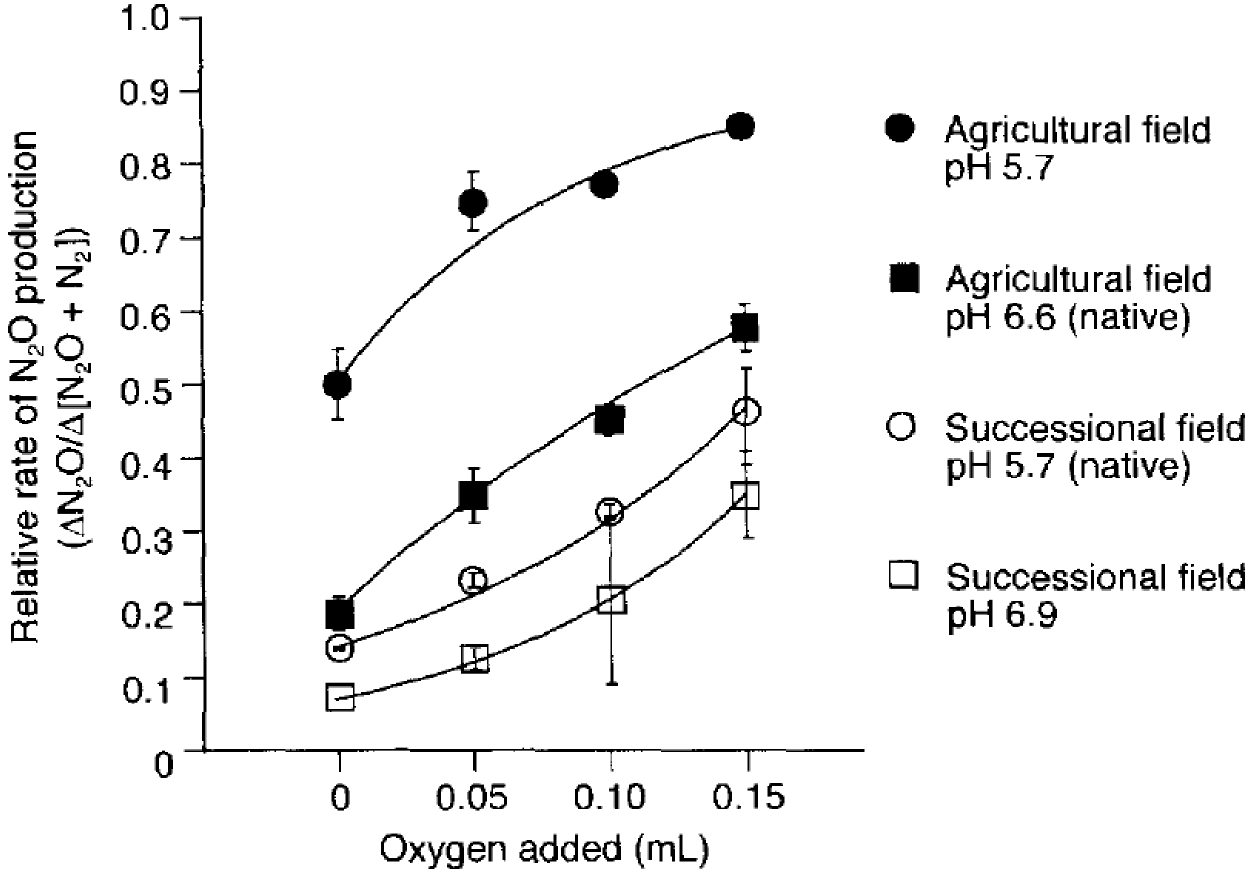
- Microbial communities and N loss/conservation pathways



# Proportion of N cycling papers that explore the role of microbial communities



# Microbial community composition and ecosystem function




Cavigelli and Robertson, 2000, Ecology (165 citations)

# Can functional gene abundance improve predictions of $N_2O$ production?

| | Potential Rate Correlated with FGA ( of studies) | | *In-situ* Rate Correlated with FGA (# of studies) | |
|---|---|---|---|---|
| | Yes | No | Yes | No |
| $N_2O$ flux | - | - | 7 | 17 |
| Nitrification | 31 | 7 | 5 | 2 |
| Denitrification | 14 | 4 | 0 | 8 |

Han and Drinkwater, Ecosystems, submitted.

# Future directions for LTER research

- Additional agroecosystem sites are needed!
- Frame research on small-scale, fast cycling processes in terms of N saturation conceptual framework
- How can plant species composition be used to manage microbial communities and ecosystem services?

# Thank-you!

Thanks to all members of the Drinkwater lab, collaborating farmers, funders and research collaborators