Using legumes to supply crop nitrogen while also reaping benefits for soil health

Laurie Drinkwater

Cornell University

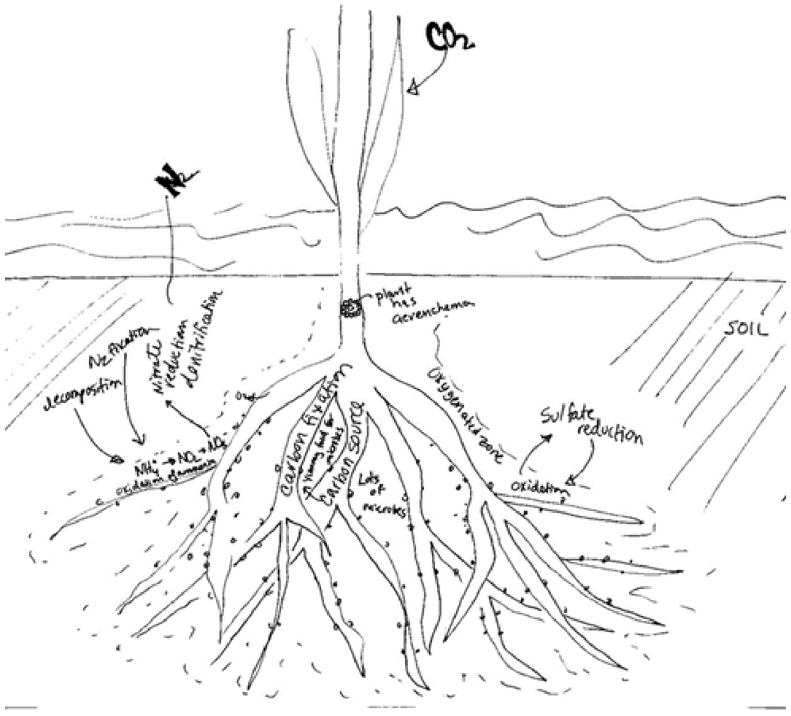
led24@cornell.edu

Presentation outline

- Leguminous green manures and nitrogen: A different mindset
  - N cycling and SOM formation
  - Digging deeper into mechanisms: plant acquisition of organic N and formation of SOM

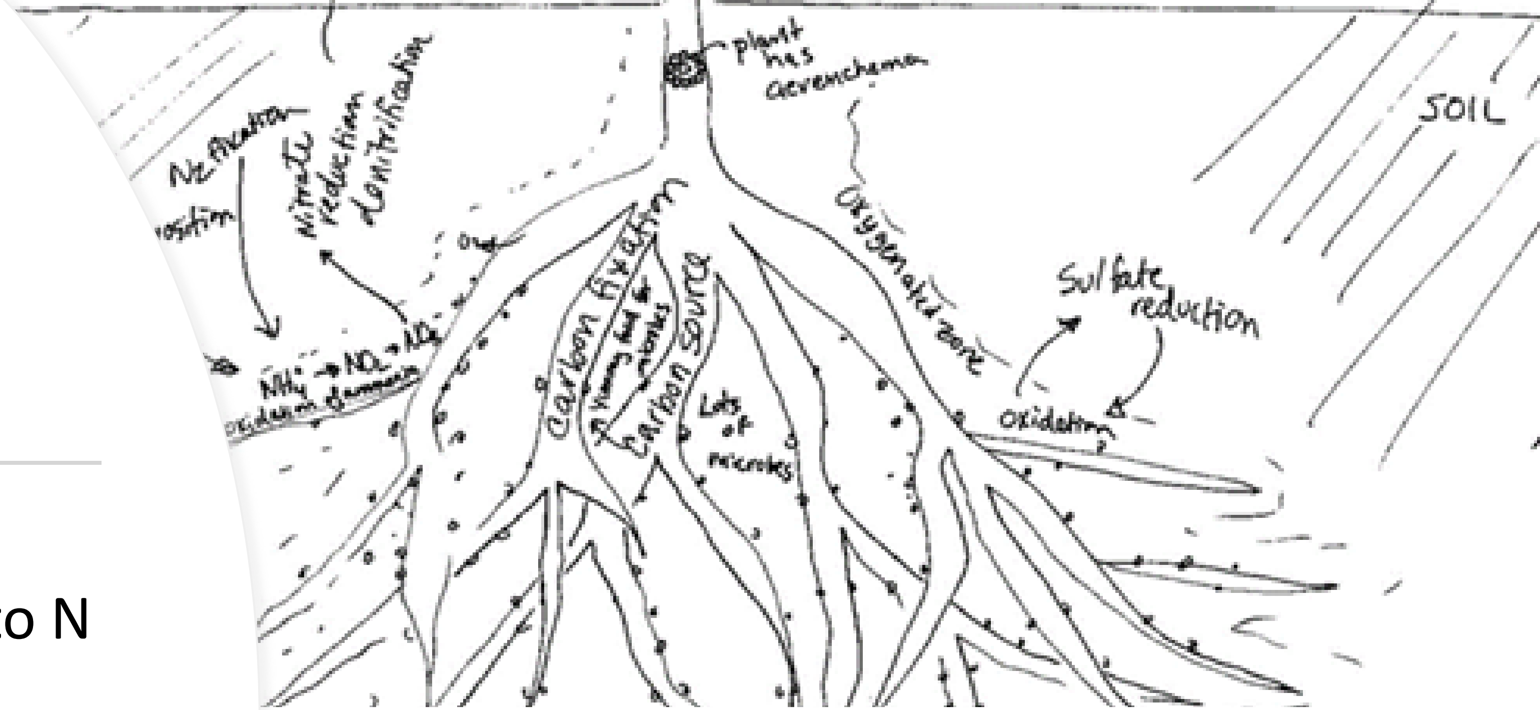
Pause for questions

- Managing leguminous cover crops to optimize symbiotic nitrogen fixation rates
  - What factors determine how much N is fixed?
  - Which management strategies might be most effective for transitioning from mineral fertilizers to legume-derived N?

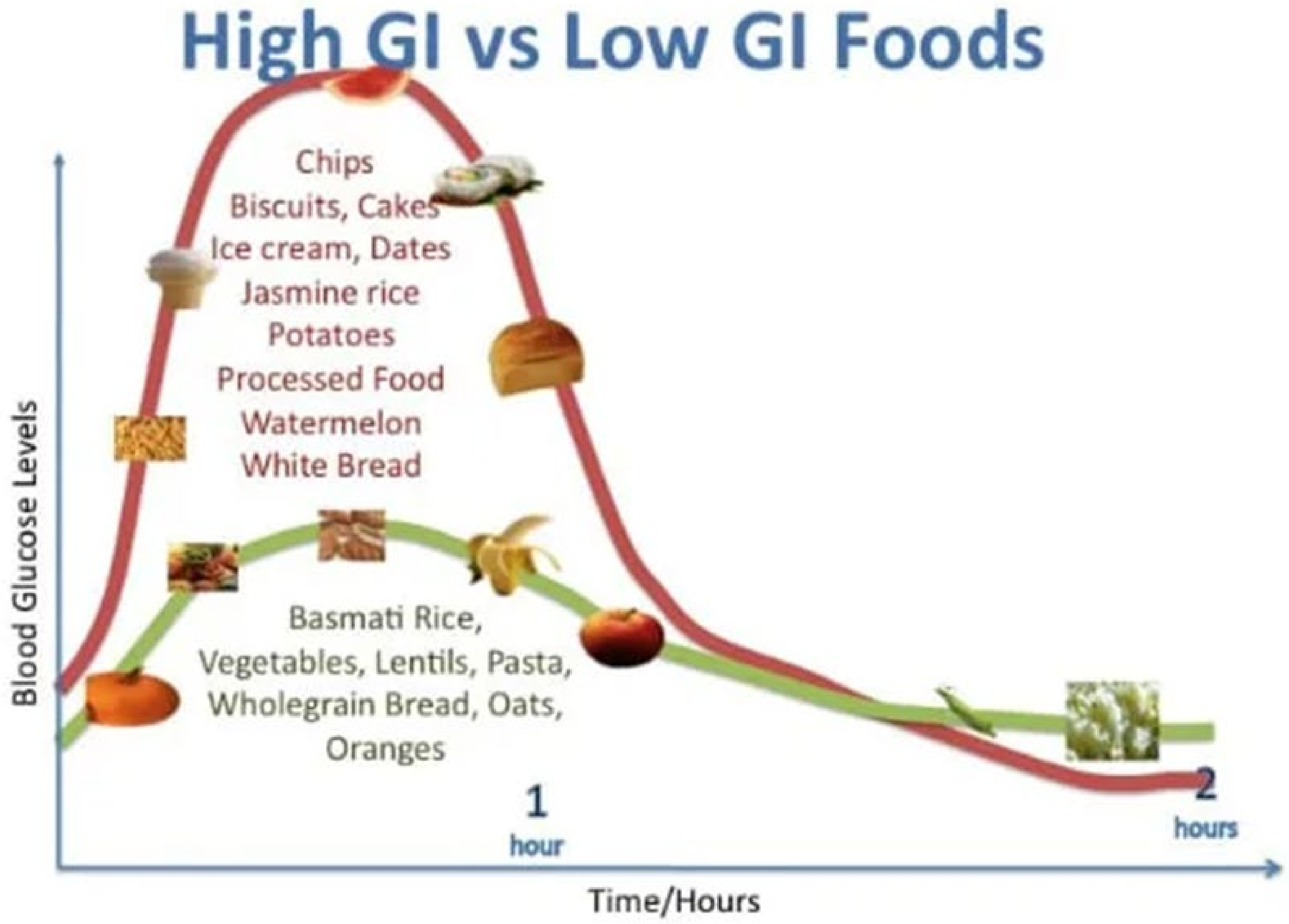


Legume N sources: A different mindset

1) How does legume N compare to N fertilizer?
2) What benefits for improved soil health result from cover cropping?



Using organic N sources requires a different mindset

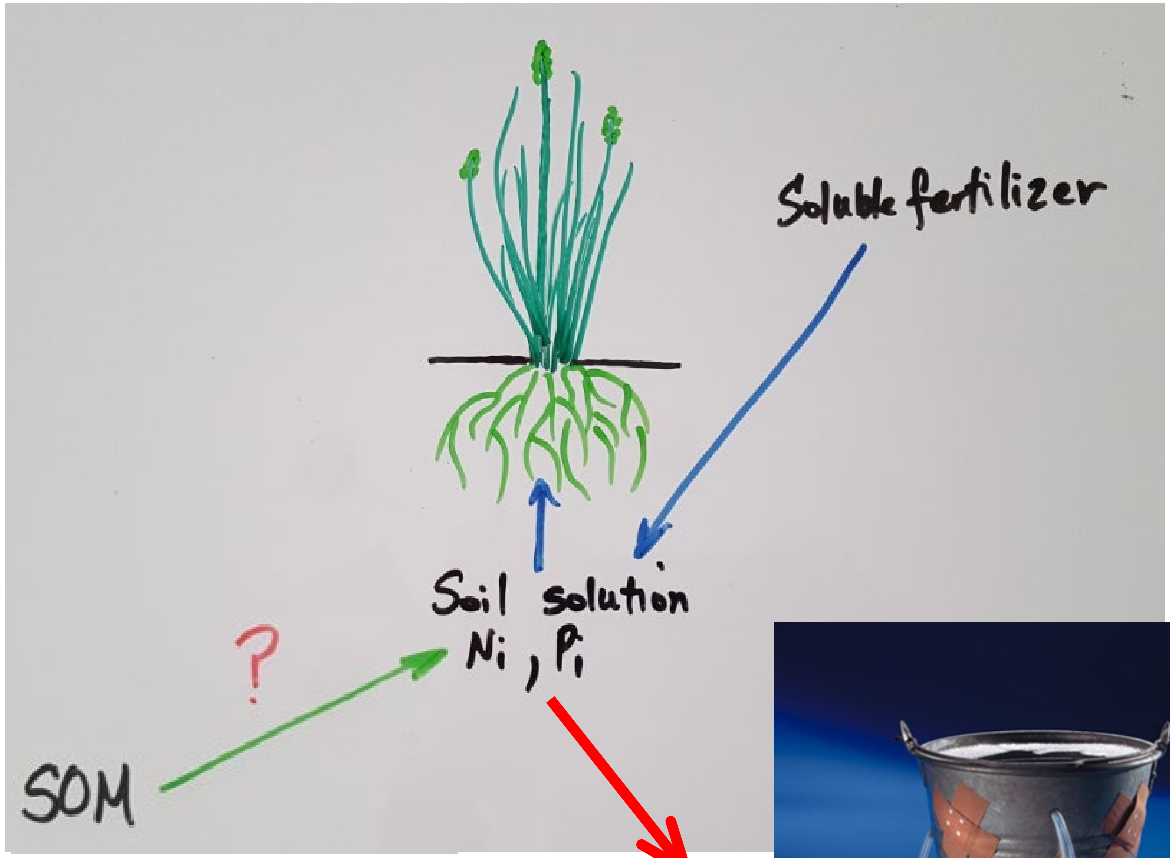


Fertilizer nitrogen = candy

Cover crop biomass = complex carbs, protein, fiber and fat

[GI-Foods-7-Health.jpg (720×540) (drsharma.ca)](GI-Foods-7-Health.jpg)

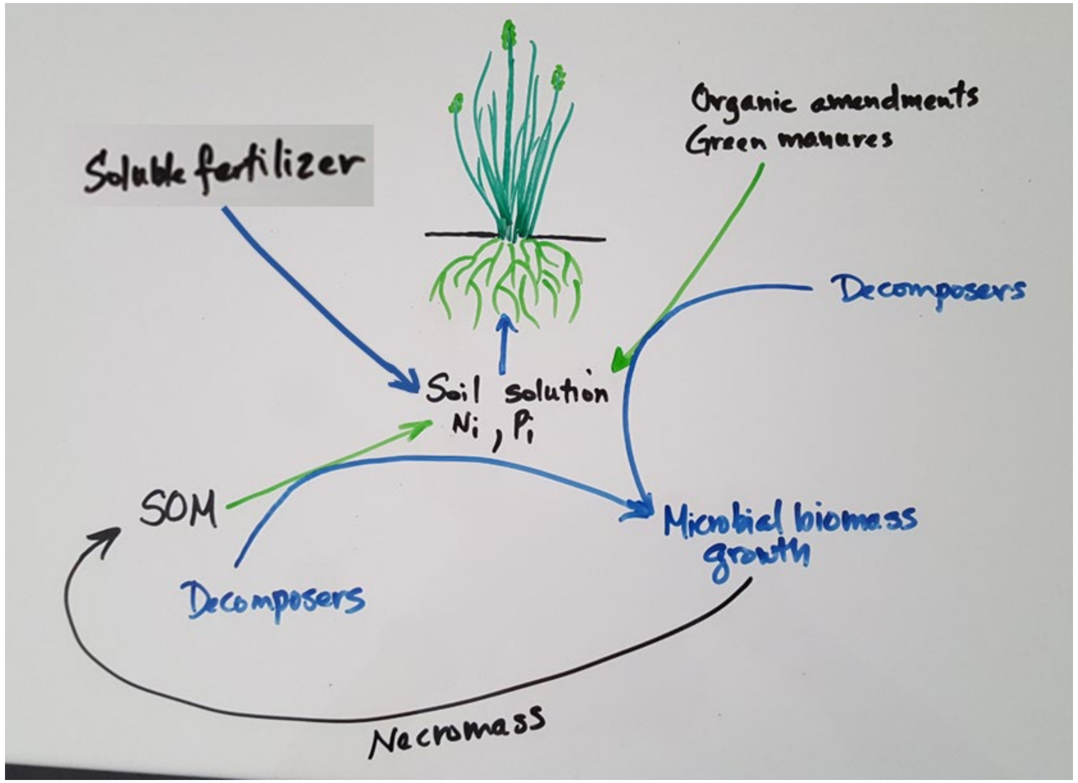
4R's nutrient management: Supply plant available nutrients directly



4R's fertilizer management:

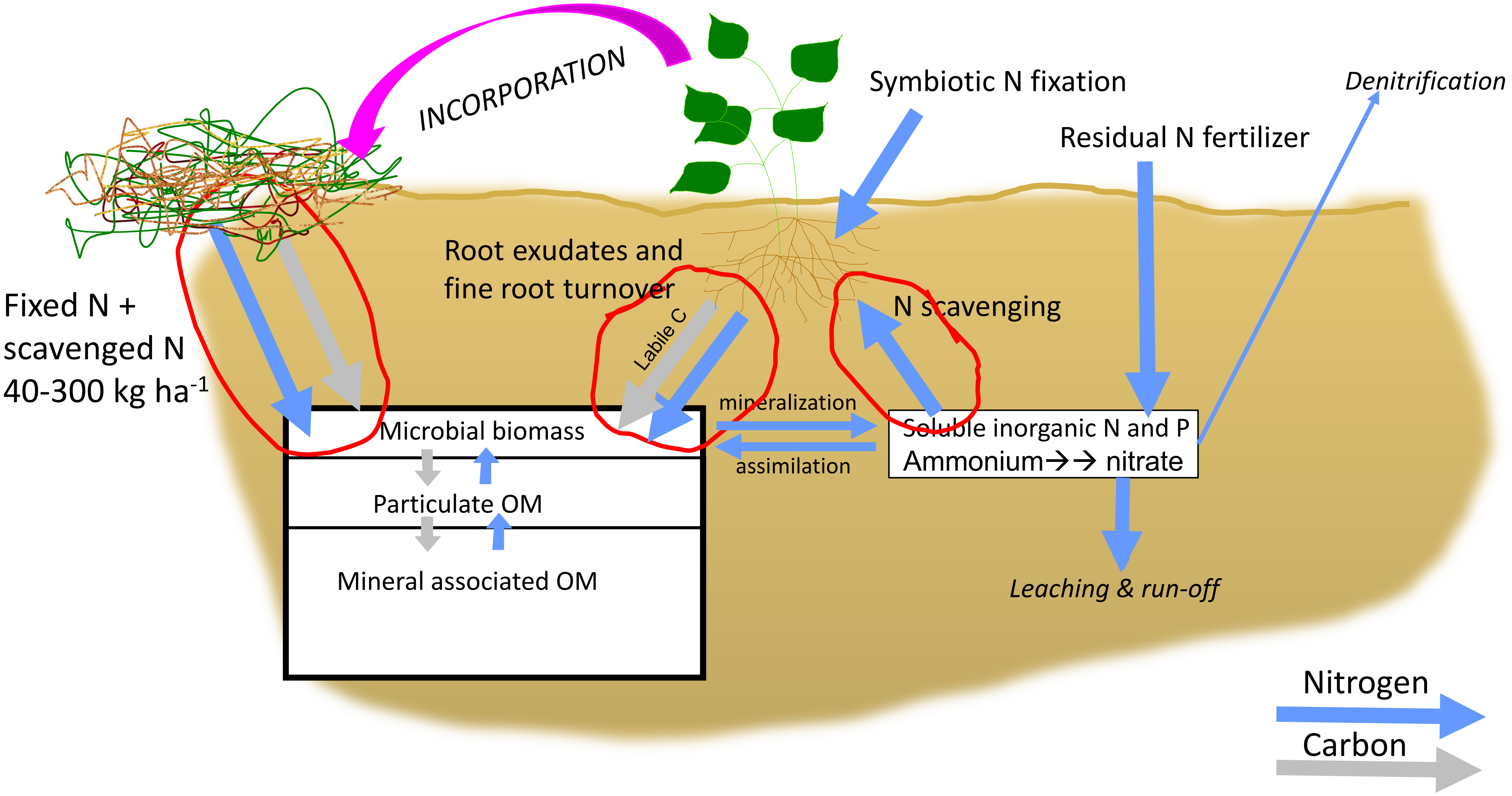
- Right source, Right rate, Right time, Right placement
- Aim is to maximize soluble nutrient delivery to the crop
- Bypasses need for N supply from decomposition

N and P cycles are strongly coupled with C cycling processes

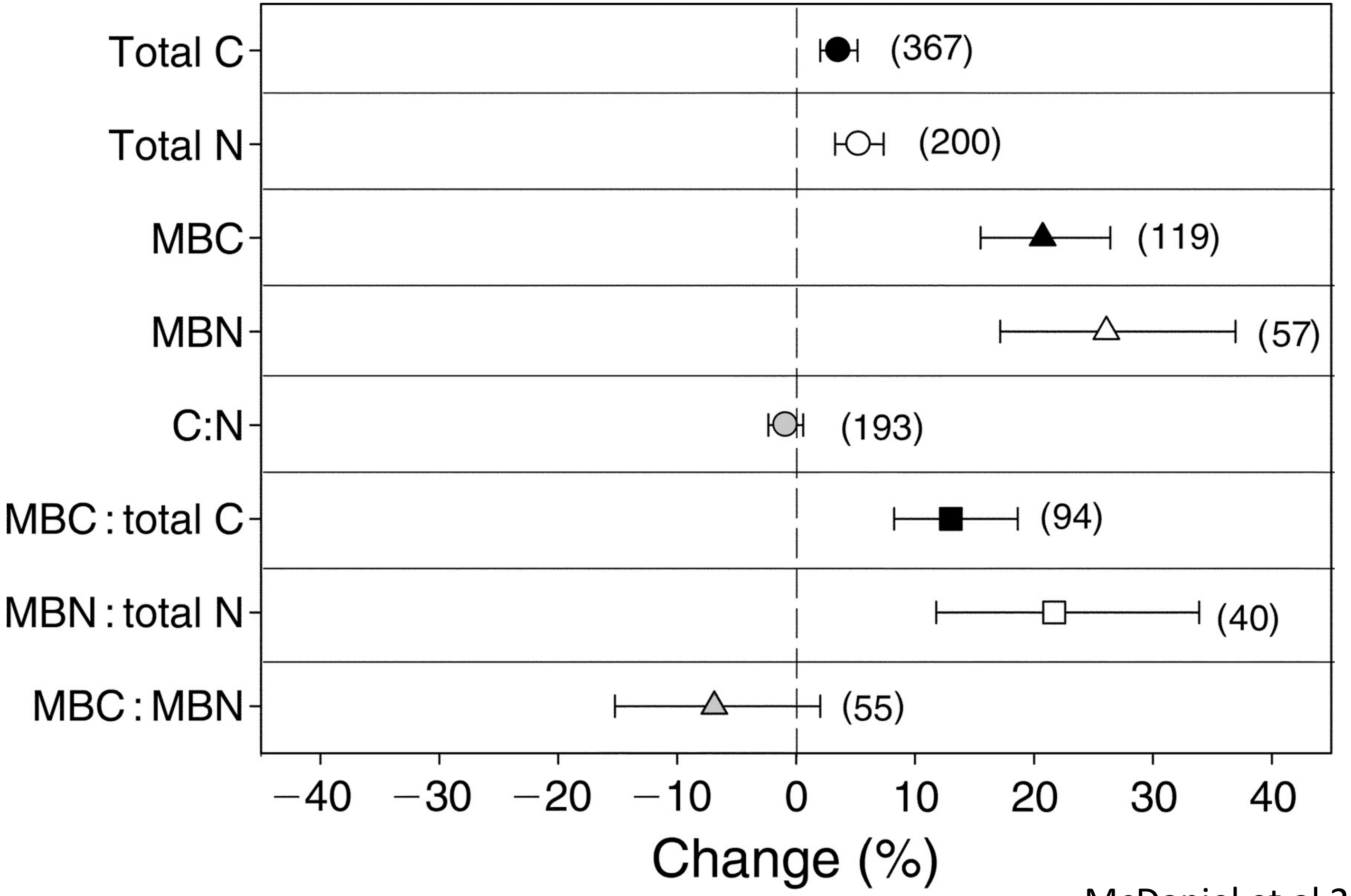


- Despite reliance on N fertilizer, decomposition of SOM is still an important N source
- Use of inorganic fertilizers in conjunction with organic inputs tends to increase FUE (Zhang et al. 2012, Advances in Agronomy)
- Decomposition supports plant and microbial growth
- Need to maintain SOM reserves
- Microbial growth leads to SOM accrual (Liang et al. 2017, Nature Microbiology)

Cover crops impact C, N, and P flows through three distinct pathways

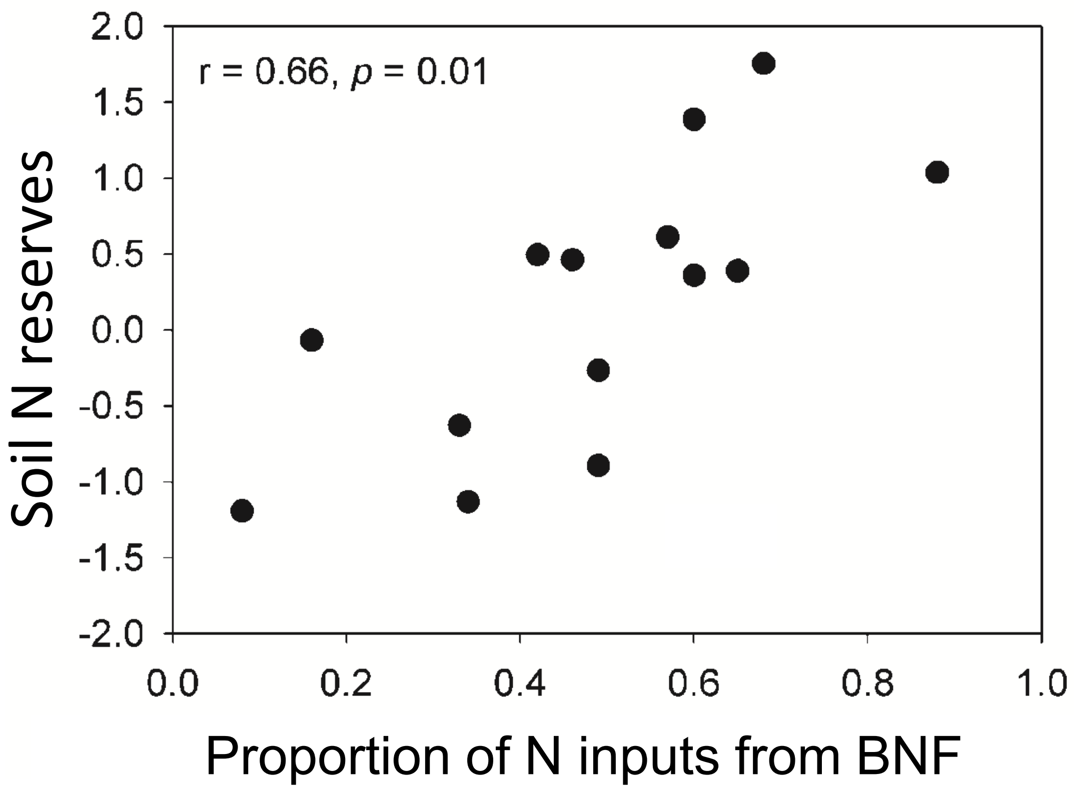


Cover cropping increases SOM reserves



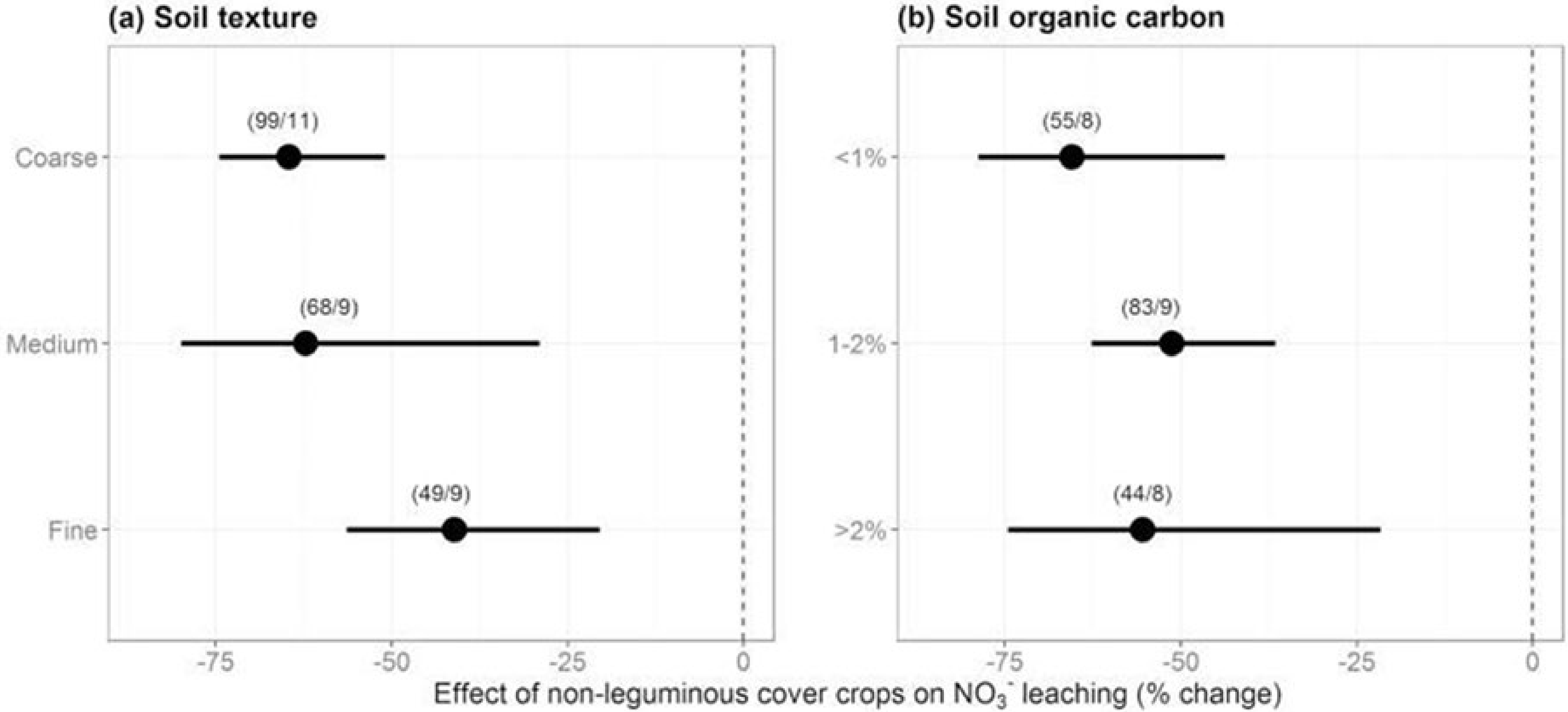
McDaniel et al 2014

Legume-based rotations increased SOM and soil N reserves



Schipanski and Drinkwater 2011, *Nutr Cycl Agroecosys*

Cover cropping effectively reduces NO_3^- leaching across varying soil texture and SOC levels



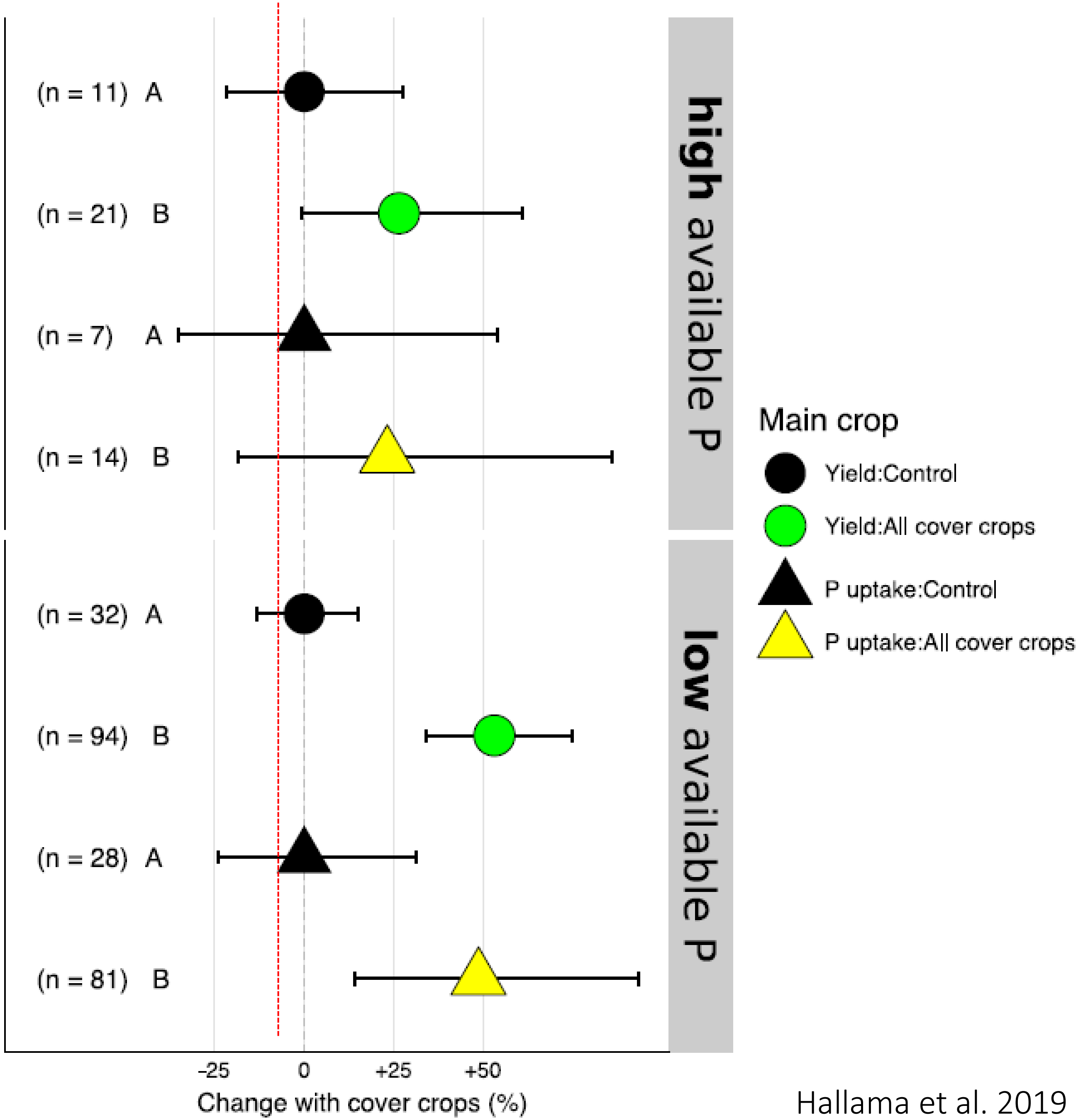
Thapa et al. 2018

Greater SOC corresponds with reduced N losses and greater N use efficiency

	Climate		Soil properties		
	Mean temperature	Mean precipitation	Soil pH	Soil organic C	Soil total N
Ndff%	−0.163	−0.164	0.054	**0.538****	0.121
^{15}N uptake % (NUE_{15N})	<0.001	−0.085	−0.090	**0.307***	0.219
^{15}N soil retention %	−0.099	−0.183	0.158	0.097	−0.117
^{15}N unrecovered %	0.020	0.135	−0.078	**−0.268***	−0.021

Quan et al. 2021

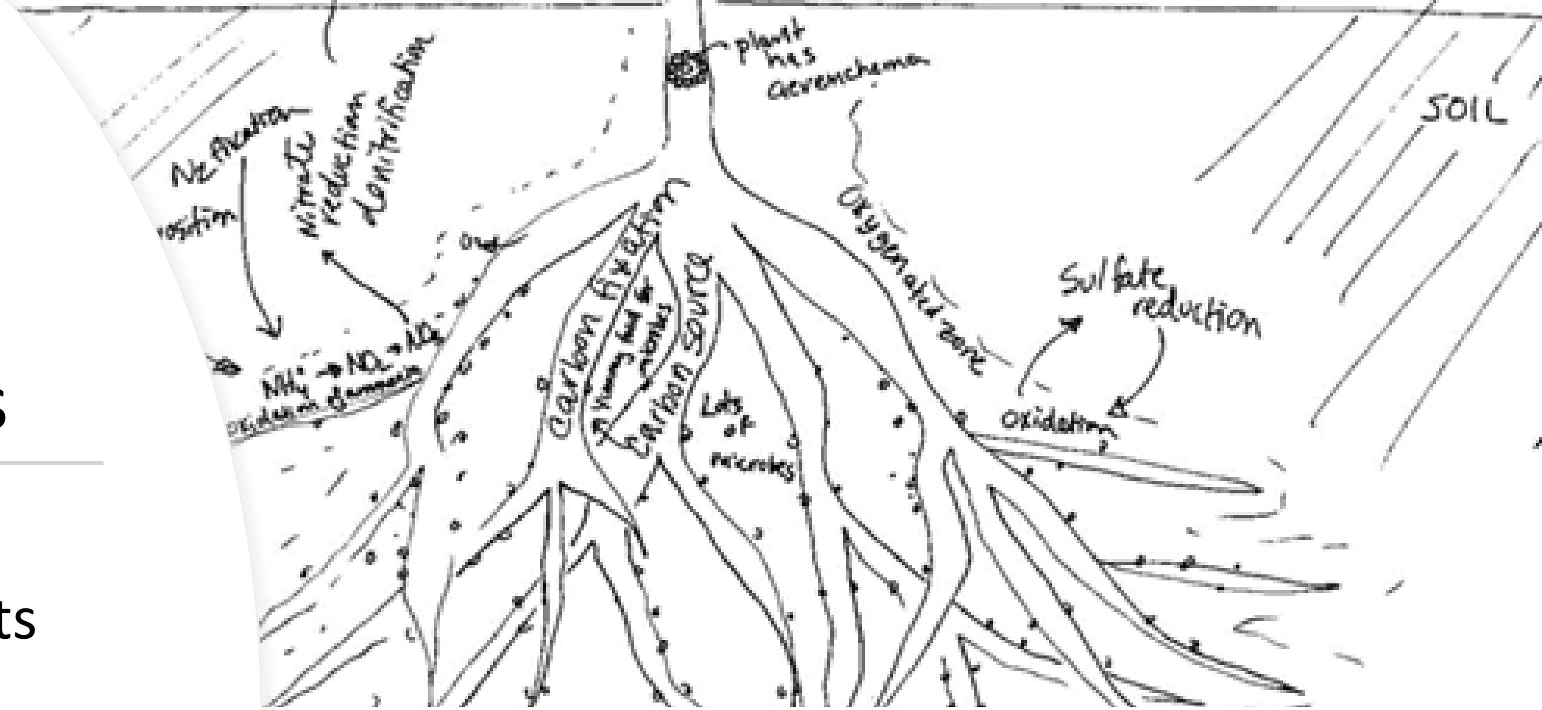
Cover crops increase P uptake and crop yields



Hallama et al. 2019

Digging deeper into underlying mechanisms

1) How do plants acquire nutrients from SOM reserves?
2) How are these soil nutrient reserves replenished?

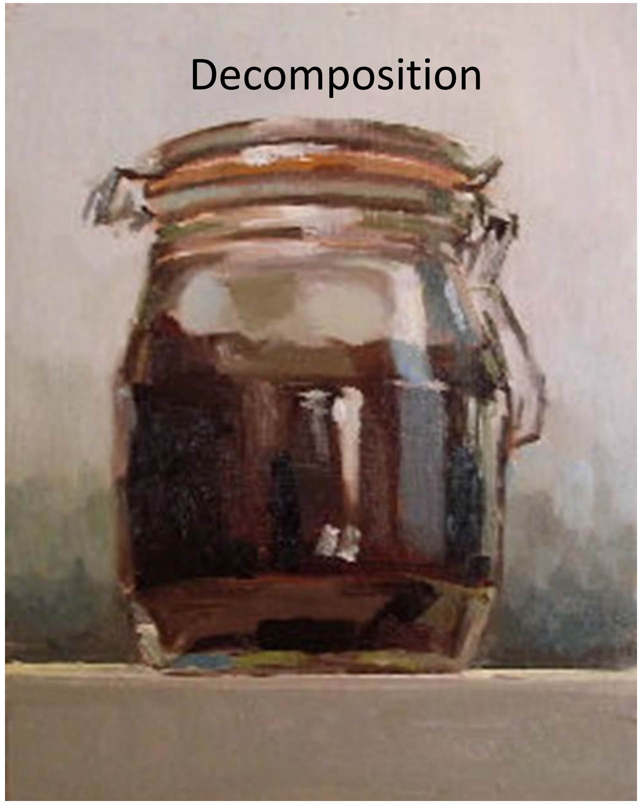


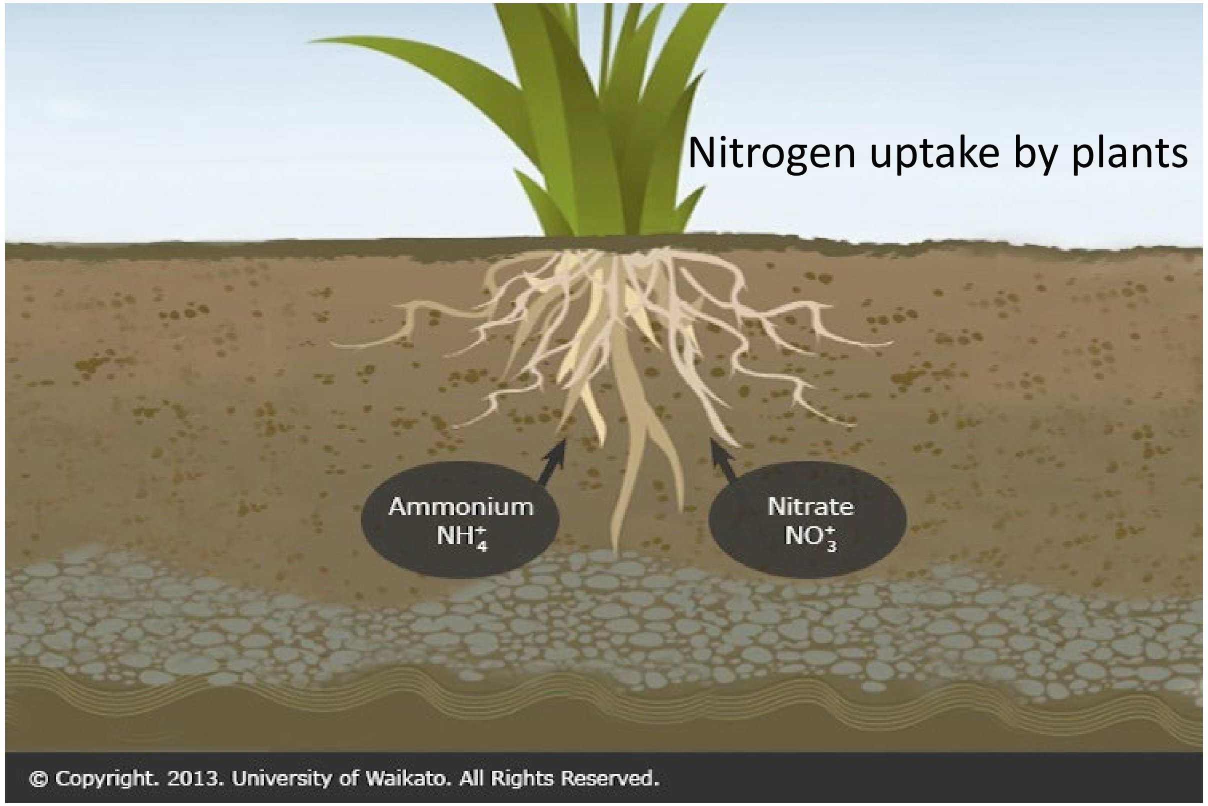
Characteristics of SOM pools

SOM Pools	Free POM (POM 5-20%)	Occluded POM	MAOM (70–80%)
Origin			
Accessibility	↑	↓	↓
Energy	←	←	←
Nutrient density	→	→	→
Residence time	→	→	→
Plant accelerated	X	↑	↑

Liang et al. 2019; Lavallee et al. 2020; Daly et al. 2021

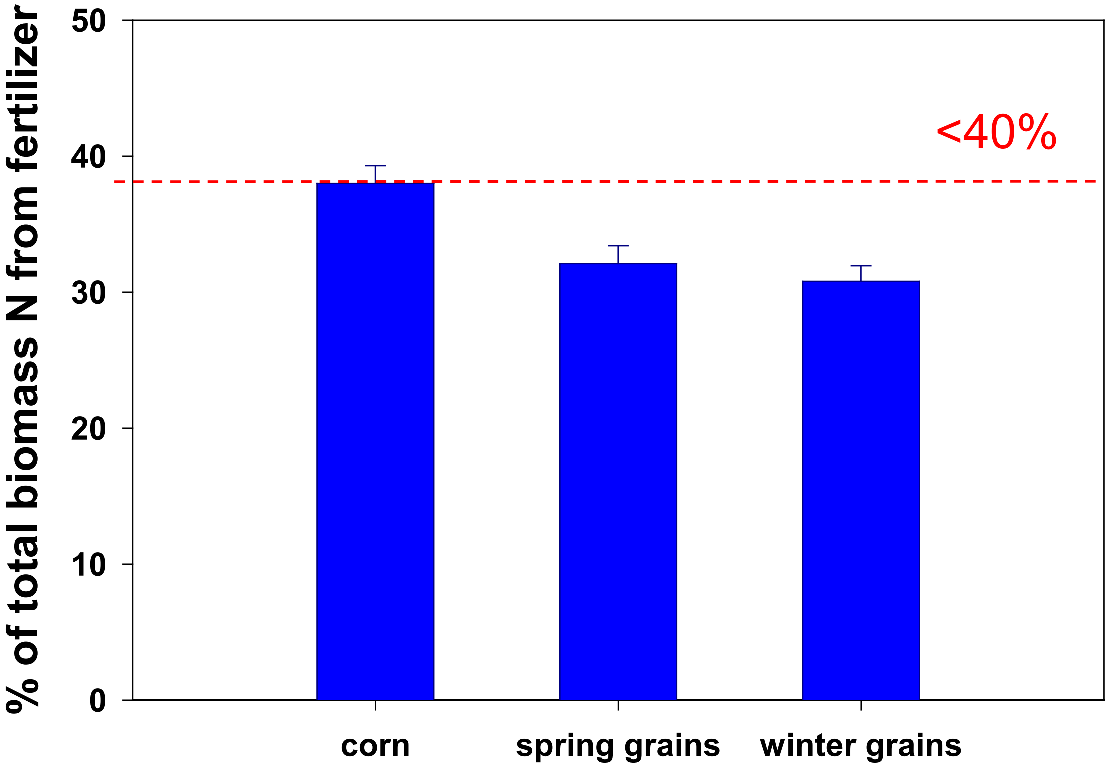
Decomposition has traditionally been viewed as a microbial process, separate from plant uptake





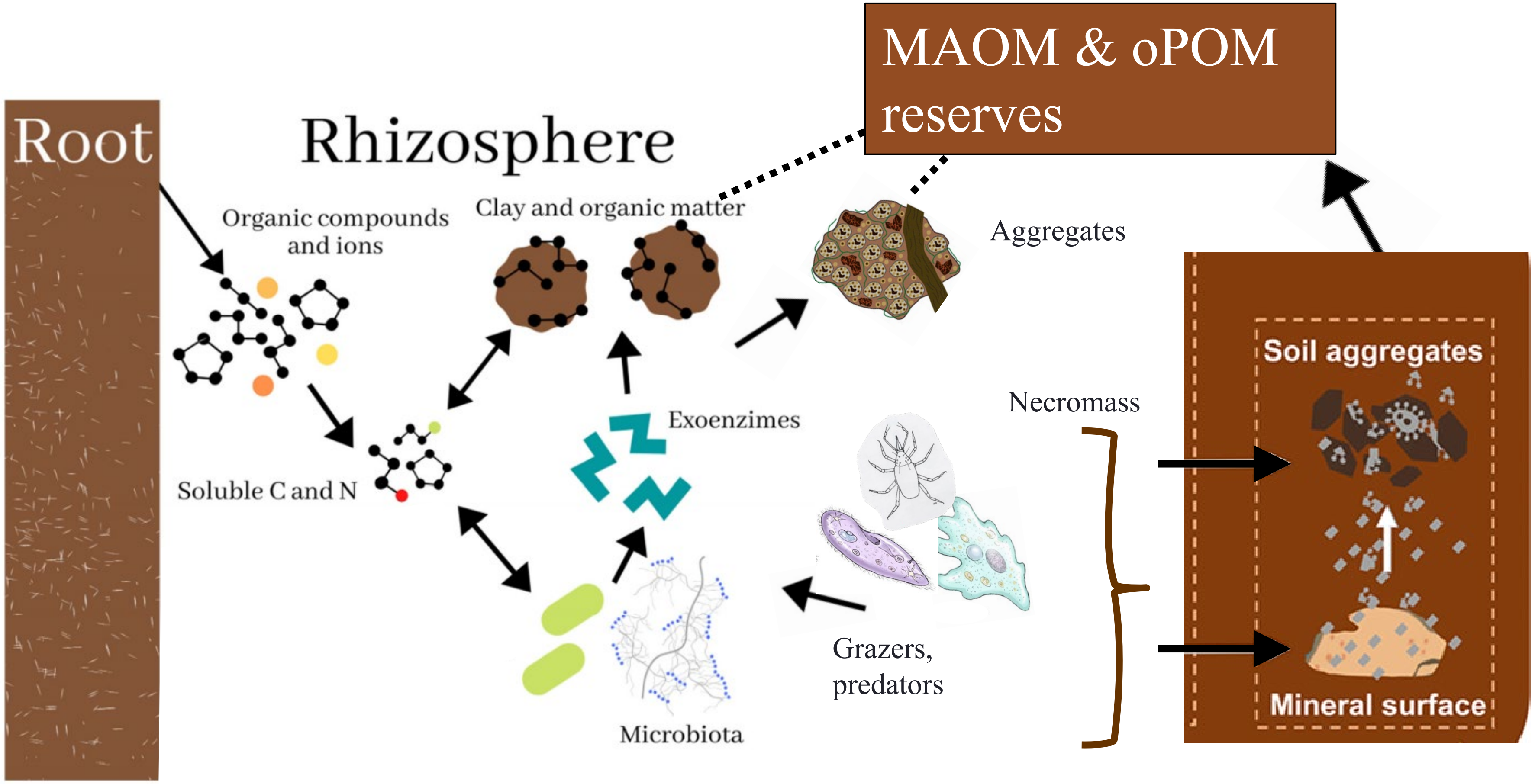
http://www.sciencelearn.org.nz

In CNV systems, 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

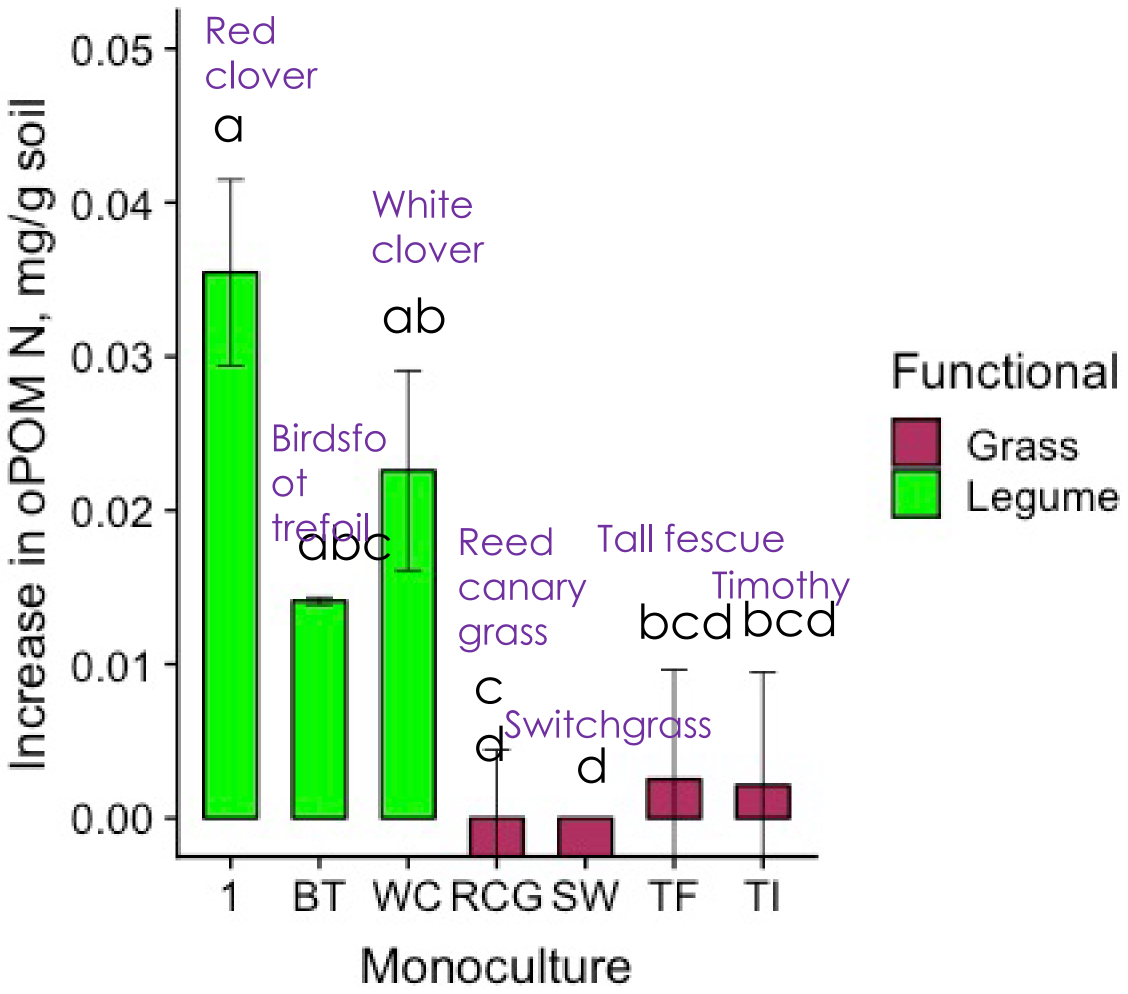
Rhizosphere: Nutrient acquisition from SOM and SOM formation



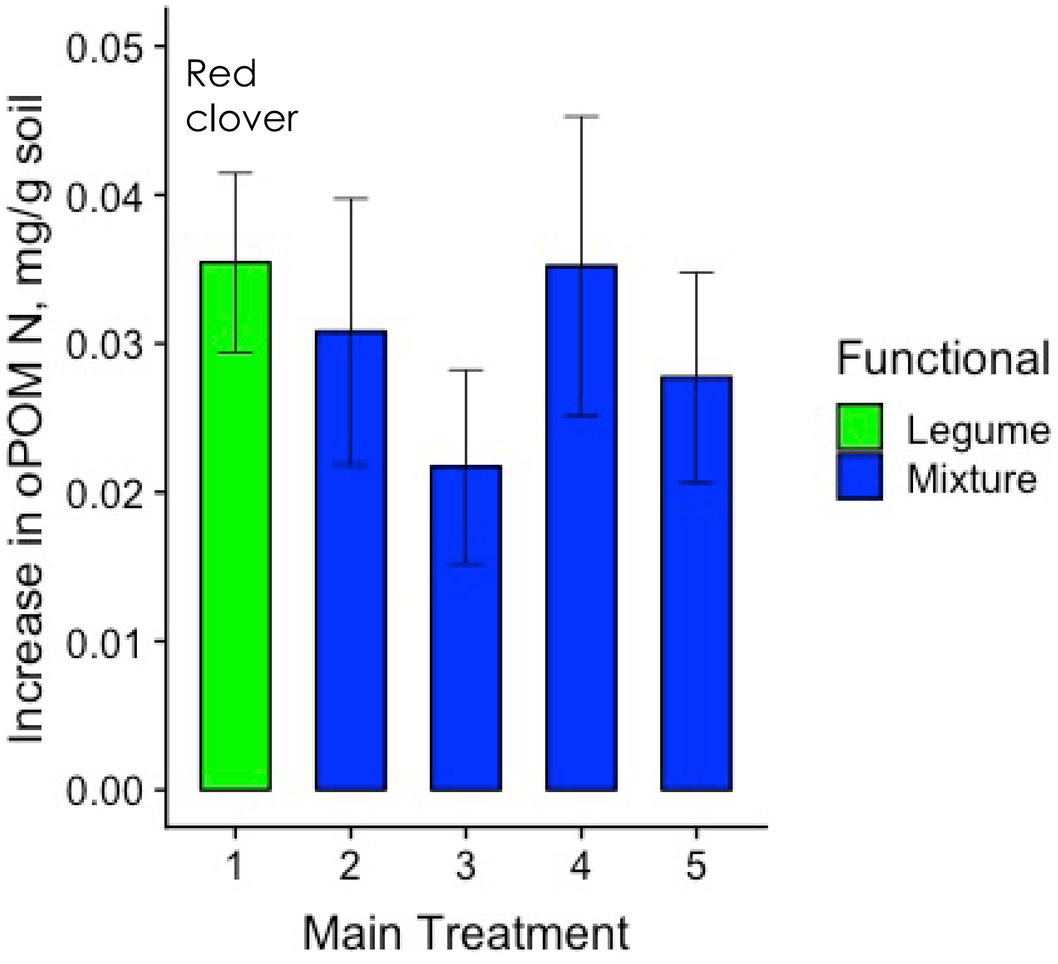
Modified after Valadares et al. 2020; Liang et al. 2019; Clarholm, 1985

Species-specific of cover crop effects on oPOM N pools

Legume and grass monocultures



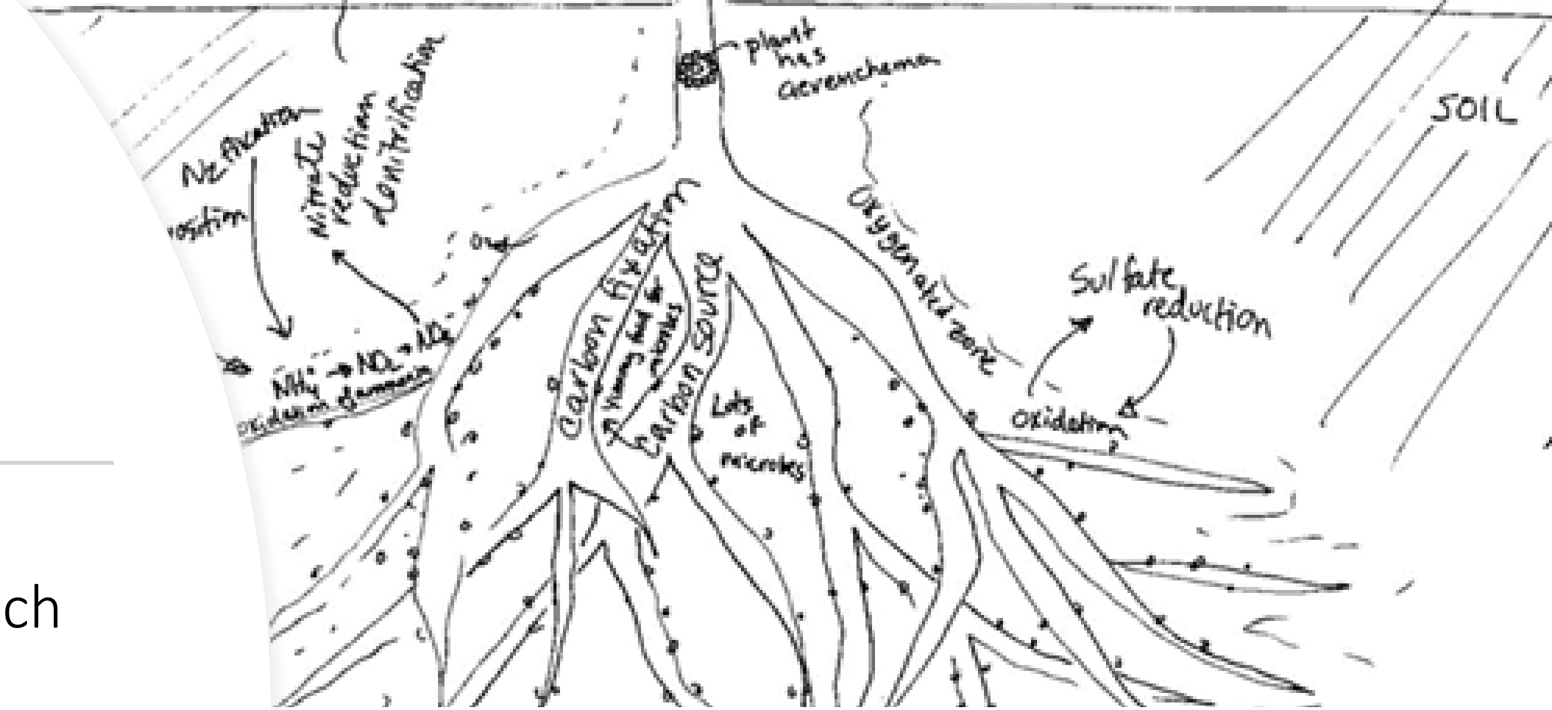
Legume-grass mixtures



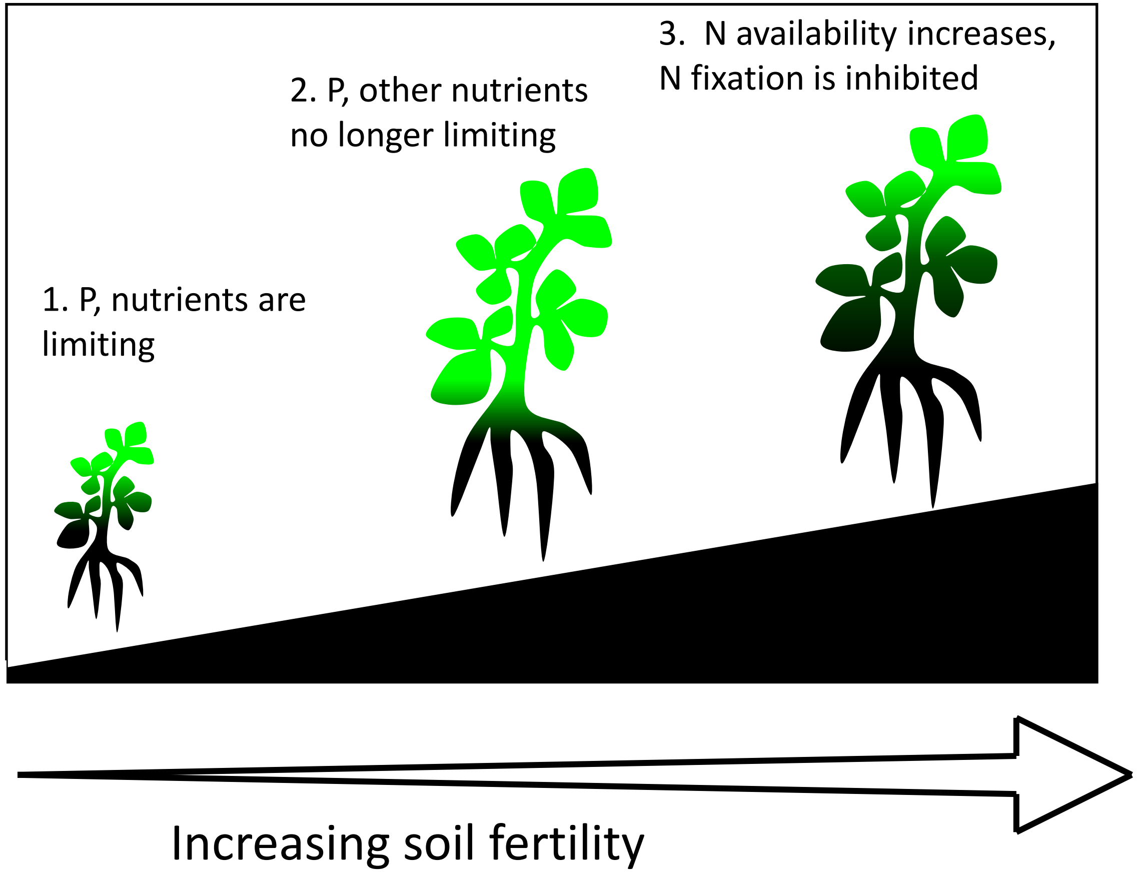
Questions?

Managing legume N

- What factors determine how much N is fixed?
- Which management strategies are most helpful for transitioning from mineral fertilizers to legume-derived nitrogen?



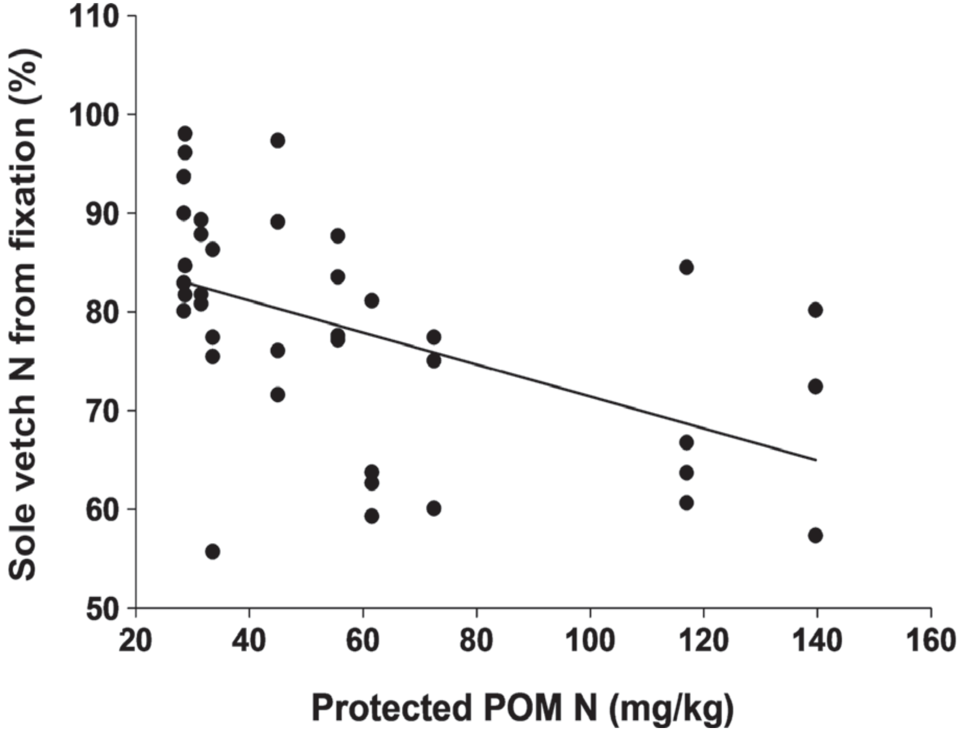
Factors affecting N fixation-1

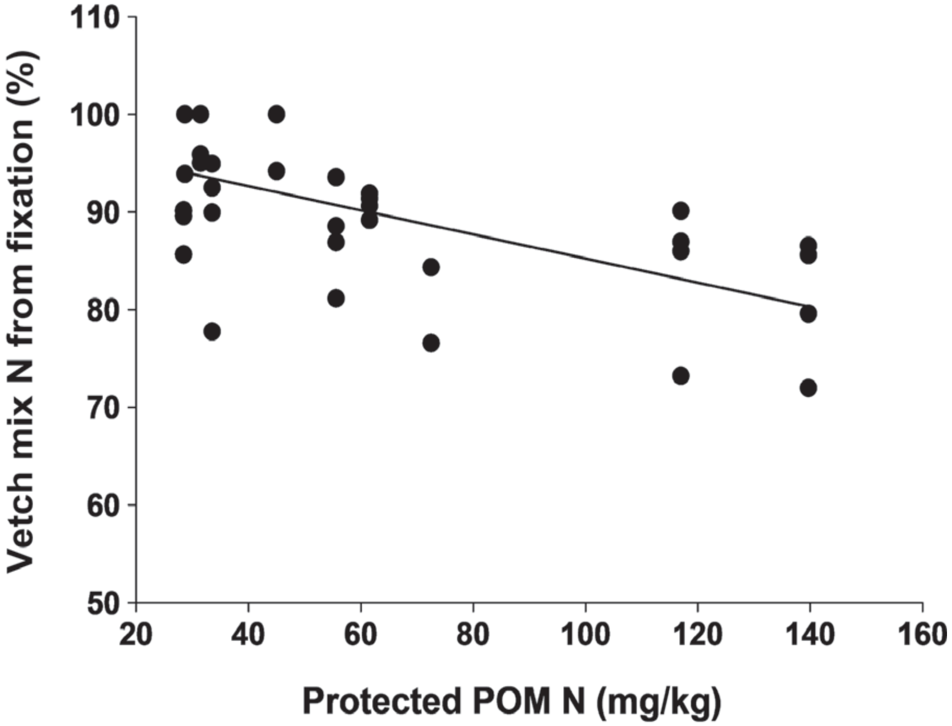


Soil fertility

- Poor fertility—lack of P and micronutrients can reduce growth and N fixation
- Nitrogen: residual fertilizer N and elevated SON suppress N fixation
- Poor drainage, low pH inhibit N fixation

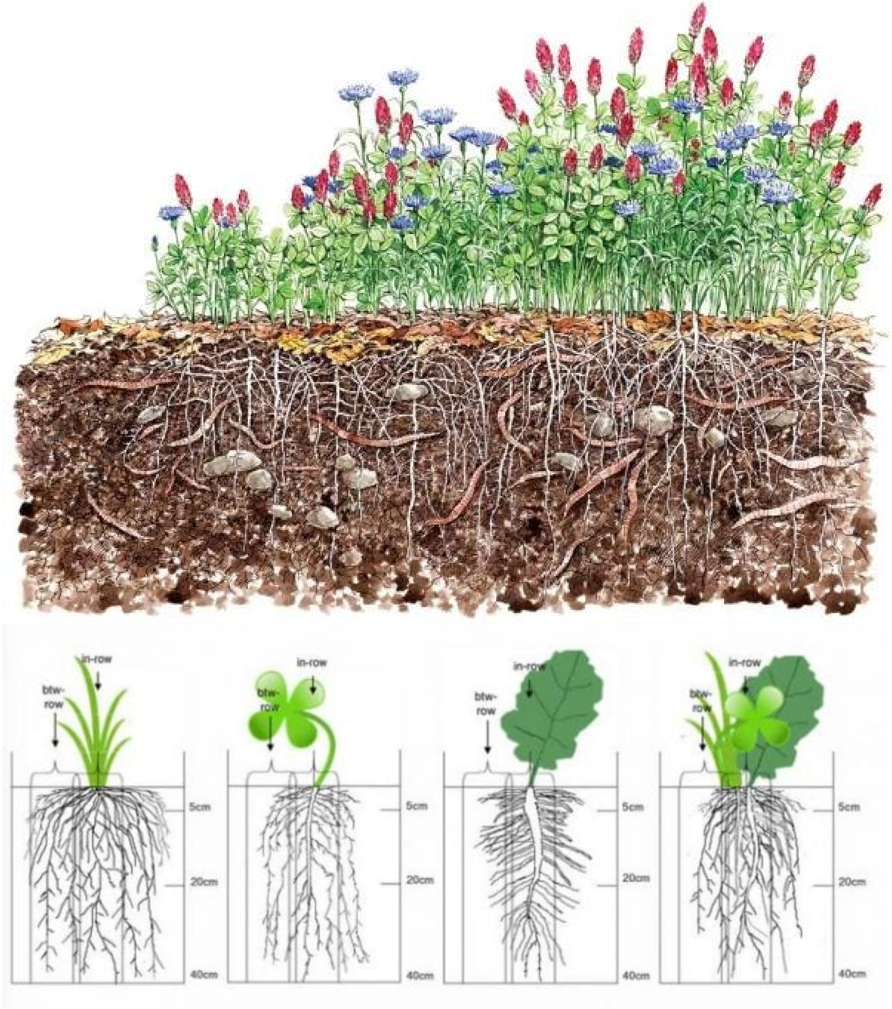
As SON increases, vetch N fixation is down regulated





Blesh 2019. Ecological Applications

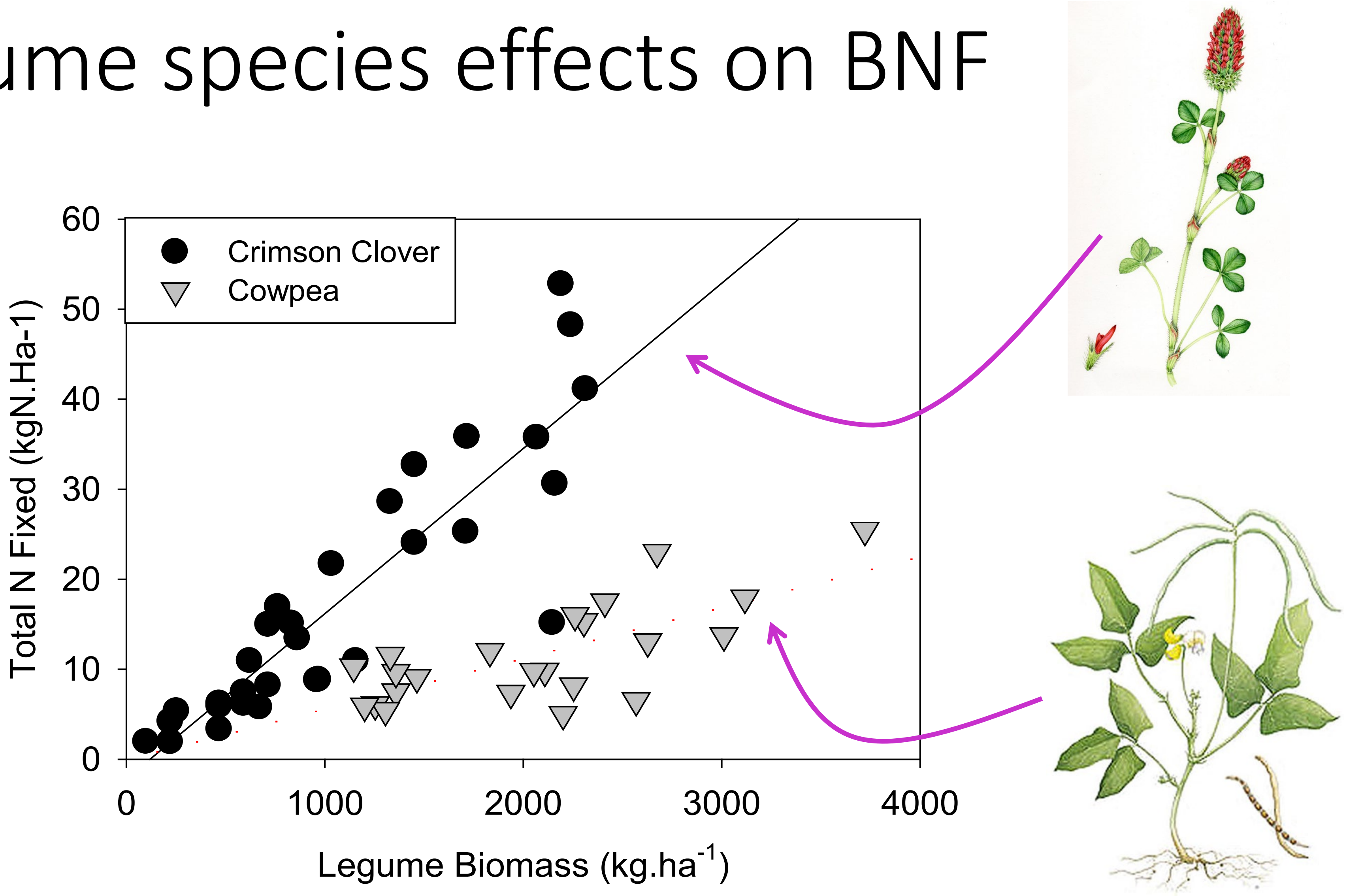
Factors affecting N fixation-2



Cover crop species

- Annuals/perennials: Faster growth/short duration vs large root biomass/SOM formation
- Legume species: Better scavengers/lower N fixation rates VS less able to access soil N/high fixation rate
- Monocultures/mixtures: Mixtures offer the best of both worlds—Scavenge and fix N/delay the initial burst of mineral N VS legume monocultures where N scavenging is reduced/nitrate peaks quickly

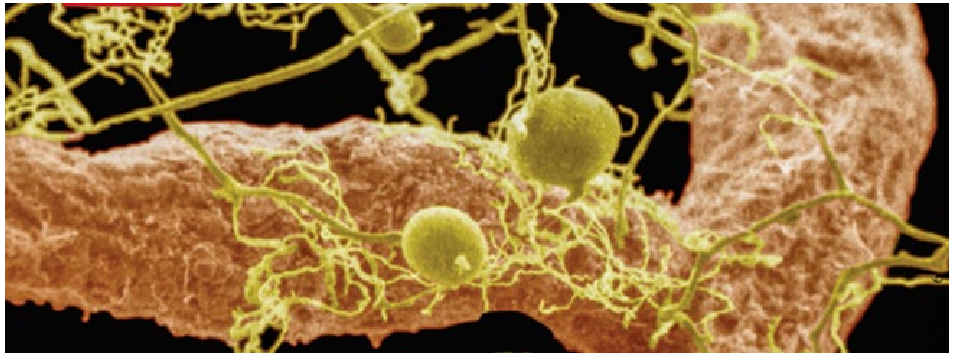
Legume species effects on BNF



Crimson Clover: $R^2 = 0.79$; $y = 0.18X - 2.18$

Cowpea: $R^2 = 0.51$, $y = 0.056X - 0.06$

Factors affecting N fixation-3

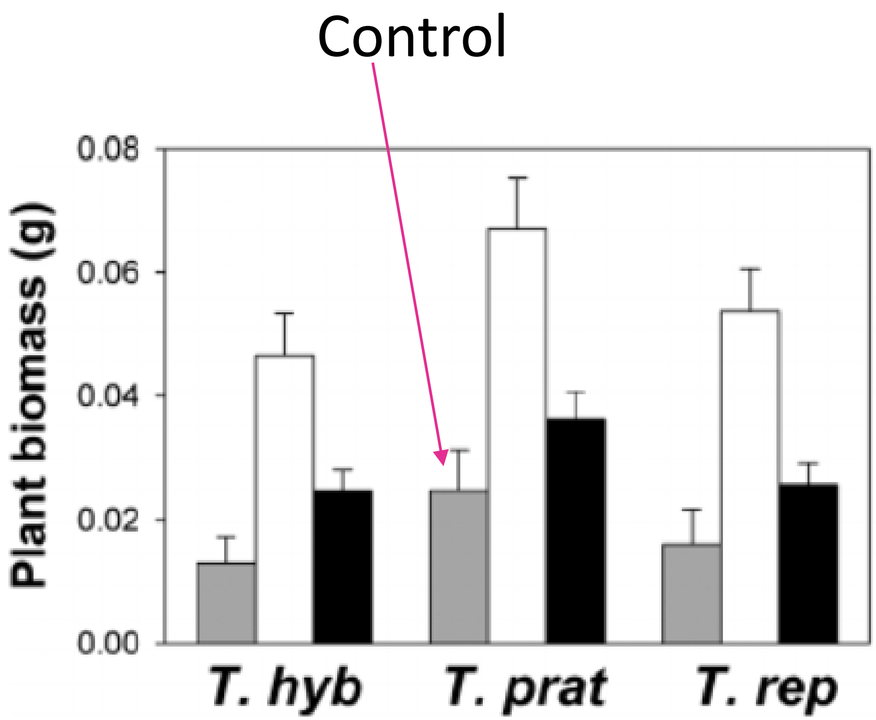


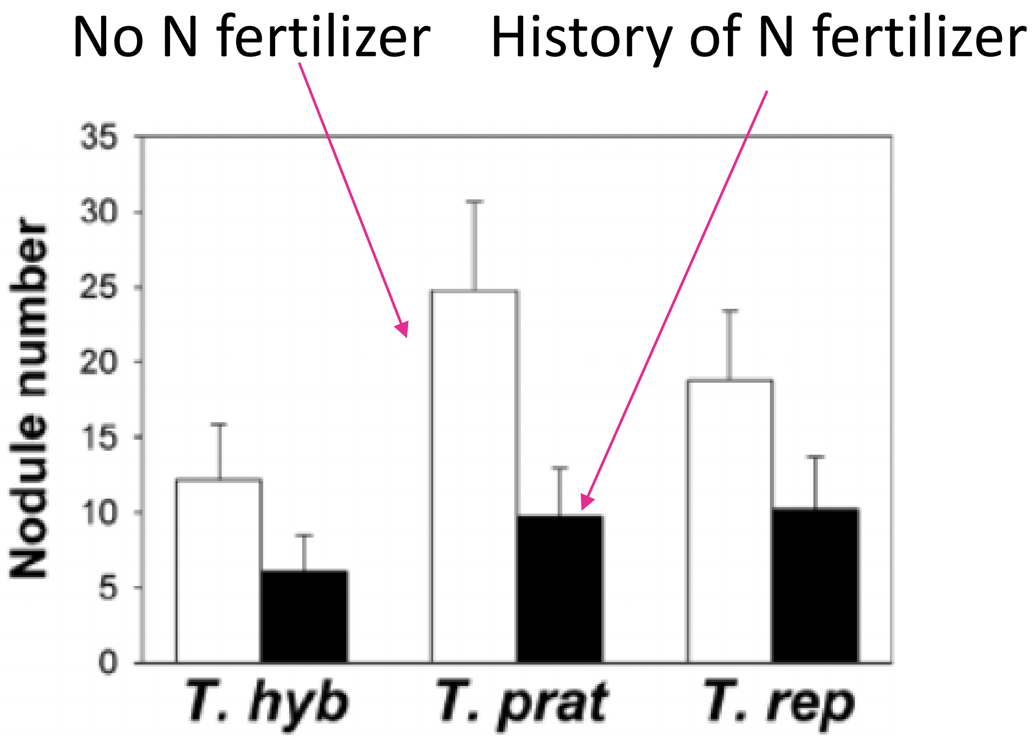
Symbiont partnerships

- Legumes rely on AM mycorrhizae and Rhizobia bacteria
- Inoculation with effective rhizobia is essential in soils that do not have a history of legumes
- Applying N fertilizer to growing legumes can select for less effective Rhizobia strains
- Bare fallows can reduce AM mycorrhizal abundance

Baker and Mohler 2015; Sietz et al. 2019

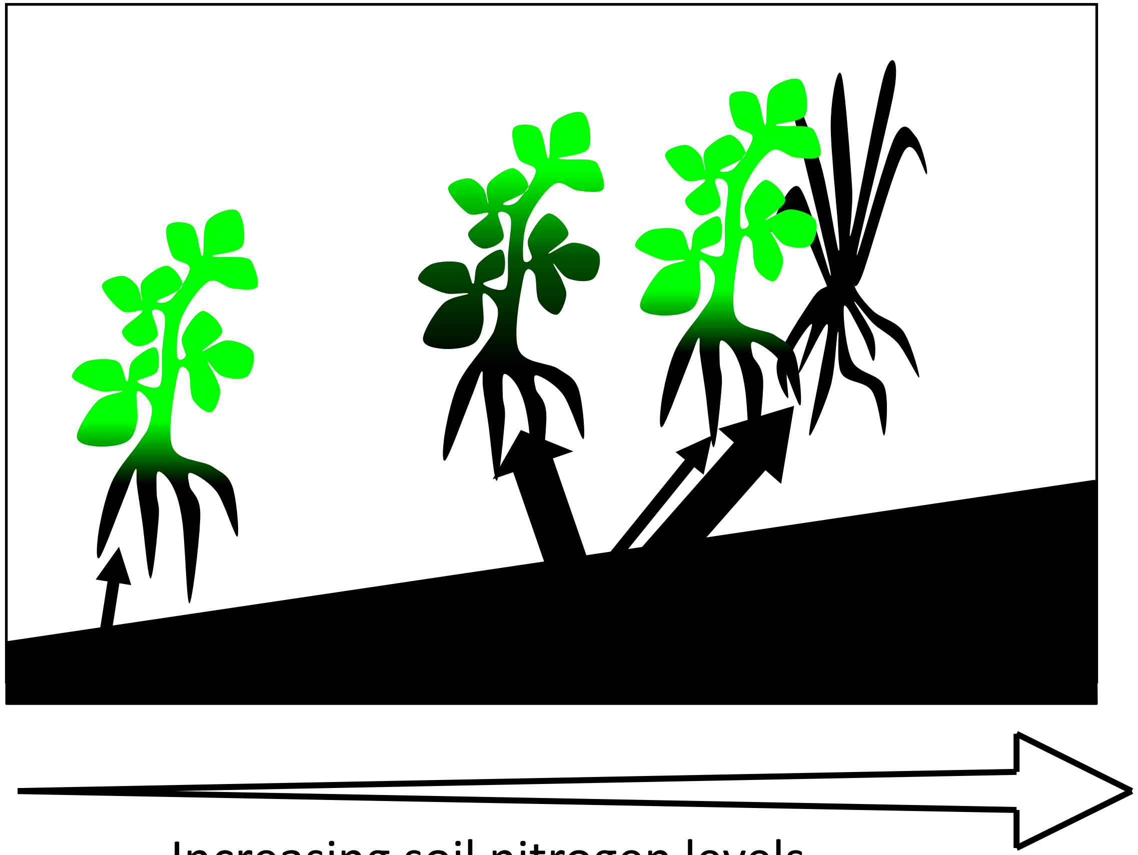
History of fertilizer additions undermines Rhizobia function





Weese et al. 2015. Evolution

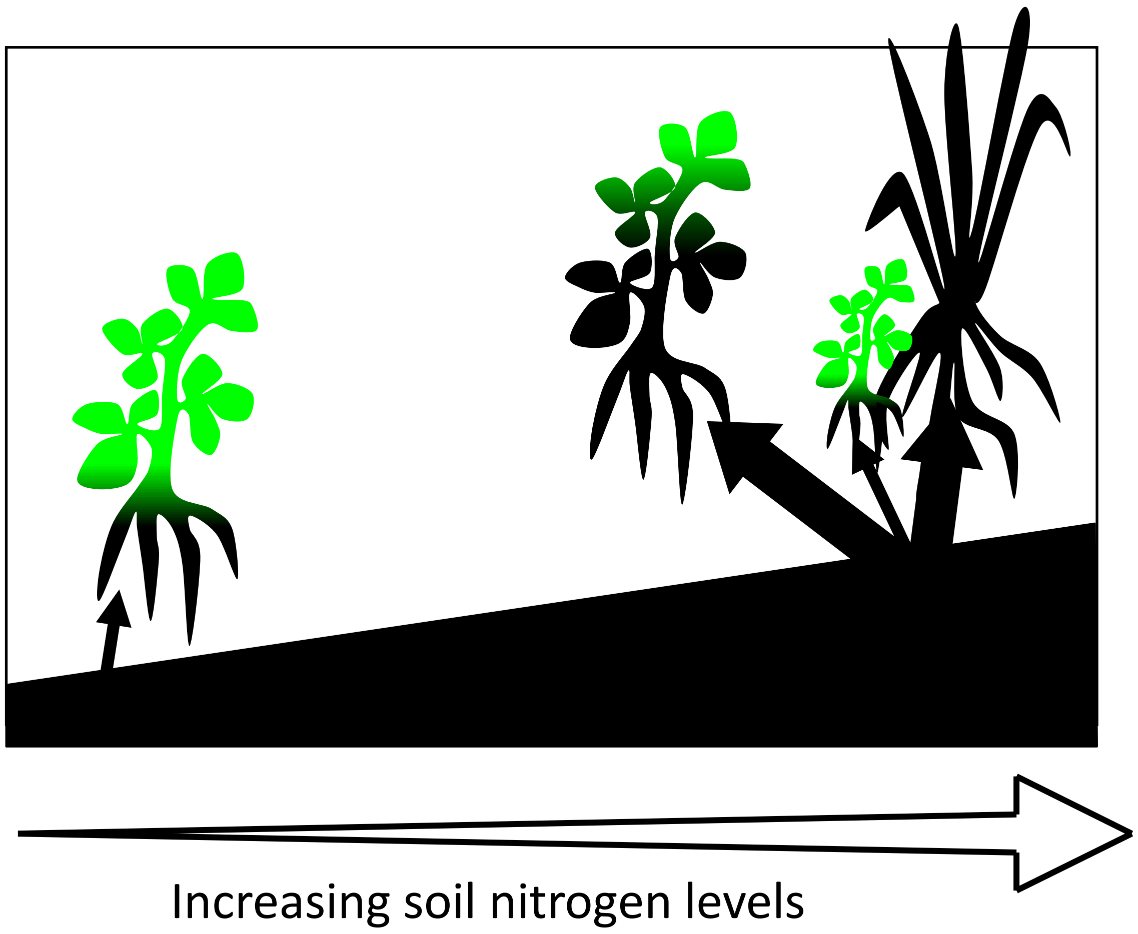
Factors affecting N fixation-4



Plant-soil interactions

- Competition between legumes and grasses (non-legumes) can either increase or reduce N fixation
- The outcome depends on soil N supply and species composition of the stand

Factors affecting N fixation-4



Plant-soil interactions

- Competition between legumes and grasses (non-legumes) can either increase or reduce N fixation
- The outcome depends on soil N supply and species composition of the stand

Cowpea fixed more N when intercropped w/Japanese millet

Cover crop species	% N from fixation	Total N fixed (lbs/ac)
Cowpea	39	37
Cowpea + Japanese millet	72	59
Cowpea + SorgumSudan	56	26

FAO

Forage soybean could not compete with either grass species

Cover crop species	% N from fixation	Total N fixed (lbs/ac)
Forage soybean	**67**	**88**
Forage soybean + Japanese millet	**82**	**28**
Forage soybean + SorgumSudan	**90**	**35**

Red clover N fixation

Total N fixed in two fields with different levels of soil N fertility (one year of red clover growth including estimates of root biomass

	High N fertility lbs N/ac	Medium N fertility lbs N/ac
Red clover	65	80
Clover/grass	38	70

Schipanski, unpublished

Example of a cover crop mixture with good weed suppression and good nitrogen fixation. Vetch/rye cover crop planted on 8/16/08 , sampled on 5/24/09. This stand was about 3-1/2 feet tall , with vetch shoots growing up most of the rye stems. Total N in the cover crop was 160 lbs nitrogen/acre with 89 lbs coming from N fixation. Seeding rates: rye 80lbs/acre ,vetch 50-60lbs/acre. Megan Gregory is former a graduate student in the Drinkwater lab.

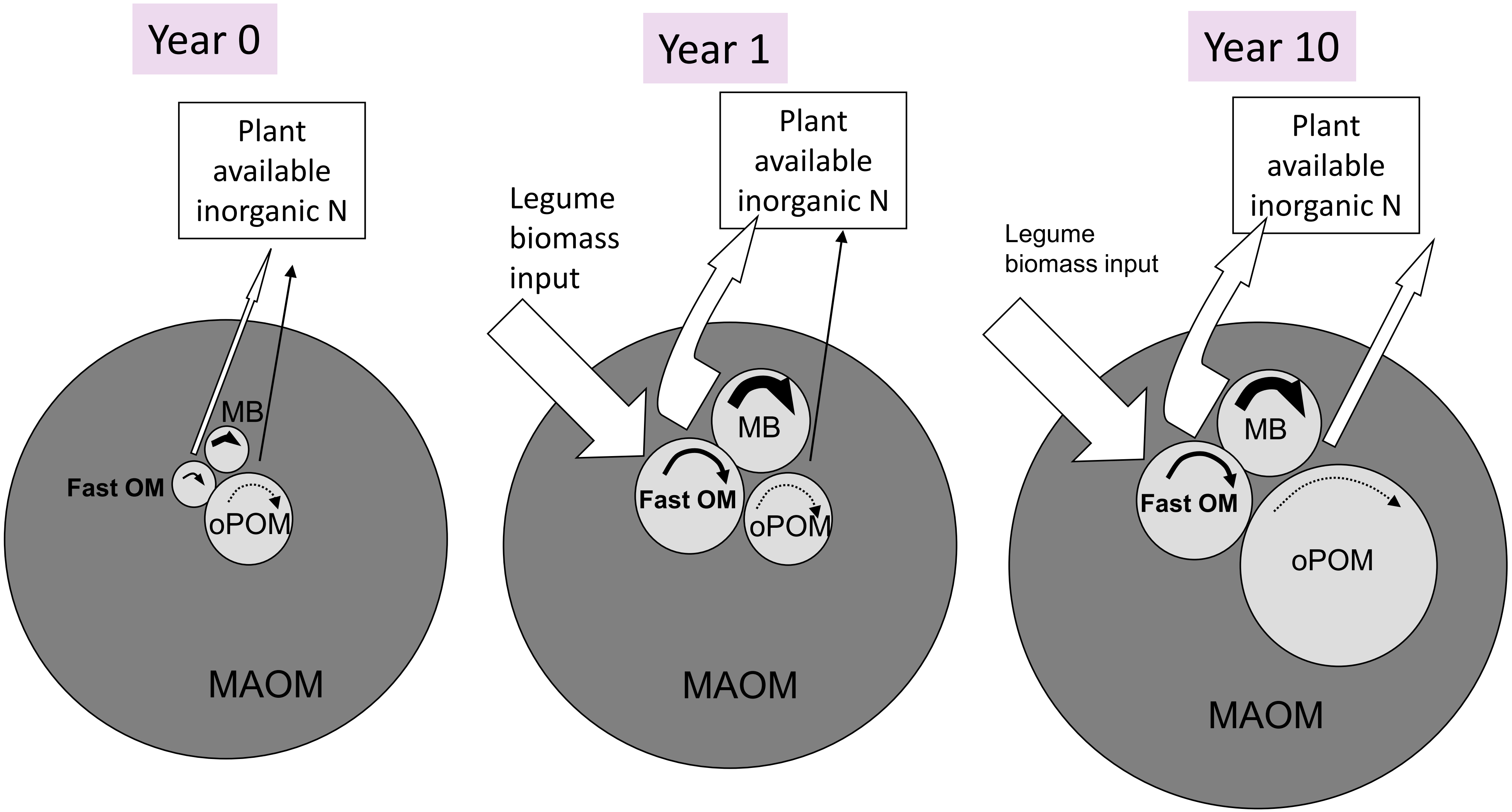
lbs/ac	Fixed N	Soil N	Total N
Vetch	89	10	99
Rye		61	61
Total	89	72	160

Nitrogen in shoot biomass

lbs/ac	Fixed N	Soil N	Total N
Bell bean	27	8	35
Field Pea	83	32	115
Rye		34	34
Total	110	74	184

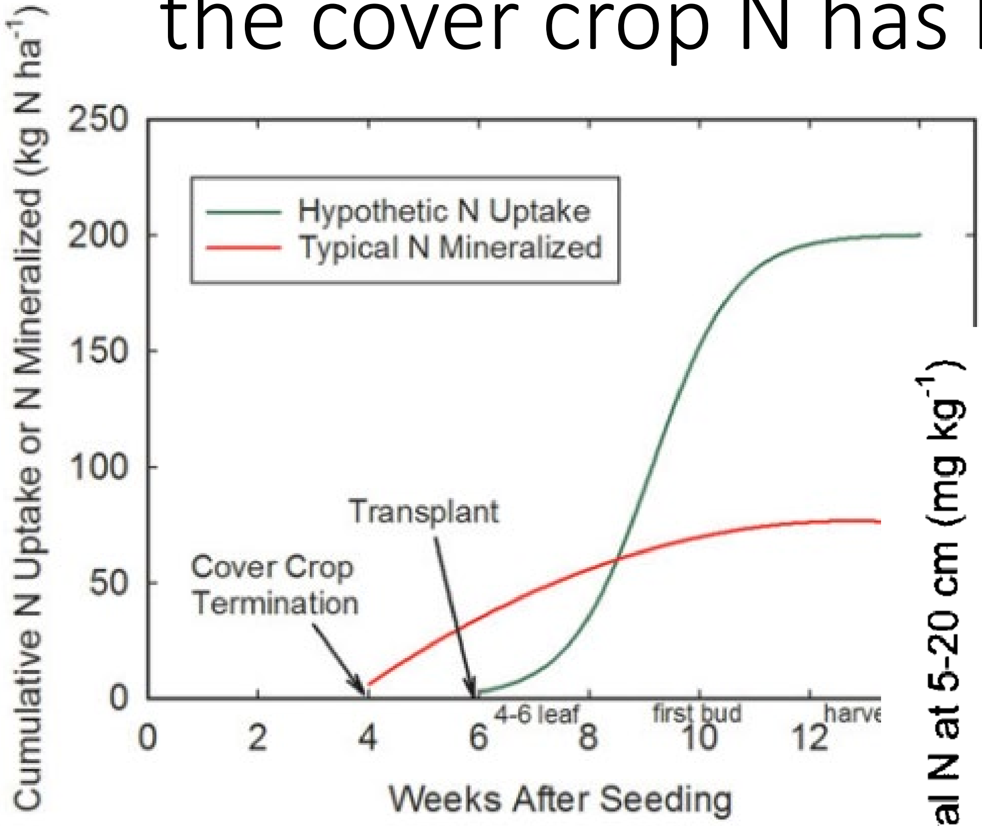
Total N content and breakdown by source in the bell bean/pea/rye cover crop. The field pea was the big nitrogen fixer (83 lbs/acre) compared to bell beans which fixed only 27 lbs/acre. Total N was 184 lbs/acre with 60% or 110 lbs of newly fixed N. The rye scavenged soil nitrogen and probably increased the proportion of nitrogen fixed by the two legumes. Adding roots into the picture would increase our estimate of total nitrogen to 205-225 lbs/acre.

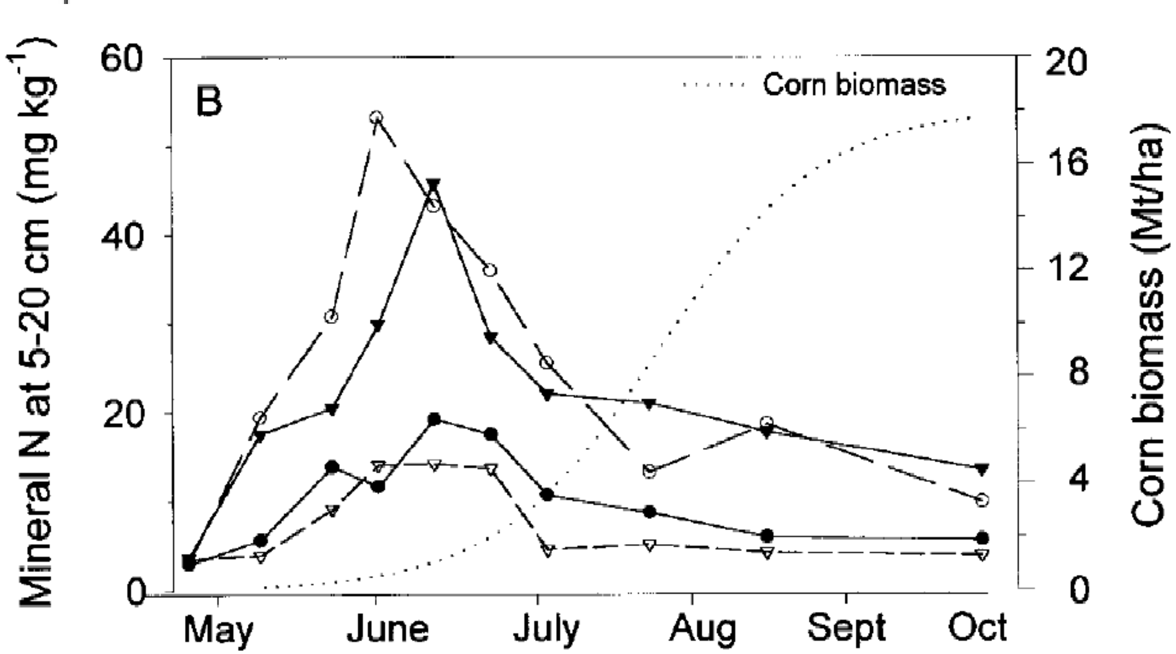
Transitioning to legume N sources: Legumes gradually build N supply from SOM



Drinkwater, et al. 2017. Ecologically based nutrient management. IN: Agricultural systems: Agroecology and rural innovation for development, 2nd Edition. Eds. Snapp, S.S. and B. Pounds.

The majority of N uptake occurs after most of the cover crop N has been mineralized





Gaskin et al. 2019. Renewable Agriculture and Food Systems, Drinkwater et al. 2000. Plant and Soil.

Keys to optimize biological N fixation from legumes

- Good drainage, soil tilth and favorable pH
- Supply adequate phosphorous, potassium, and micronutrients and avoid over-application of N
- Match legume species with time available in the rotation
- Most legume species start fixing N after six weeks of growth—maximum N fixation occurs at flowering
- Longer growing legumes generally fix more nitrogen
- Use a cover crop decision tool to identify best bet species

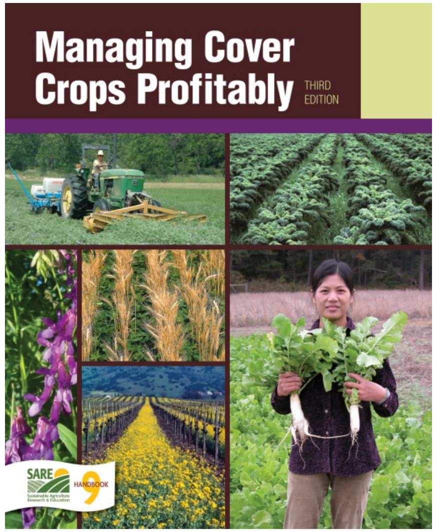
Strategies for the short-term

- In the first few years of using cover crops and legume N sources, soil testing is essential, including SOM measurements
- Estimates of stand biomass/N content are also useful and may be combined with soil tests to estimate supplemental N fertilizer rates
- Since in many cases, rotations will need to be modified, starting with a few fields reduces risk
- Avoid over application of N fertilizer—excess mineral N suppresses N fixation and can accelerate decomposition of some SOM pools and undermine SOM accrual
- Cover crop N calculators are available in some regions

Strategies for the long-term

- Routine soil testing continues, increased SOM should be detectable
- Fine tuning cover crop seeding rates and stand composition is necessary to adapt to changing soil conditions
- In the early years of using legumes as N sources, application of other organic amendments can accelerate SOM accrual and reduce the need for supplemental N fertilizer
- Cover crop guides can help to select species that can provide other ecosystem services (i.e., promote aggregation, disease suppression, winter hardiness, etc.)

Resources



- SARE: Managing cover crops profitably. https://www.sare.org/resources/managing-cover-crops-profitably-3rd-edition/
- Cover crop decision tools: Midwest- https://mccc.msu.edu/selector-tool/; Northeast- https://northeastcovercrops.com/decision-tool/; New York- http://covercrop.org/; Pacific Northwest- https://www.nrcs.usda.gov/wps/portal/nrcs/detail/plantmaterials/technical/toolsdata/plant/?cid=nrcseprd894840
- White et al. 2020. Modeling the contributions of nitrogen mineralization to yield of corn. *Agronomy J.*
- Gaskin et al. 2019. Using the cover crop N calculator for adaptive nitrogen fertilizer management: a proof-of-concept. *Renewable Agriculture and Food Systems.*

Thank-you! Questions?

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