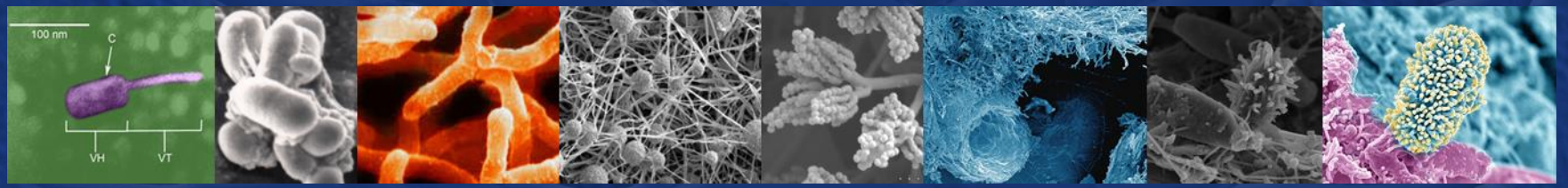
Soils Are Alive!
When Biology and Agronomy Meet

FarmSmart 2017



Presented by Lori A. Phillips and Jake Munroe

Guelph, January 20, 2017

Agriculture and Agri-Food Canada
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Soils contain 25% of our planet's biodiversity

One teaspoon of soil contains:

- Millions of different microbial species
- Billions of individual organisms critical for healthy soils

These microbes are mainly invisible and mostly still unidentified

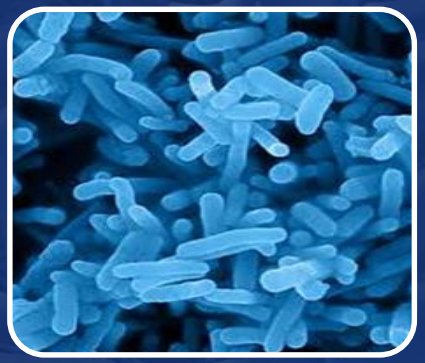
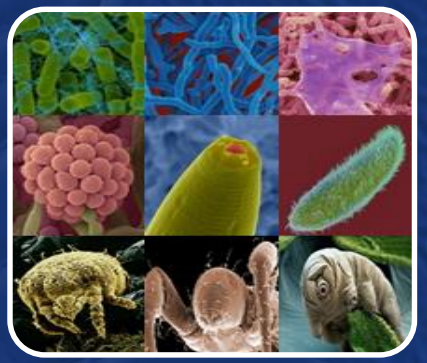
Microbial group	*Size*	*Estimated # individuals*	*Estimated # species*	*Global Species estimates*
Archaea	**0.5-3 µm**	**> 10^9**	**unknown**	**>10,000**
Bacteria	**1-5 µm**	**> 10^9**	**9000**	**>4,000,000**
Fungi	**>4 µm**	**> 10^6**	**250**	**>1,500,000**
Protozoa	**5-200µm**	**> 10^6**	**1200**	**> 150,000**
Nematodes	**10µm-2mm**	**>10^6 (m^2)**	**100**	**>20,000**
Other Fauna	**250µm-2mm 2mm-2m**	**>10^6 (m^2)**	**>200**	**>100,000**

What do soil microbes do for us?

1. Microbes cycle C by photosynthesis & decomposition
2. Microbes regulate plant nutrient supply & loss (eg. N, P, K, Fe) through symbiotic & asymbiotic interactions
3. Microbes capture & release greenhouse gases

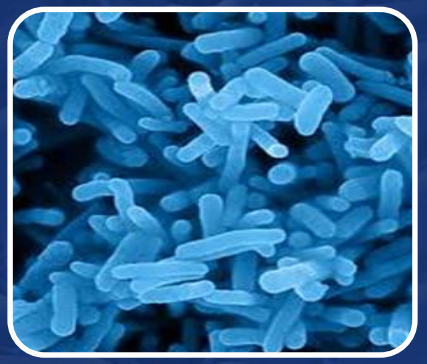
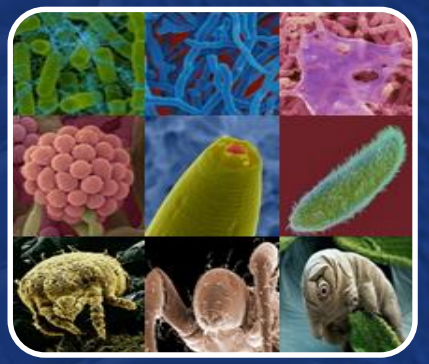
   (carbon dioxide, methane, nitrous oxide)
4. Microbes improve soil structure (aggregate stability)
5. Microbes degrade pesticides
6. Microbes regulate water quality (e.g. filters nutrients)
7. Microbes suppress soil borne diseases

Soil Biodiversity and Agricultural Resilience

Soil Structure	Carbon transformation	Nutrient Cycling	Biocontrol
			
Macro-fauna Meso-fauna Fungi Bacteria	Macro-fauna Meso-fauna Micro-fauna Fungi Bacteria	Micro-fauna Fungi Bacteria Archaea	Increased biodiversity at all levels Predators Parasites

Agricultural Resilience and Human Health

Soil Structure | **Carbon transformation** | **Nutrient Cycling** | **Biocontrol**

Loss of provided ecosystem goods and services

Increased soil-borne pathogens
Increased xenobiotic persistence and movement

Human health impacts
Increased risk of diseases: increased pests and pathogens, lack of clean air and water

Reduced supply of food and clean water and air

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Modified from Wall et al. 2015

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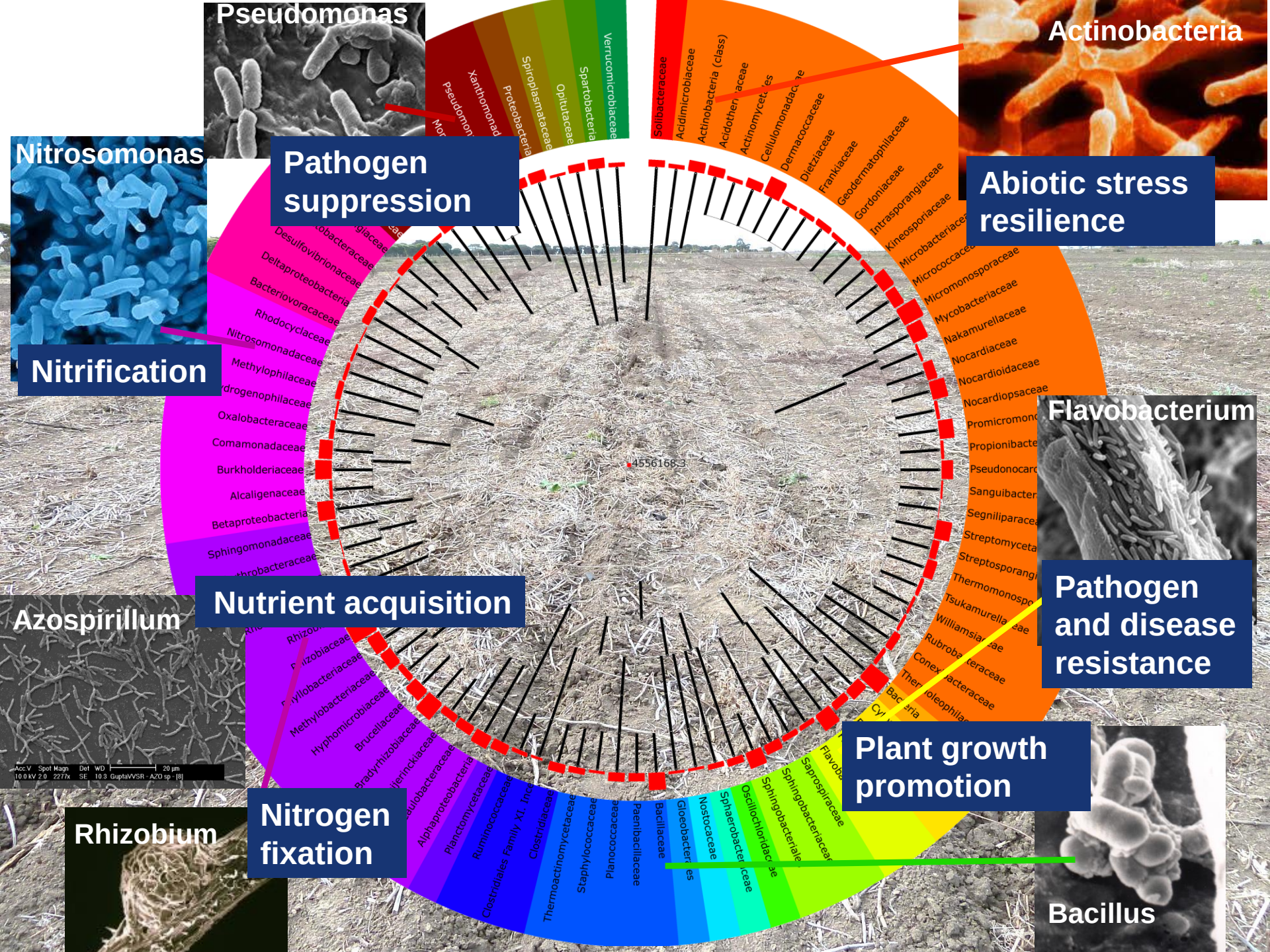
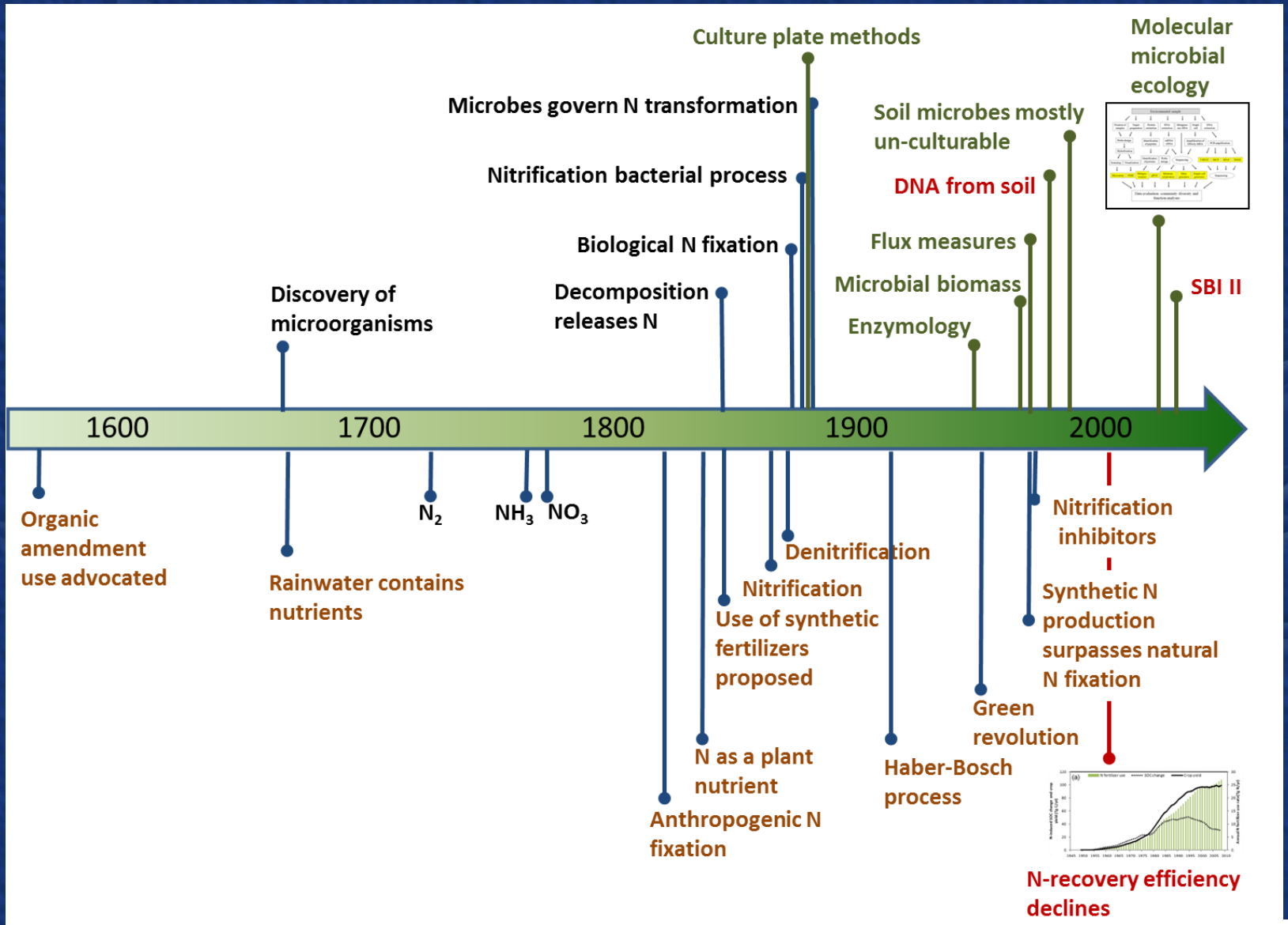
Molecular tools now allow us to open the 'black box' of this complex soil ecosystem


Pseudomonas
Pathogen suppression
Actinobacteria
Abiotic stress resilience
Nitrosomonas
Nitrification
Flavobacterium
Pathogen and disease resistance
Nutrient acquisition
Azospirillum
Plant growth promotion
Nitrogen fixation
Rhizobium
Bacillus

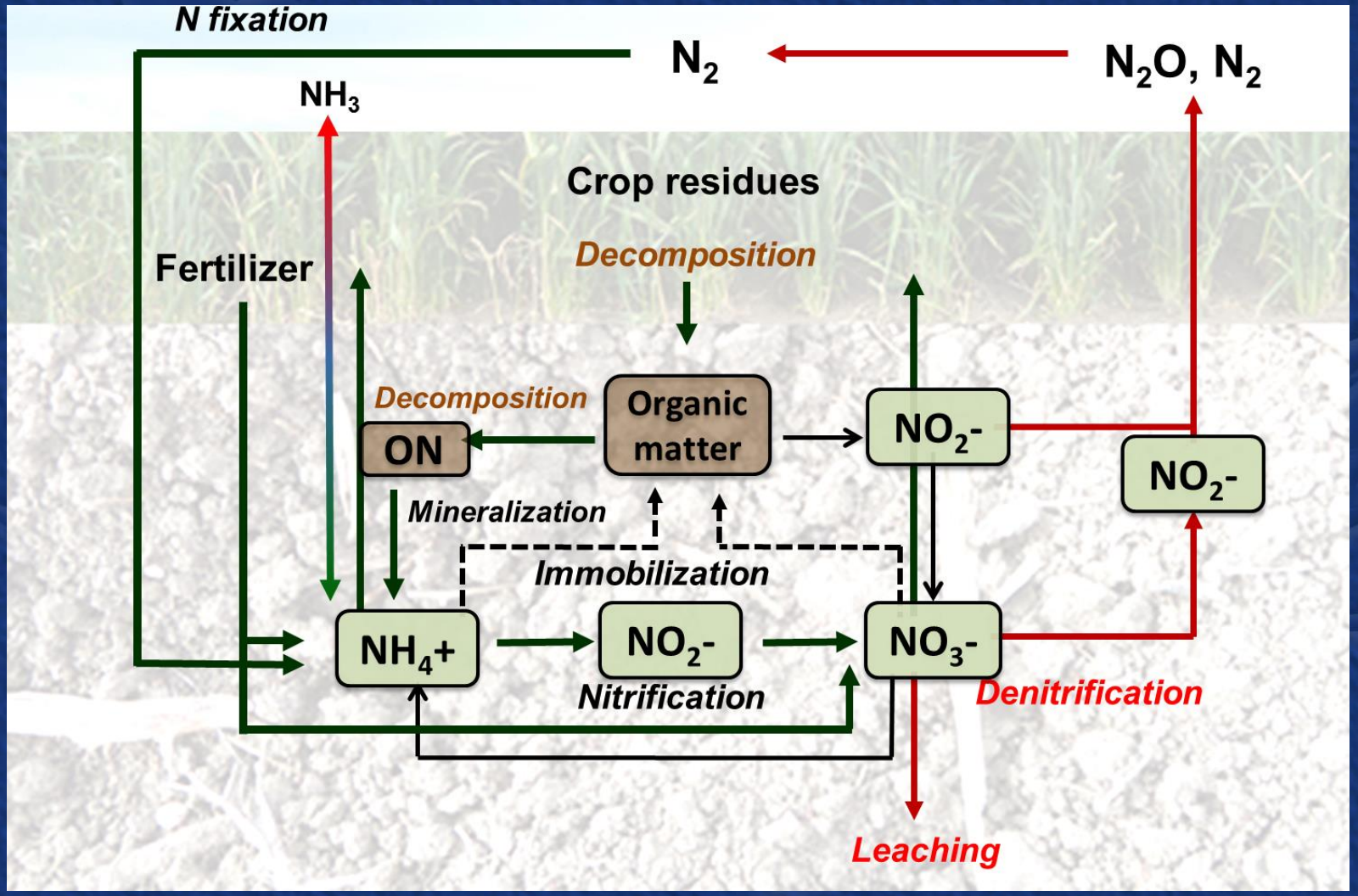
In the grand scheme of things…



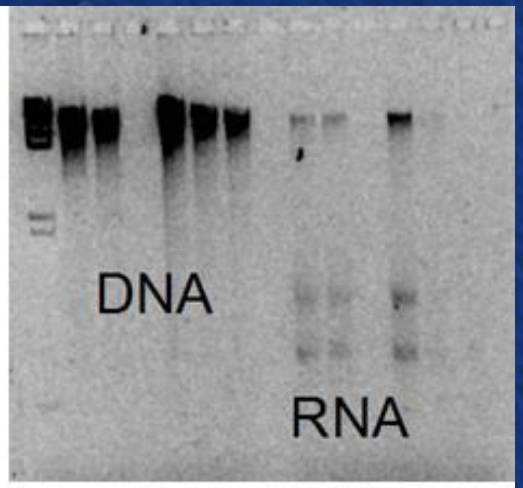
How does agriculture affect soil life?

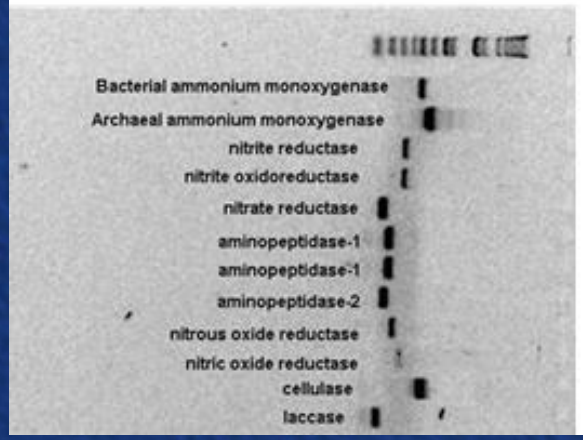
- **Residue management and fertilizer inputs**
  - ➢ modify the quantity and quality of microbial nutrient supplies
- **Tillage practices**
  - ➢ affect habitat properties & biopore networks
- **Crop rotations**
  - ➢ alter microbial diversity and function
- **Pesticide and herbicide application**
  - ➢ induce transient changes in community composition
- **Soil amendments**
  - ➢ change microbial population dynamics

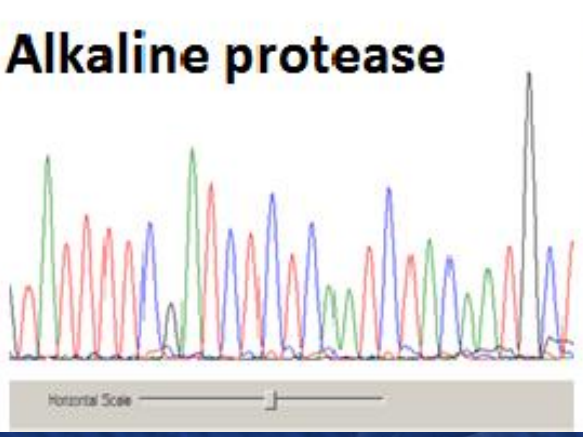
How does agronomic management affect the soil microbial functions that release organic N?

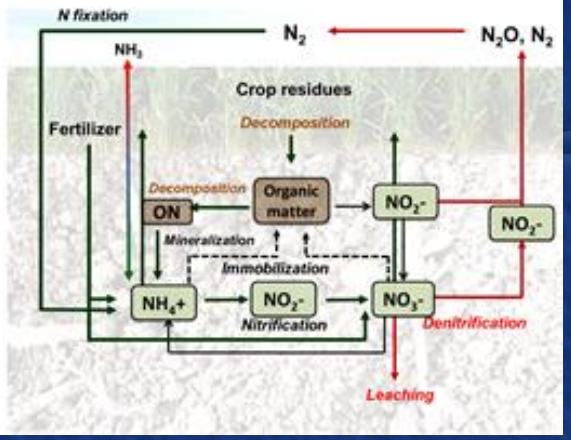


How does agronomic management affect the soil microbial functions that release organic N?









SCRIME: Sustainable Cropping Rotations in Mediterranean Environments

- **DEDJTR LTAE**
- **Established 1998**
- **Grey Vertosol**
  - **alkaline grey self mulching clay**
- **Rotation and tillage treatments**
  - **Till vs no-till**
  - **Canola→wheat→pea**

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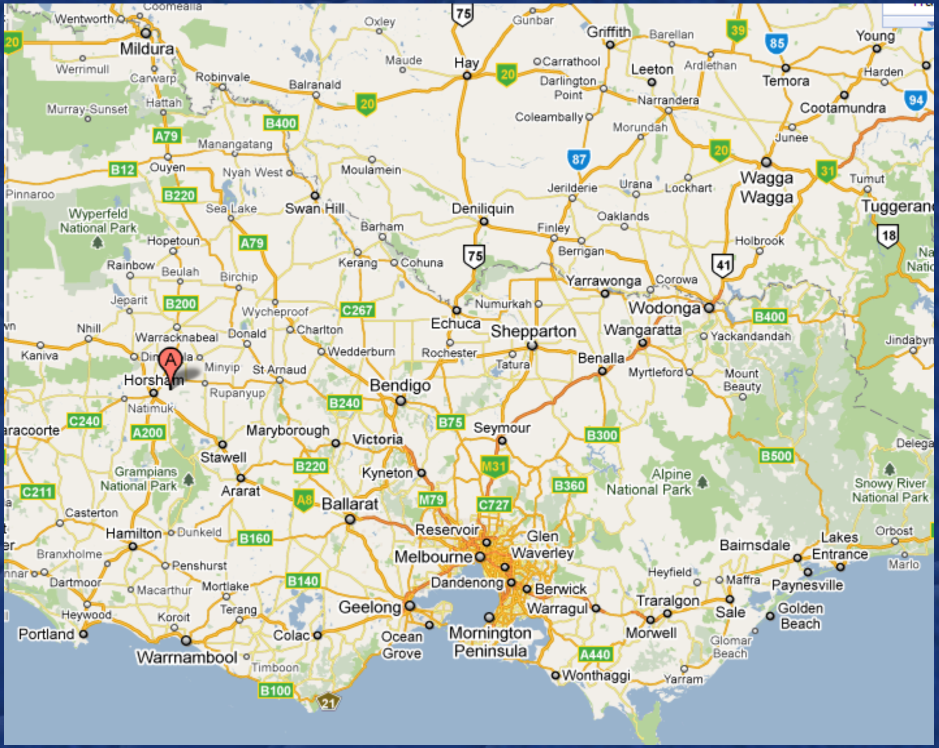

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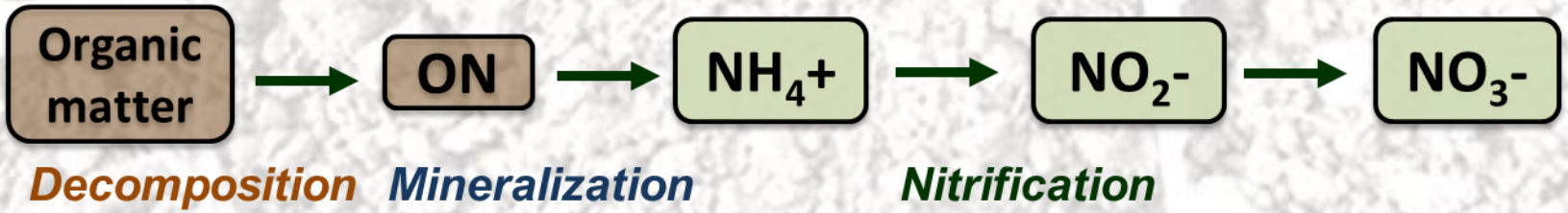
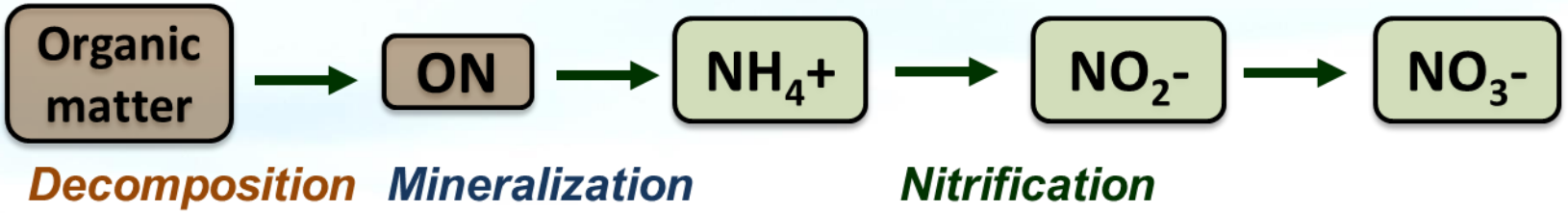
Till treatments after a legume rotation had 20-30% more mineral-N than no-till treatments

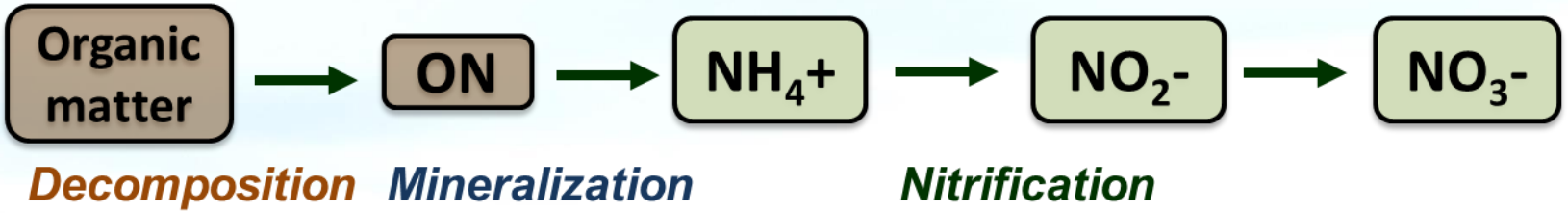




NUMBER of genes associated with SOM decomposition in Till vs No-till systems

Previous	Current	S	G	T	A	H
Canola	Wheat	<	<	<	<	<
Wheat	Pea	<	<	<	<	>
Pea	Canola	>	>	=	=	<

So, till legume residues into the soil → prime the responsive community → more residue decomposing microbes → more N released from those residues. Simple, right?



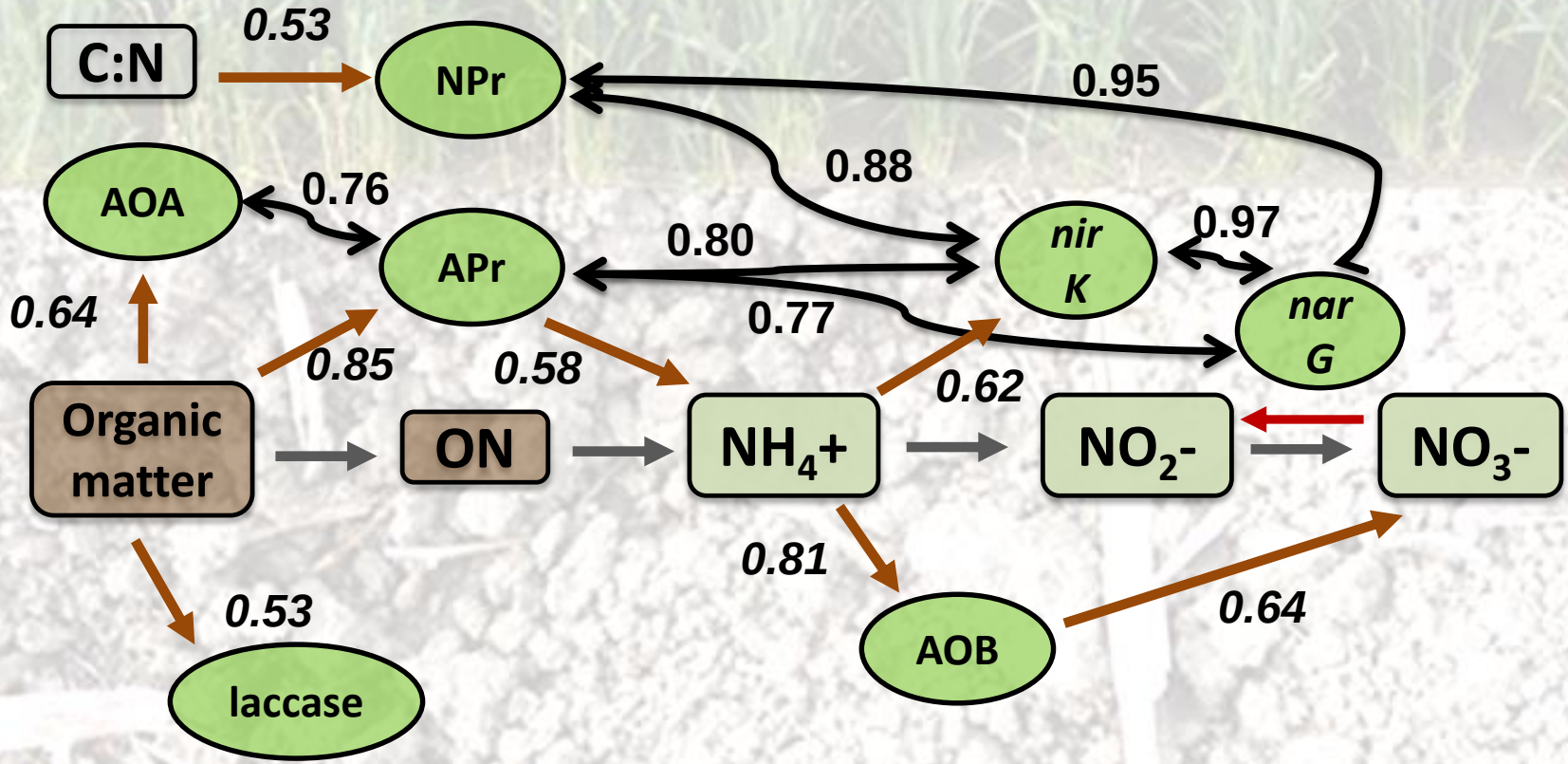
ACTIVITY of genes associated with SOM decomposition in Till vs No-till systems

Previous	Current	S	G	T	A	H
Canola	Wheat	<	<	<	<	<
Wheat	Pea	<	<	<	<	<
Pea	Canola	<	<	<	<	<

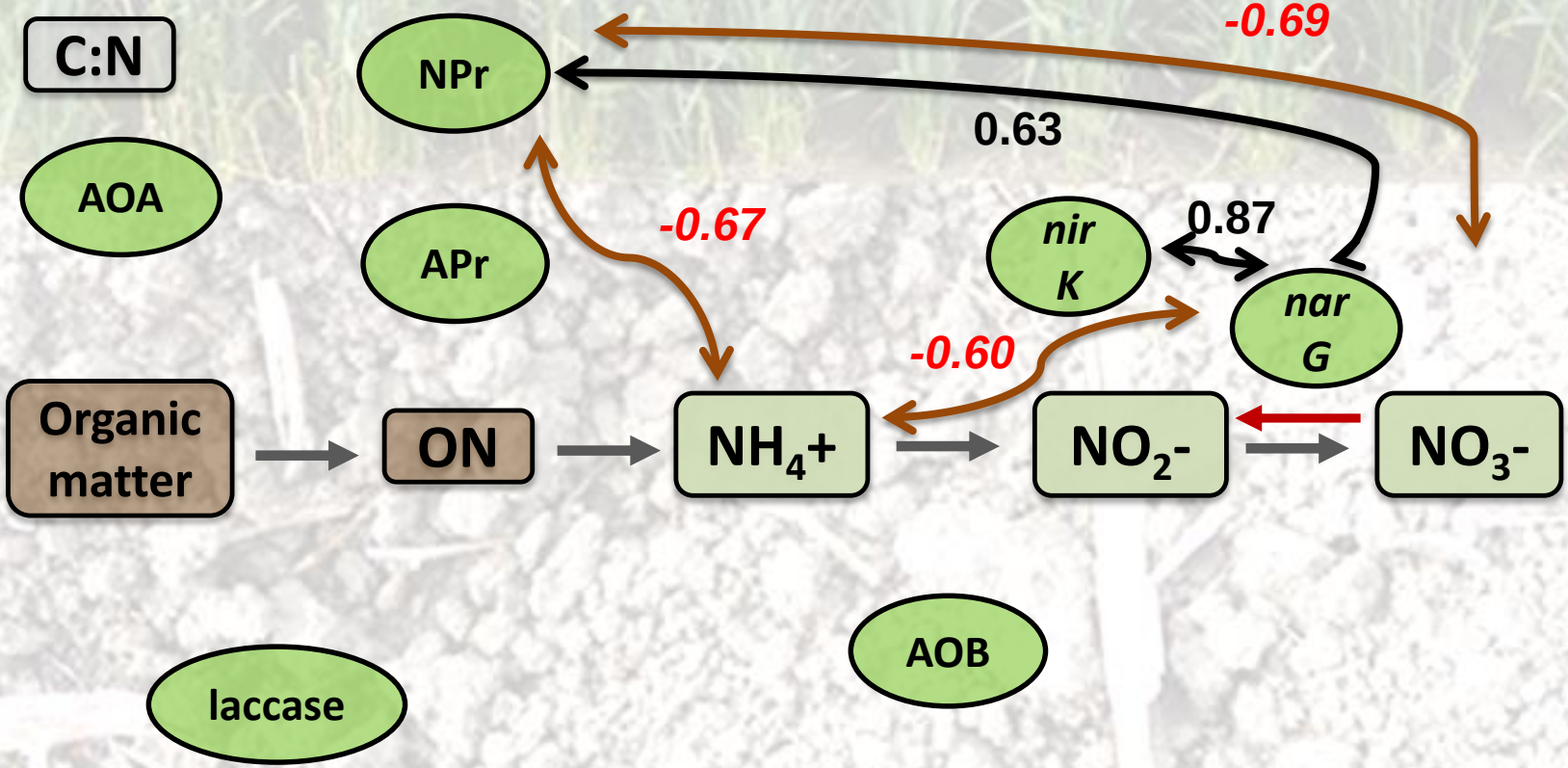
So, till legume residues into the soil → prime the responsive community → more residue decomposing microbes → more N released from those residues. Simple, right?

Except those microbes were not more active

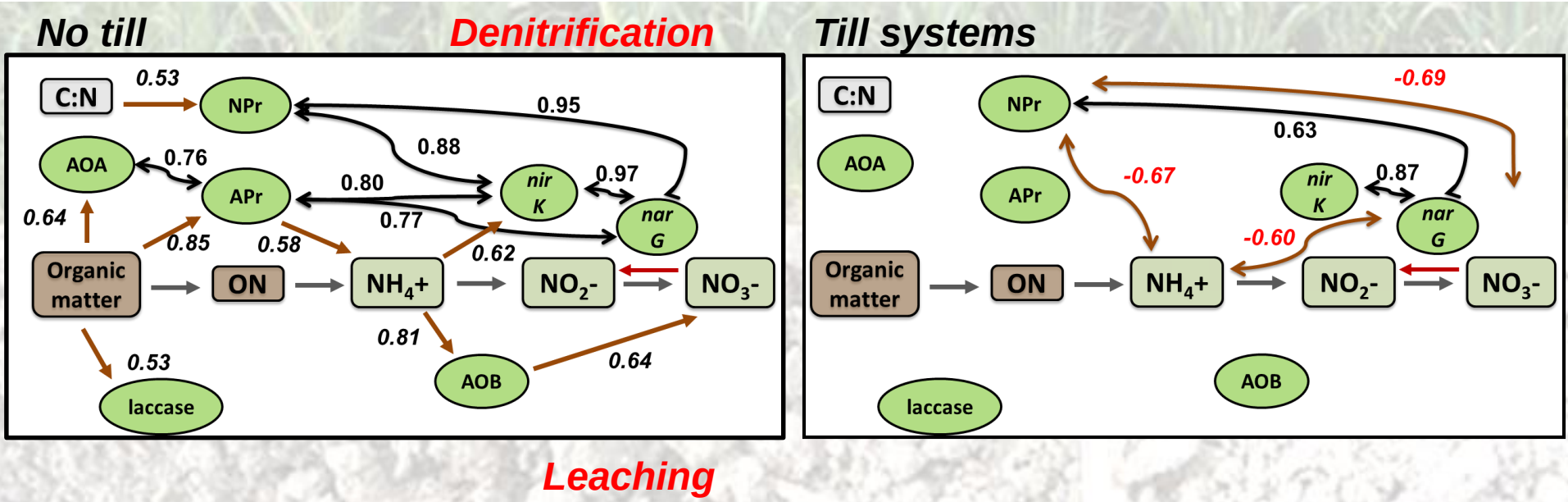
In the early cropping season, microbial ACTIVITIES and nutrient pools are highly COUPLED in no-till systems



In the early cropping season, microbial ACTIVITIES and nutrient pools are UNCOUPLED in till systems



Till treatments after a legume rotation had 20-30% more mineral-N than no-till treatments



- Processes includes loss pathways
- Wet autumn → no-till had greater organic-N release efficiency → mineral N lost before sowing
- Detectable after legume due to N-rich residues inputs

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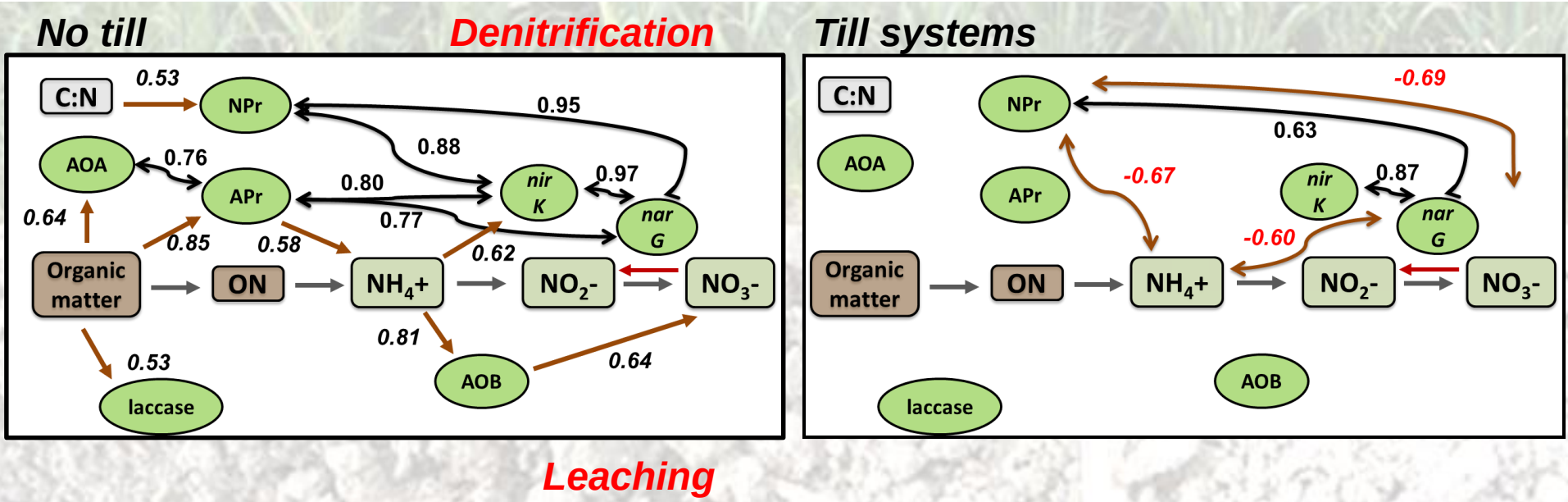


- **Yields still higher in no-till systems!**
- Cumulative beneficial impacts on soil health and in-season water holding capacity

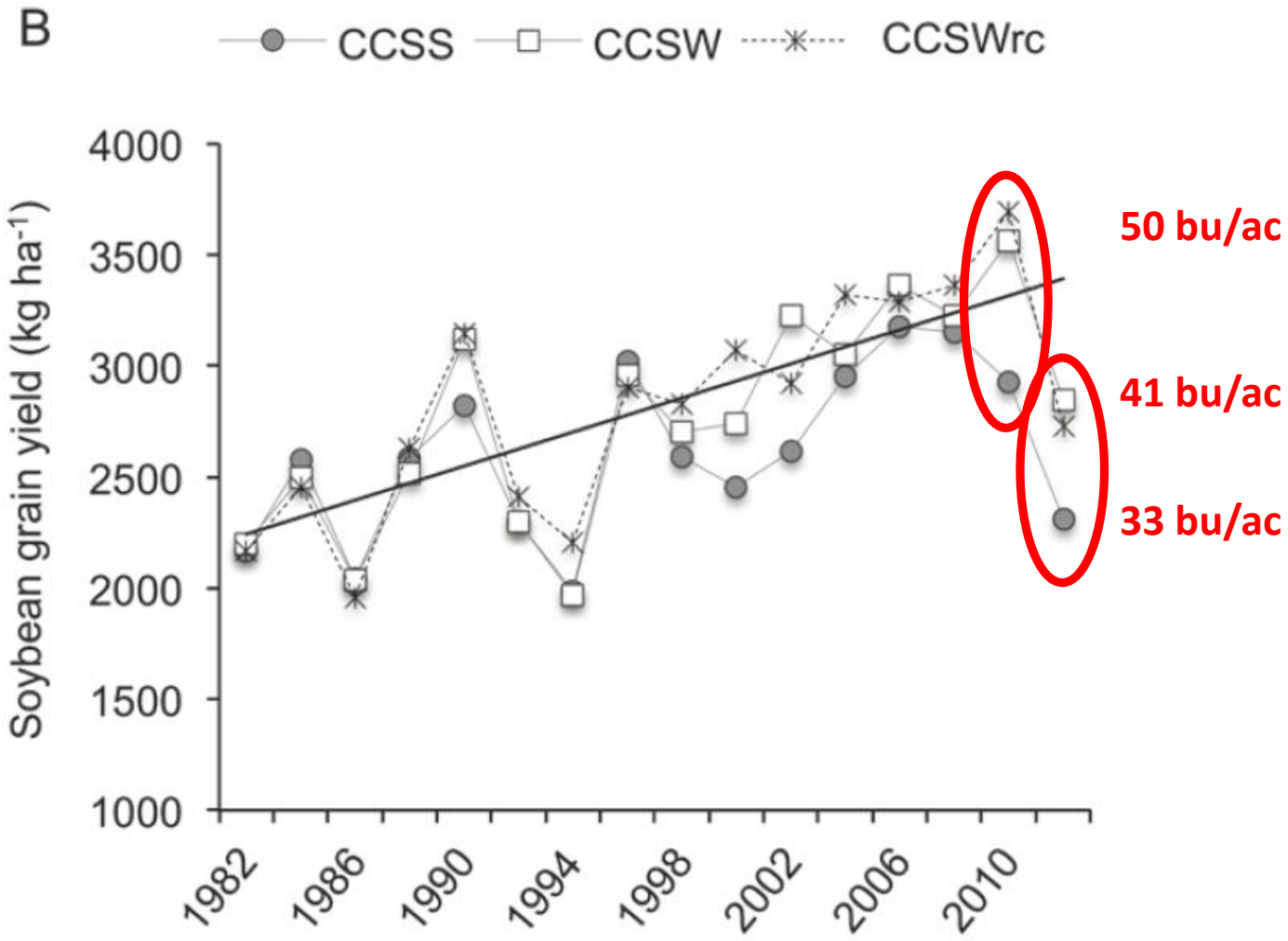
Microbial communities respond to management

- This means that they **can be managed**, and if they can be managed they **can be manipulated**
- Understand where and under what circumstances specific microbial functions are most active
- Use that information to inform management
- Start with the basic principles that improve overall soil health

Principles

- Minimize soil disturbance (to protect habitat)
- Diversify crops (to diversify soil life)
- Maintain a living root system (to feed soil life)
- Keep the soil covered (to feed and protect soil life)
- Add organic amendments if possible (to feed soil life)

Soybean Yields at Elora



Gaudin et al., 2015

Effect of Rotation on Soil Health

Crop rotation	Ridgetown	
	CSHA	OSHA
MonoA	–	–
MonoC	64 (1.6) b	48 (8.5) ab
MonoS	64 (2.1) ab	37 (9.9) b
MonoW	–	–
A–A–C–C	–	–
S–W	70 (1.6) a	72 (7.9) a
C–S–W or C–C–S–W	66 (1.6) ab	52 (7.5) ab
C–C–S–W/rc	–	–
C–C–O–B	–	–
C–C–O/rc-B/rc	–	–
S–C or S–S–C–C	63 (1.6) b	33 (8.2) b
T–T–R	–	–
P value	0.0022	0.0002

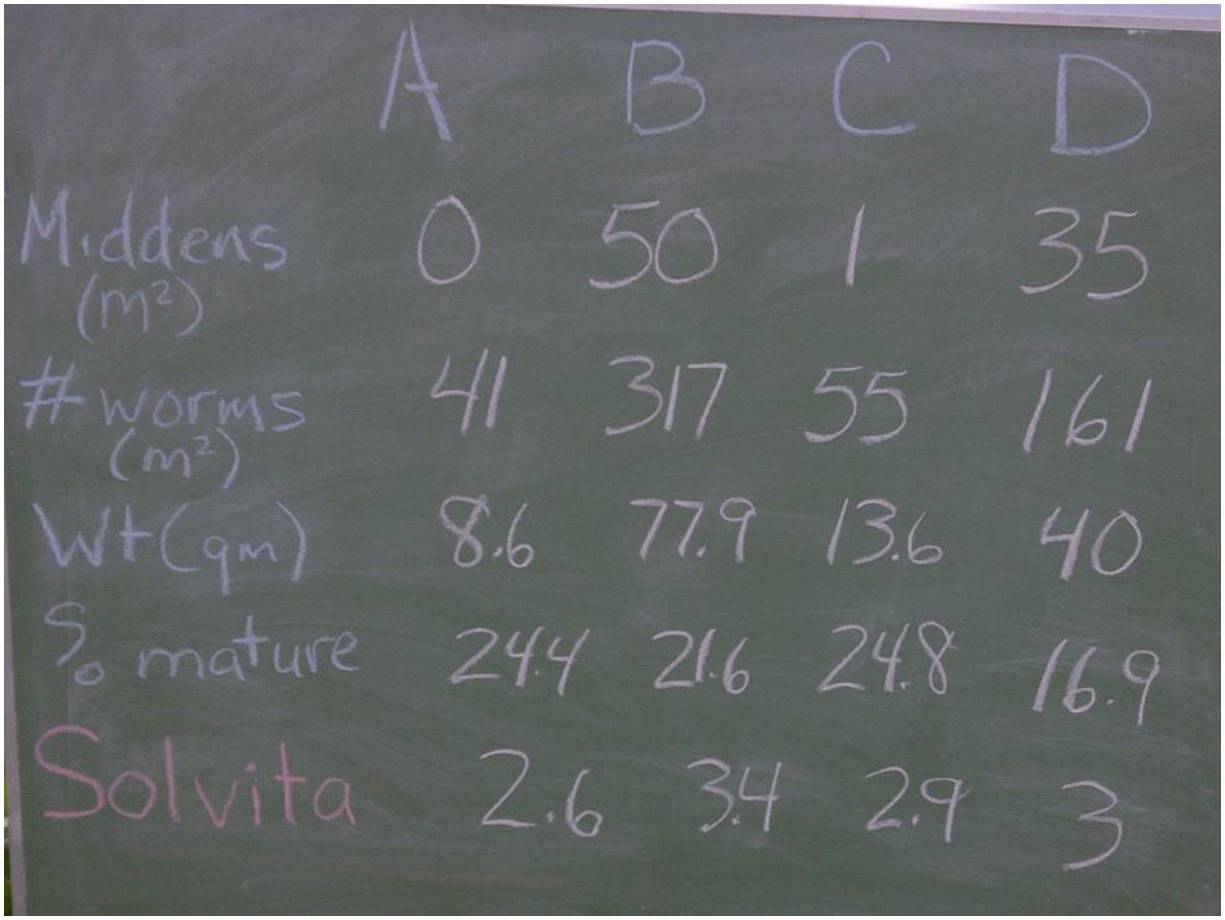
Congreves et al., 2015

Effect of Tillage on Soil Health

Soil attribute	Tillage	
	CT	NT
Aggregate stability (%)	29 (1.5) b	46 (1.5) a
Organic matter (%)	4.3 (0.16)	4.6 (0.16)
Active C ($mg\,kg^{-1}$)	690 (6.3)	700 (6.3)
PMN ($mg\,kg^{-1}$)[a]	8.0 (1.0)	11 (1.0)
Root health	2.1 (0.14)	2.0 (0.14)
pH	6.8 (0.057) a	6.5 (0.057) b
P ($mg\,kg^{-1}$)	34 (2.1)	37 (2.1)
K ($mg\,kg^{-1}$)	186 (14)	204 (14)
Ca ($mg\,kg^{-1}$)	4200 (317)	4000 (317)
Mg ($mg\,kg^{-1}$)	230 (14.1)	250 (14.1)
Zn ($mg\,kg^{-1}$)	2.0 (0.11)	2.3 (0.11)
Zn index	22 (0.72) b	25 (0.74) a
Mn ($mg\,kg^{-1}$)	36 (3.6)	34 (3.6)
Mn index	22 (1.3)	25 (1.3)
CEC ($M_{eq}\ 100\,g^{-1}$)	24 (1.7)	24 (1.7)

Congreves et al., 2015

Can You Determine the Rotation & Tillage?



Tillage

- Conv. till
- No-till

Rotation

- Cont. corn (C)
- Cont. soys (S)
- Corn-soys
- Soys-Wheat (W)
- C-S-W (RC)

Credit: Adam Hayes

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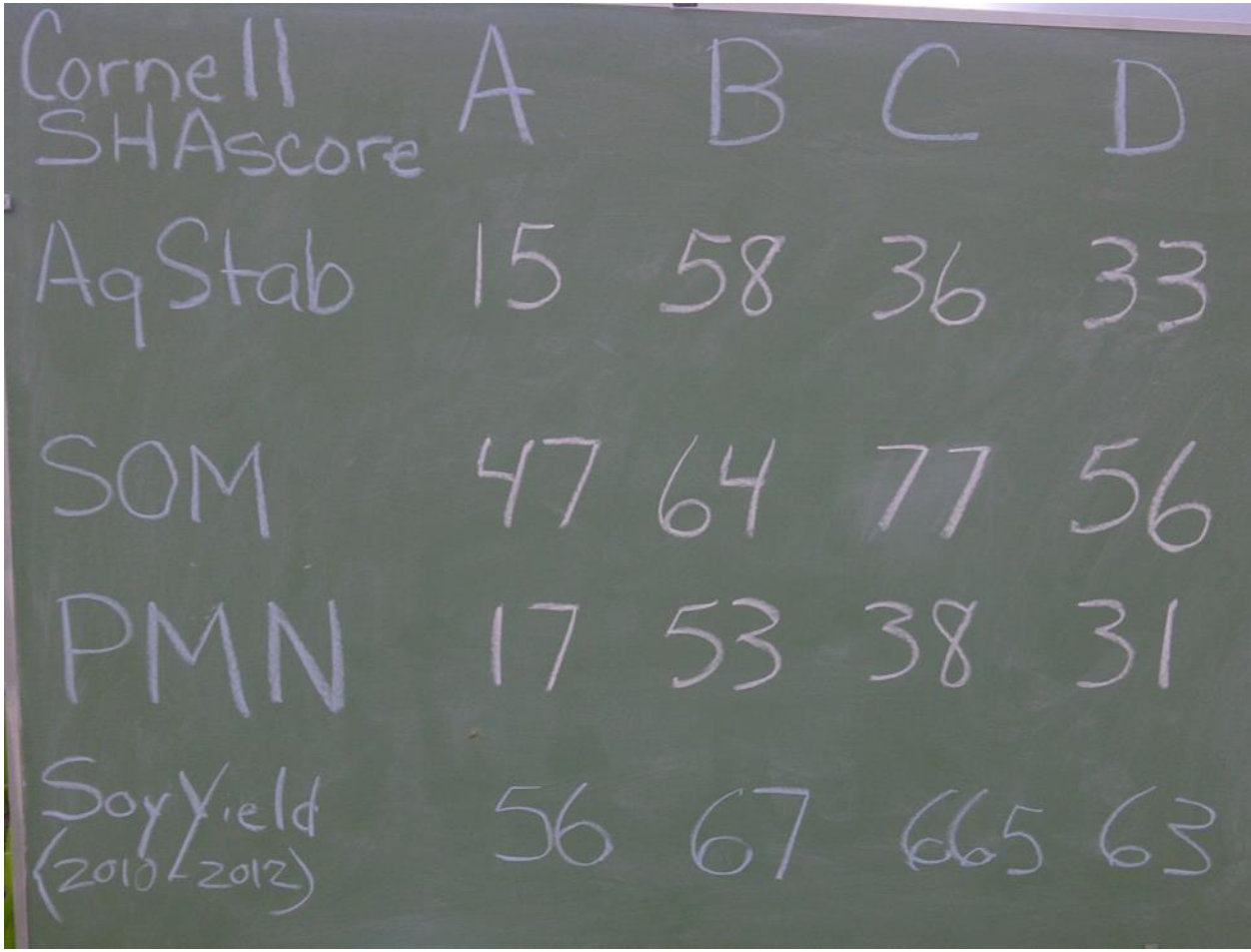

Credit: Adam Hayes

Can You Determine the Rotation & Tillage?

1. Cont. Corn, 2. Cont. Soys, 3. C-S, 4. S-Wheat, 5. C-S-W (R.Clover)

1. Conventional tillage, 2. No-till

	A	B	C	D
Middens/m^2	0	50	1	35
# of Worms/m^2	41	317	55	161
Wt. in grams	8.6	77.9	13.6	40
% Mature	24.4	21.6	24.8	16.9
Solvita	2.6	3.4	2.9	3.0
PMN	17	53	38	31
Organic matter	47	64	77	56
Aggregate Stability	15	58	36	33
Soybean Yield	56	67	66.5	63

Credit: Adam Hayes

Can You Determine the Rotation & Tillage?

	Cont. Soys CT	C-S-W(RC) NT	S-W CT	C-S NT
Middens/m^2	0	50	1	35
# of Worms/m^2	41	317	55	161
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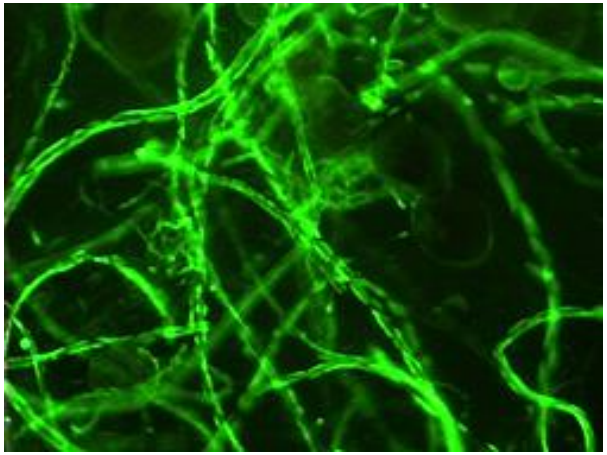
Credit: Adam Hayes

Earthworms

Soil Structure

- Large soil aggregates (crumbs) created by roots and fungi

- Glomalin is a waxy coating created by mycorrhizal fungi
  - It helps aggregates form (acts like chewing gum) and protects them
  - Very tough – good protector of soil aggregates
  - Lots in the soil!
    - 6,000-15,000 lbs/acre in top 6 inches



Soil Structure

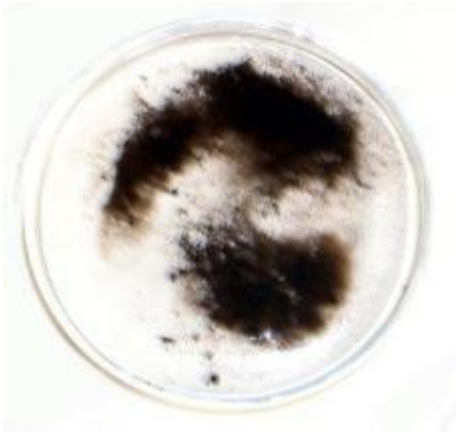
Dry

CT, SW-F

NT, SW-WW-SF

Moderately-grazed pasture

Wet



Total glomalin = 2.4 mg/g

Total glomalin = 3.2 mg/g

Total glomalin = 7.9 mg/g

Adapted from: "The Role of Soil Biology in Improving Soil Quality", Dr. Kristine Nichols

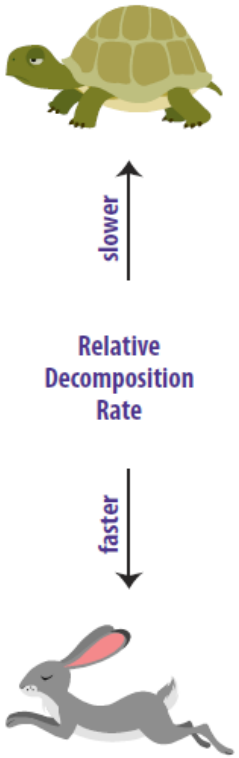
Soil Structure

Soil Organic Matter

- How does soil life affect soil organic matter levels?
  - Old microbial cells and their by-products make up large % of OM
  - Fungi help form soil aggregates (protect OM)
- How can you enhance OM levels?
  - Feed and protect soil life
  - Include “high quality” residues

Table 1. Carbon to nitrogen ratios of crop residues and other organic materials

Material	C:N Ratio
rye straw	82:1
wheat straw	80:1
oat straw	70:1
corn stover	57:1
rye cover crop (anthesis)	37:1
pea straw	29:1
rye cover crop (vegetative)	26:1
mature alfalfa hay	25:1
Ideal Microbial Diet	**24:1**
rotted barnyard manure	20:1
legume hay	17:1
beef manure	17:1
young alfalfa hay	13:1
hairy vetch cover crop	11:1
soil microbes (average)	8:1



Source: USDA NRCS

The Cotton Test (“Soil Your Undies”)

- Bury men's cotton briefs for 60 days (wash new ones first)
- Leave the waistband showing so they can be easily found, then dig up to see how much has been eaten
- A good indicator soil biological activity

Managing for Living Soil: Vollmershausen Farms

Managing for Living Soil: Terwidlen Farms

- Soybean – Oats/Winter Wheat (underseeded Red Clover) – Red Clover (1st cut hay, 2nd seed) – Winter Wheat (Red Clover) – Grain corn

Managing for Living Soil: Drudge Family Farm

- **Crops include:** corn, soybeans, edible beans, oats, canola, peas, winter wheat + cover crops

Managing for Living Soil:
Steve Sickle

Take home messages

- Minimize soil disturbance
  - Maintenance of habitat, water & food supply
  - Increased OM
- Diversify crops
  - Increased biodiversity = reduced pests & disease
  - Increased nutrient supply
- Maintain a living root system
  - Increase soil biodiversity
- Keep the soil covered
  - Feed and protect soil life
  - Preserve OM
- Add organic amendments if possible
  - Feed soil life