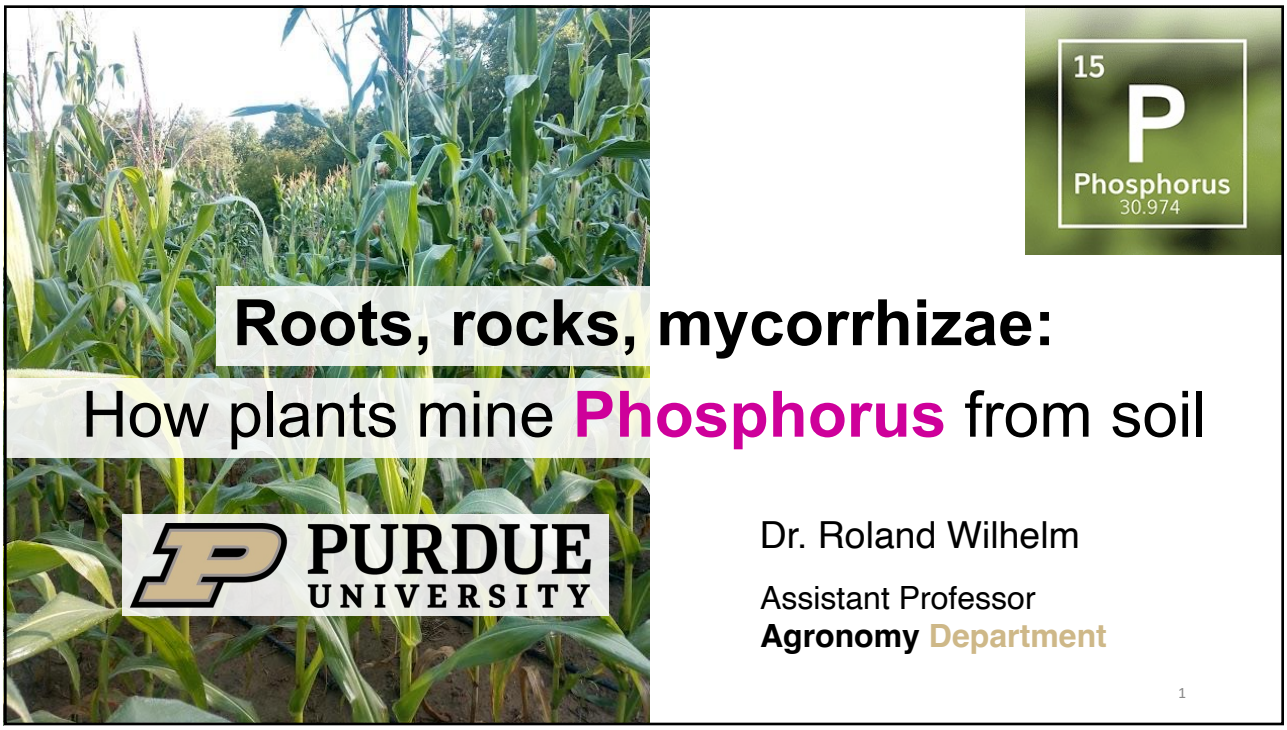
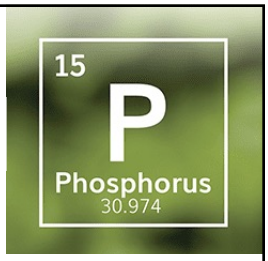

15
P
Phosphorus
30.974
Roots, rocks, mycorrhizae:
How plants mine Phosphorus from soil
PURDUE UNIVERSITY
Dr. Roland Wilhelm
Assistant Professor
Agronomy Department
1

1


Unlocking P in Three Key Lessons
15
P
Phosphorus
30.974
Lesson I. Roots, Rocks, and Mycorrhizae
• An introduction to the belowground biological players
Lesson II. Agronomic Benefits from Symbiosis
• An overview of the ROI from nurturing soil biology
Lesson III. Managing P efficient Soils
• Best practices to support biological P supply
2

2

Unlocking P in Three Key Lessons



Lesson I. Roots, Rocks, and Mycorrhizae

- An introduction to the belowground biological players

Lesson II. Agronomic Benefits from Symbiosis

- An overview of the ROI from nurturing mycorrhizae

Lesson III. Managing P efficient Soils

- Best practices to support biological P supply

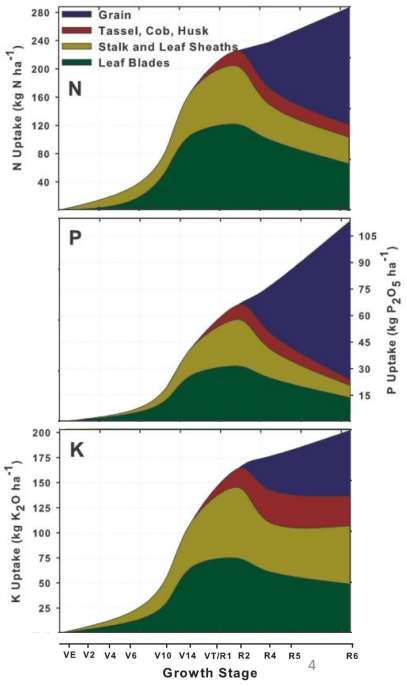
3

3

- **P** is the most exported nutrient during grain harvest.

Nutrient	Total corn uptake (unit / acre)	Total grain removal (unit / acre)	Harvest index (%)
N (lb)	256	148	58
P_2O_5 (lb)	**101**	**80**	**79**
K_2O (lb)	180	59	32
S (lb)	23	13	57
Mg (lb)	52	15	29

Bender *et al.*, 2013



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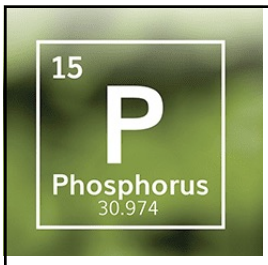
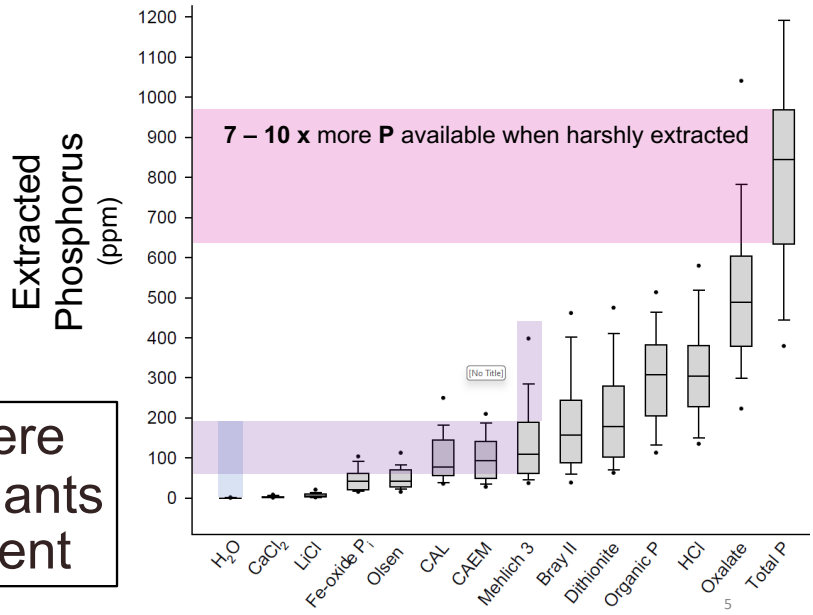


Wuenscher *et al.*, 2015

A comparison of 14 soil P extraction methods



Even in soils where **P** is abundant, plants can still be deficient

5

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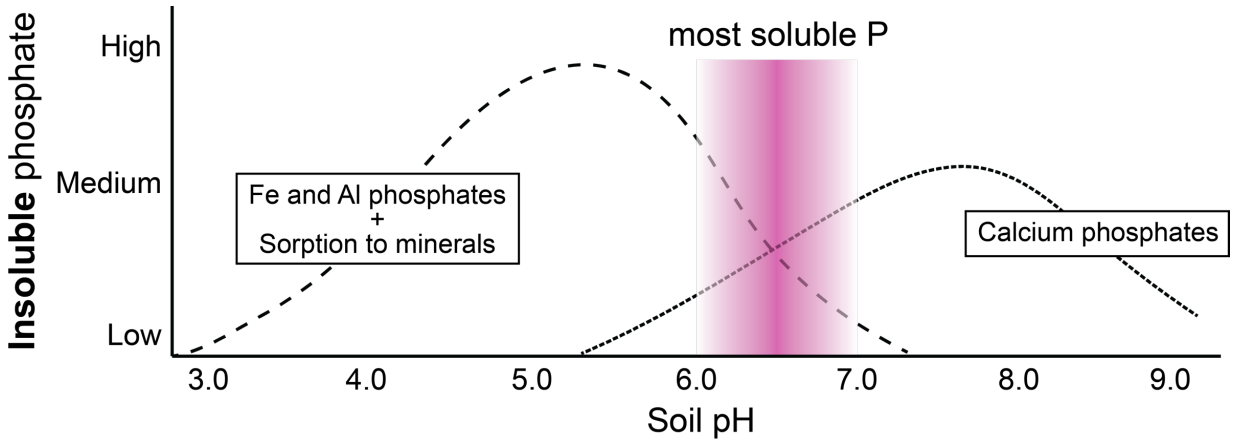
- In ag soils, **P** is locked up in or stuck on minerals (with a lesser sum bound-up in organic matter).

6

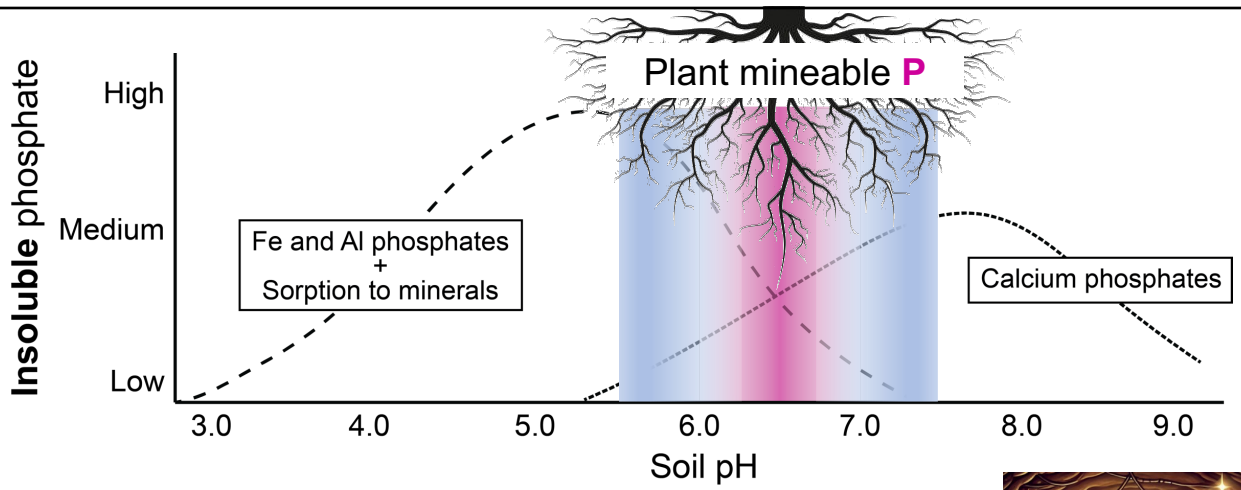
6



- Soils **P** is narrowly available and will <u>sorb to minerals</u> or <u>form precipitates</u> with Fe, Al, & Ca

7

7



- Plant roots have developed ways to mine **P** in <u>partnership with microbes</u>

8

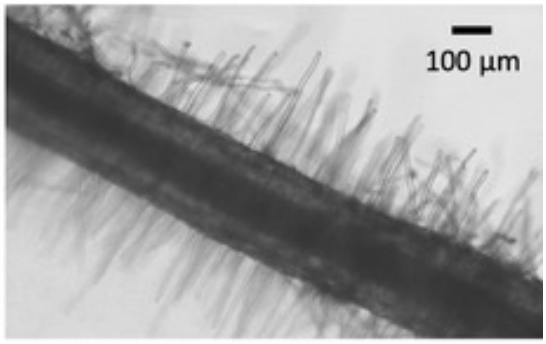
Plant extraction process

9

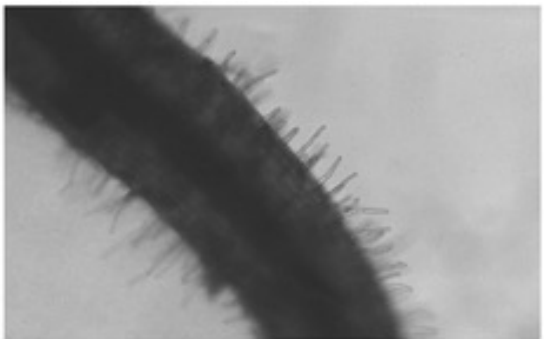
9

theme alert

- Mining is a **dynamic process**, with more fine roots grown when **P** is limiting



P limiting conditions



P surplus conditions

Ma *et al.* 2001

10

10

11

Mycorrhizae

Mykós (fungus) - riza (root)

Cost to Plant

- Plants supply 5-20 % of C from photosynthesis to mycorrhizae

12

12

Mycorrhizae

Mykós (fungus) - riza (root)

Cost to Plant

- Plants supply 5-20 % of C from photosynthesis to mycorrhizae

Benefits to Plant (and Farmer!)

- increase absorptive root surface area
- solubilize ('mine') minerals, like **P**
- enhance drought tolerance
- Improved disease resistance

13

13

- Mycorrhizae extend the root area upwards of **10 to 70-fold**

14

14

- Mycorrhiza extract mineral **P** from soil to supply the plant roots in **return for sugar**

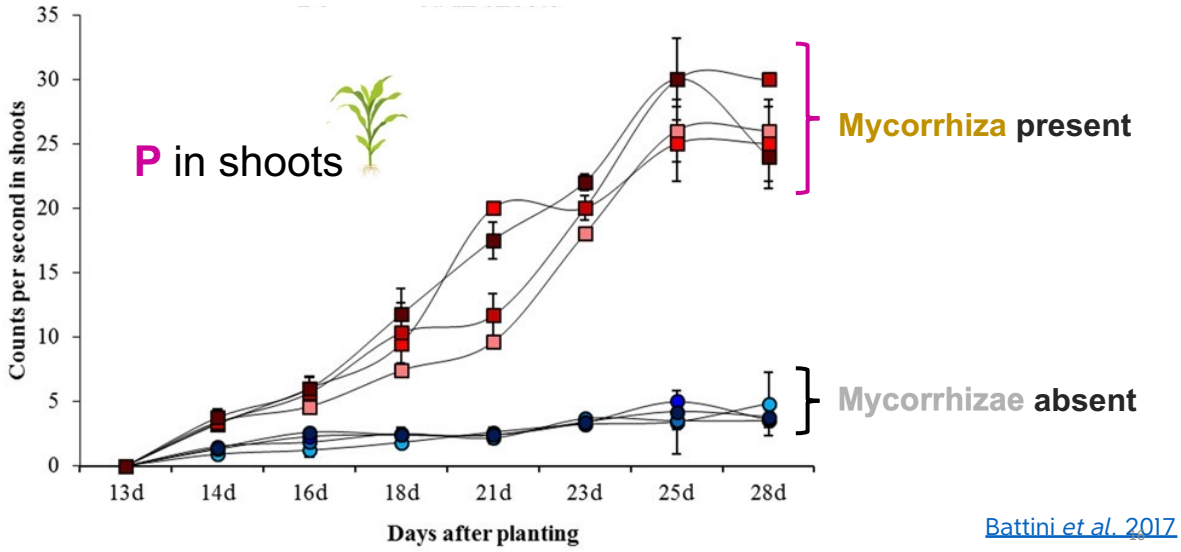
Qi *et al.*, 2022

Mineral P + mycorrhiza	Mineral P No mycorrhiza	No mineral P + mycorrhiza	No mineral P No mycorrhiza

15

15

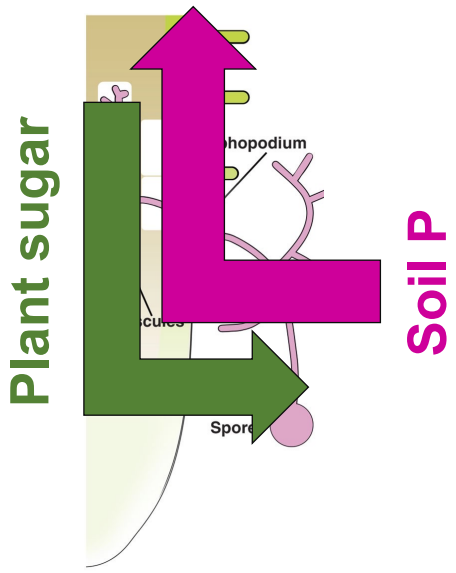
- Mycorrhiza can mine **P** from soil minerals and supply it to plant roots, fertilizing the whole plant



Battini *et al.*, 2017

16

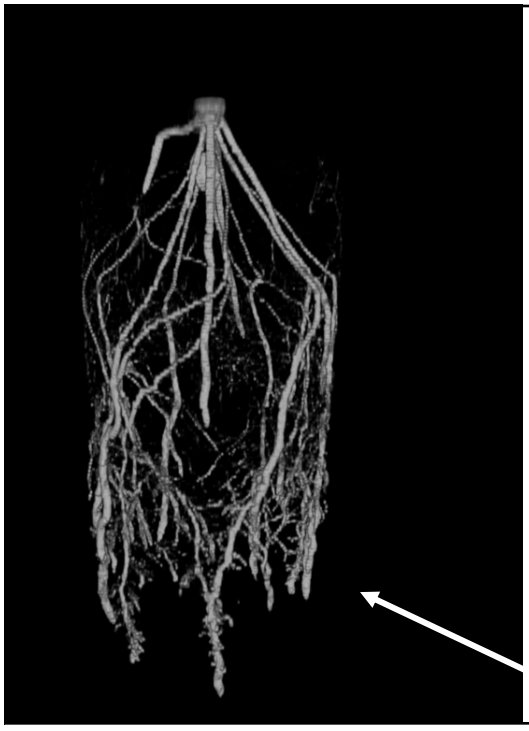
Mycorrhizae



- Mycorrhiza are fed by the plant in the form of **sugar**

17

17



Mycorrhizae

- Mycorrhiza are fed by the plant in the form of **sugar**
- Plants transfer sugar to roots to **sustain microbial partnerships**.

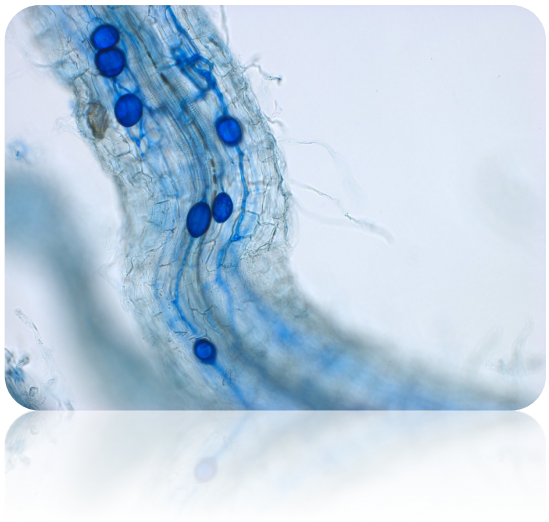
Real-time tracking of the movement **of sugar** from **above to belowground** in corn.

18

18

Arbuscular Mycorrhizae

- Most mycorrhiza **live inside root cells** and form an 'arbuscule'
- The arbuscule is the site of nutrient exchange.



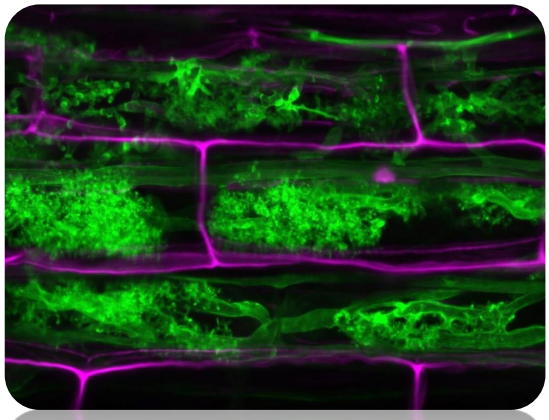
19

19

Arbuscular Mycorrhizae

- Most mycorrhiza **live inside root cells** and form an 'arbuscule'
- The arbuscule is the site of nutrient exchange.

Arbuscular mycorrhizae are called "**AM**" or "AMF" and are common crop bioinoculants.



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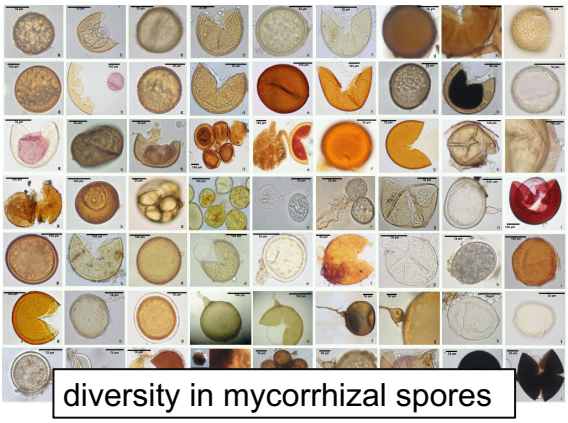
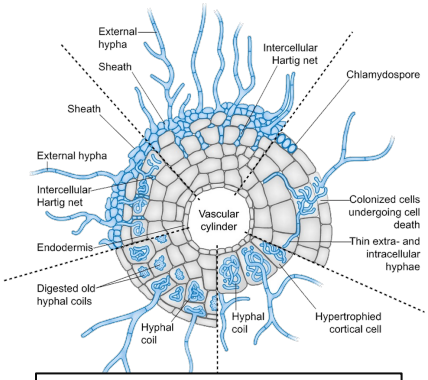
20

Two things to know about AM

- There are lots of different types of AM fungi
- The partnerships are dynamic and managed by plants



diversity in mycorrhizal spores



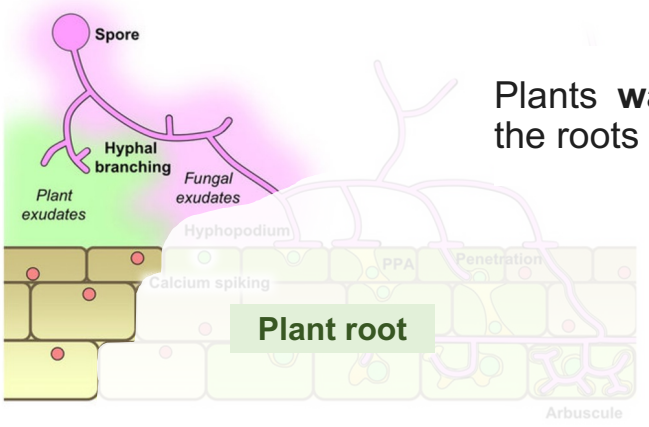
diversity in root growth

21

21

Two things to know about AM

- There are lots of different types of AM fungi
- The partnerships are dynamic and managed by plants



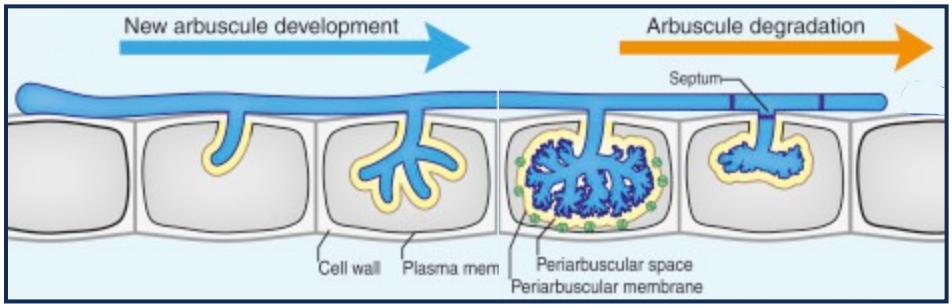
Plants **wake up AM spores** as the roots grow through soil.

22

22

Two things to know about AM

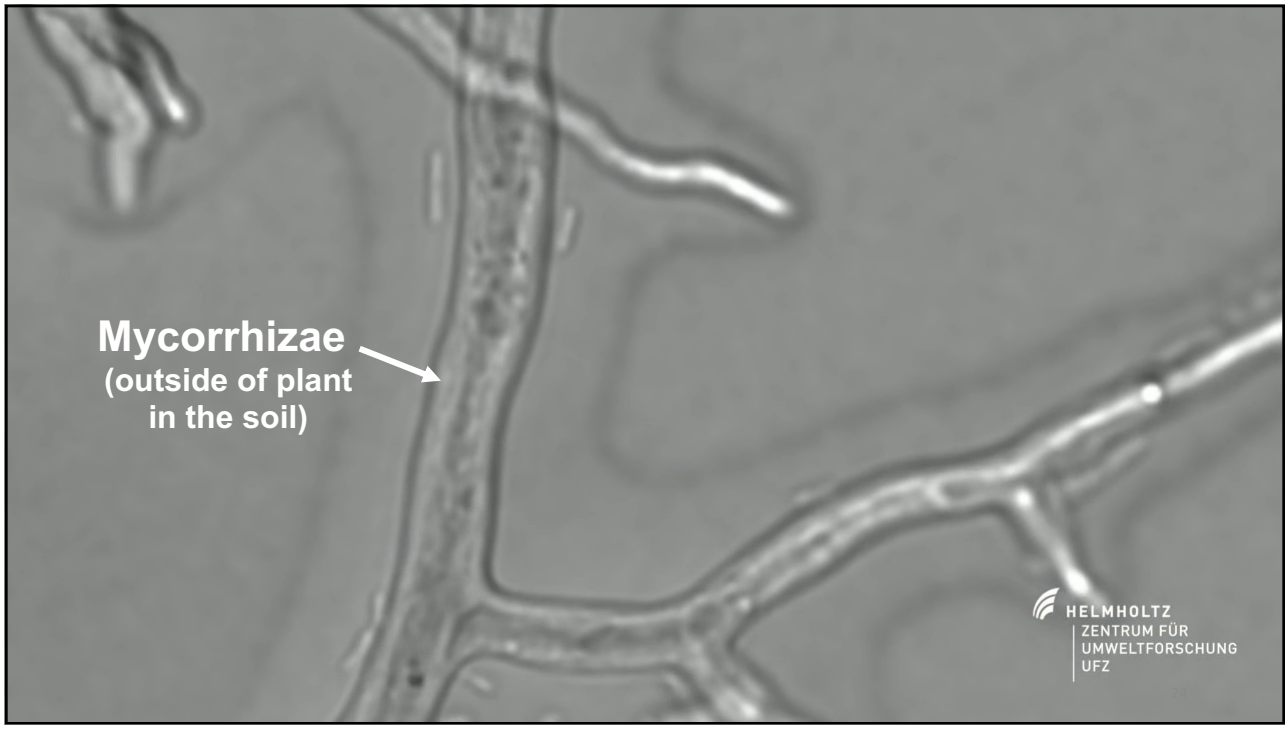
- There are lots of different types of AM fungi
- The partnerships are dynamic and managed by plants



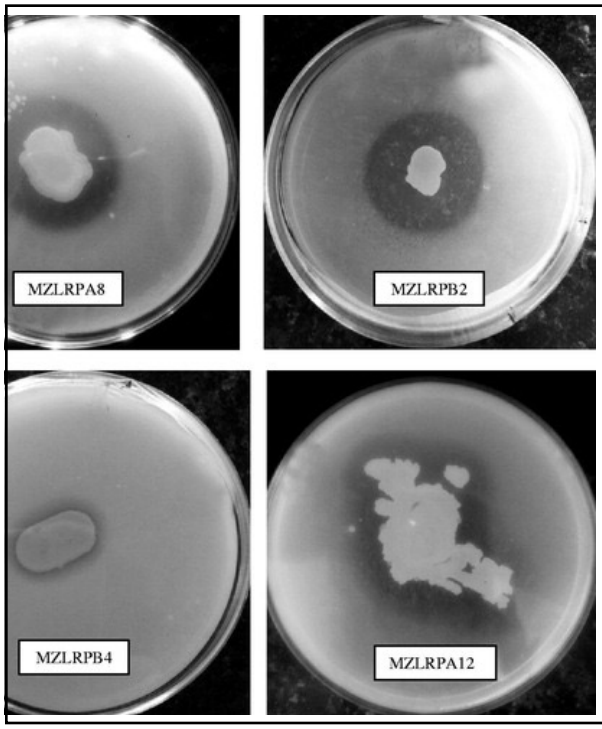
Plants **let AM colonize roots** when they are P starved & **evict them** when they are not needed.

23

23



24



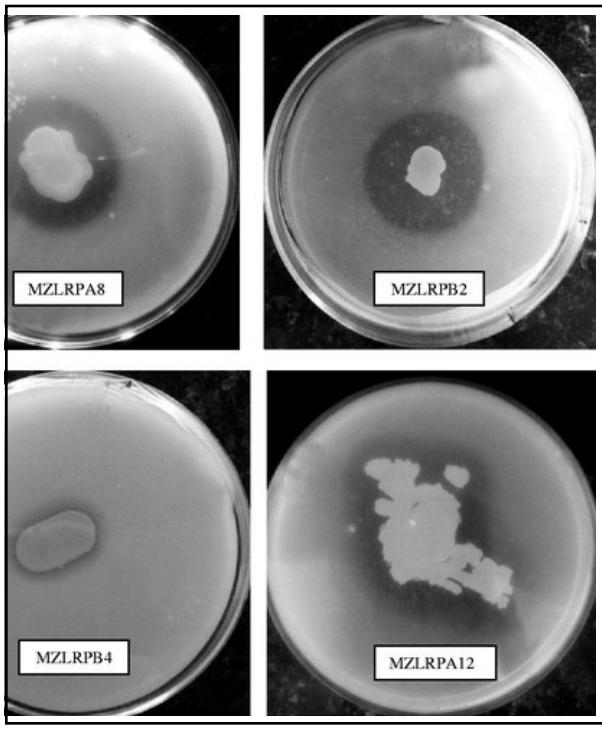
Helper Bacteria

- Mycorrhizae rely on bacteria to mine **P** from minerals

  also called "**P** solubilization"

25

25



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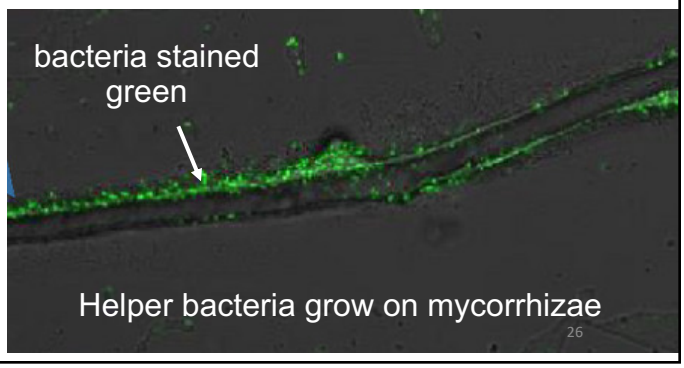

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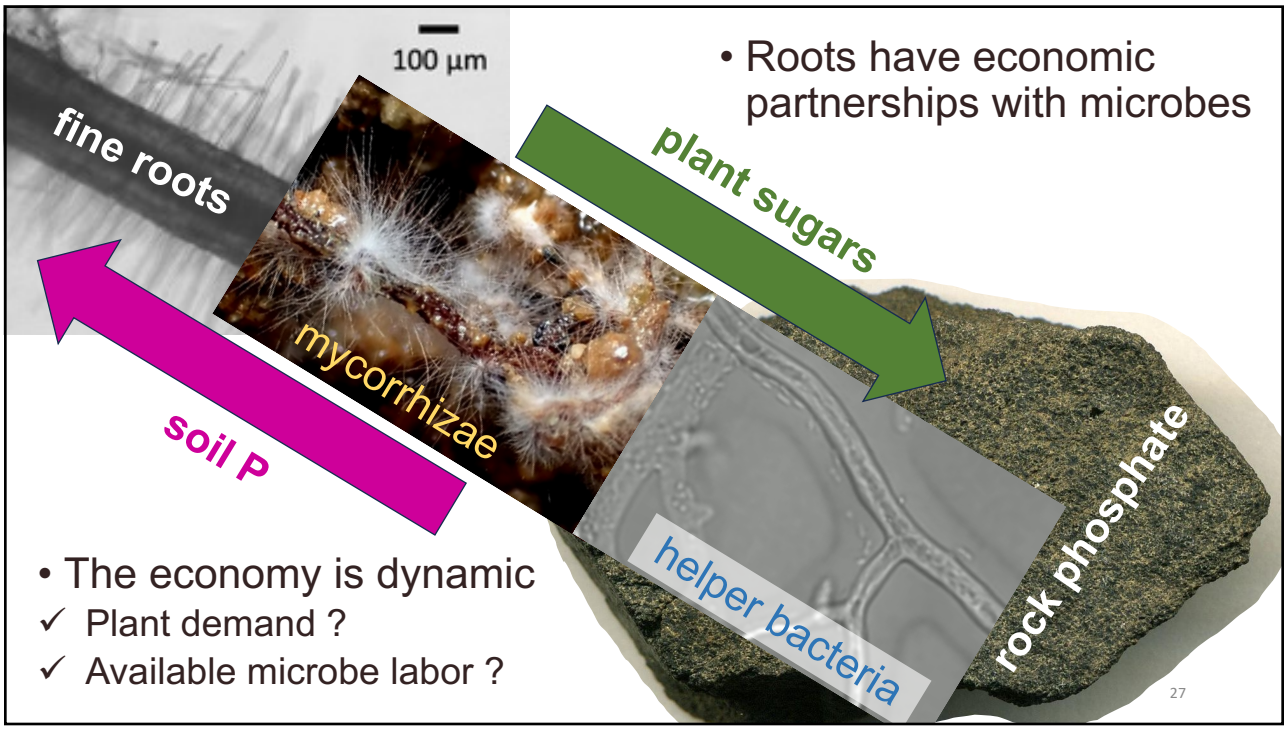
100 µm
fine roots
mycorrhizae
plant sugars
soil P
helper bacteria
rock phosphate
• Roots have economic partnerships with microbes
• The economy is dynamic
✓ Plant demand ?
✓ Available microbe labor ?
27

27


Unlocking P: Three Key Lessons
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P
Phosphorus
30.974
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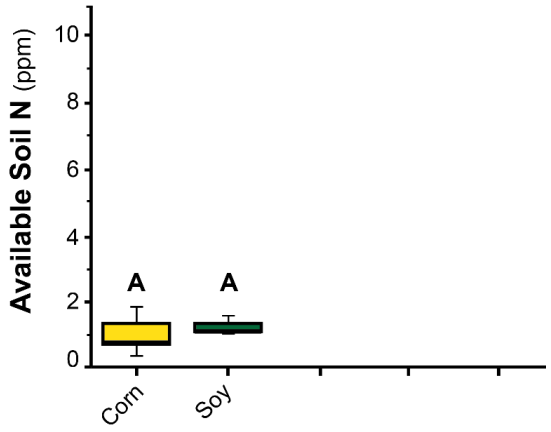
28

28

- Let's start with a more familiar symbioses. How much **nitrogen** is provided by **rhizobia**?



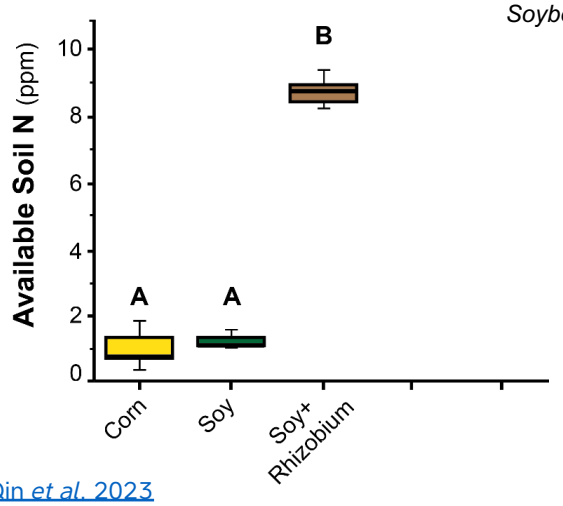
Root nodules full of rhizobia

Qin *et al.* 2023

29

29

- Do mycorrhizae impact plant-available **N** ?



Soybean a

Root nodules full of rhizobia

Qin *et al.* 2023

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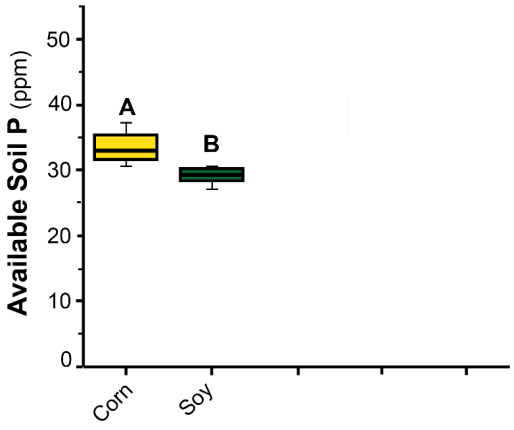
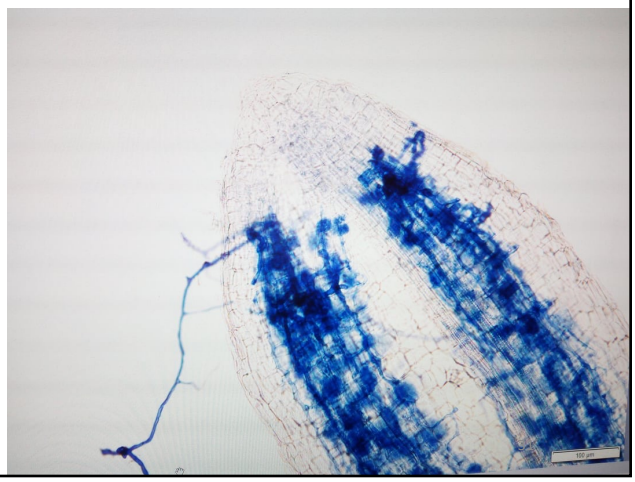
30

- Ok, how much **P** is mined from soil minerals by arbuscular mycorrhizae (AM)?



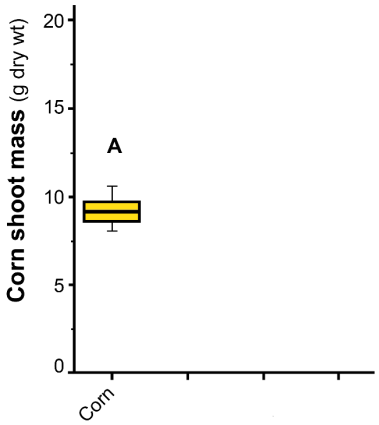
Corn root tip with arbuscular mycorrhizae



Qin *et al.* 2023

31

- What impact does AM have on **corn growth**?

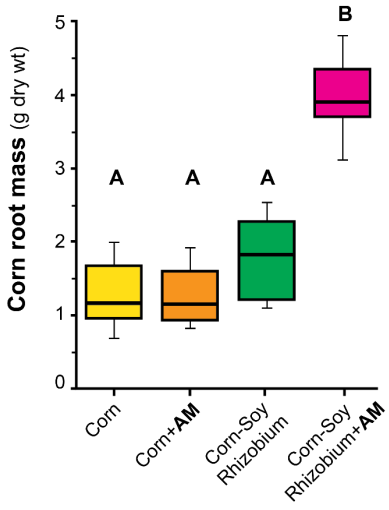


Qin *et al.* 2023

32

32

- What impact does AM have on **corn growth**?

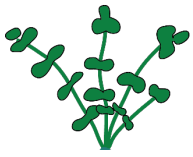


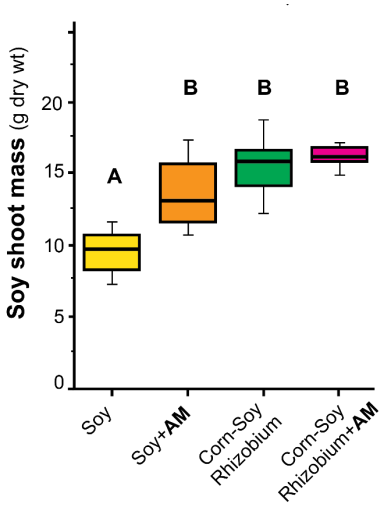
Qin *et al.* 2023

33

33

- What impact does AM have on **soy growth**?



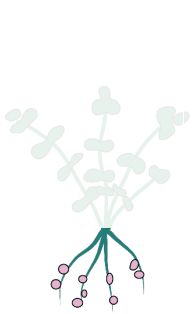


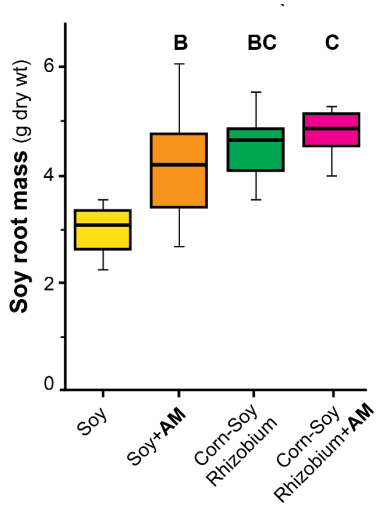
Qin *et al.* 2023

34

34

- What impact does AM have on **soy growth**?





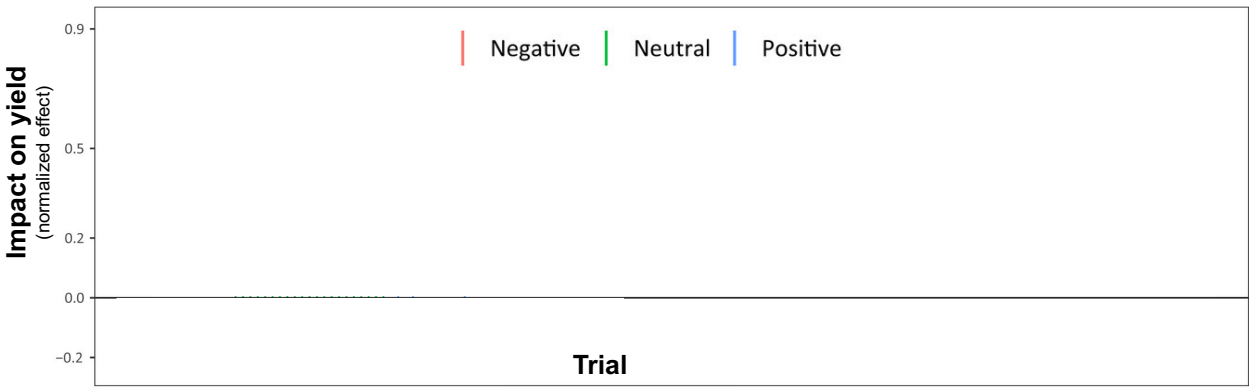
Qin *et al.* 2023

35

35

- What impact do AM fungi have **on yield**?

Zhang *et al.*, 2018

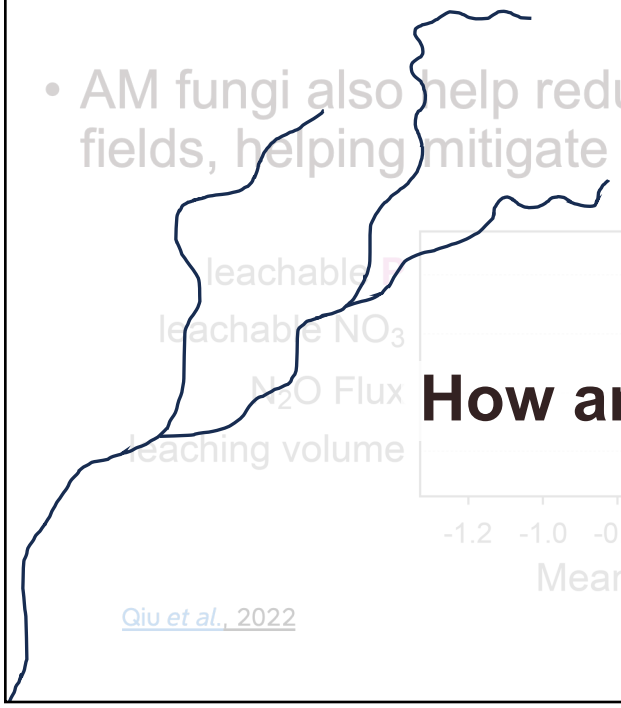


- In a majority of 168 trials, the incidence or inoculation of AM led to a **consistent yield bump.**

36

36

- AM fungi also help reduce N and P leaching from fields, helping mitigate downstream impacts



How are AM so impactful?

Qiu *et al.*, 2022

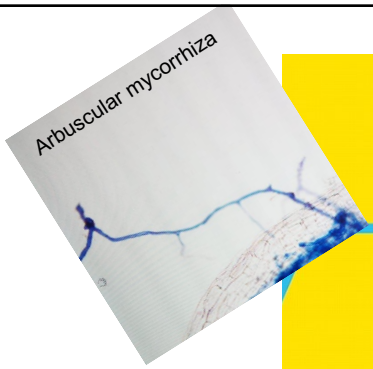
37

37

- **Recall**: Mycorrhizae extend the root area upwards of **ten to seventy-fold***

38

38



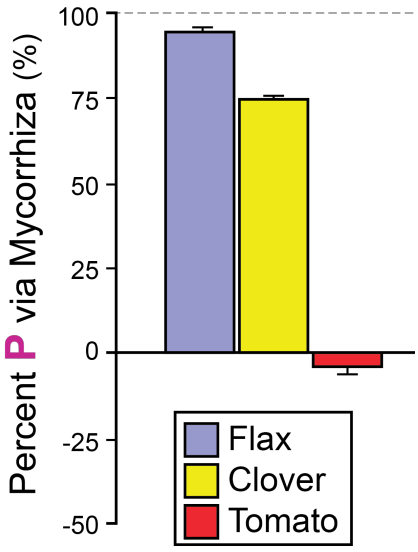
P can be soaked up directly by either **fine-roots** or **mycorrhizae**

P into roots via **mycorrhizae** (option 2)

P directly from soil (option 1)

39

39



Smith *et al.* 2003

Most **P** is soaked up through **mycorrhizae**, when present.

**But, it is not the same for every crop or AM species

40

40

Mycorrhizae

Mykós (fungus) - riza (root)

Cost to Plant

- Plants supply 5-20 % of C from photosynthesis to mycorrhizae

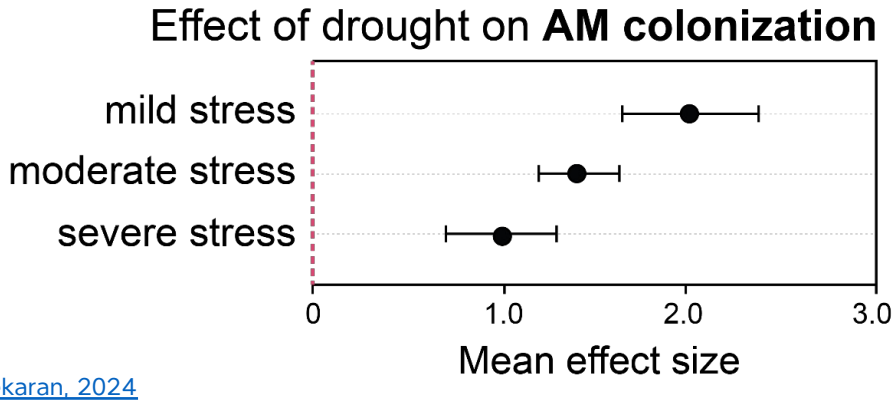
Benefits to Plant (and Farmer)

- increase absorptive root surface area
- solubilize ('mine') minerals
- enhance **drought tolerance**
- suppress pests and diseases

41

41

- AM fungi remain partners with plants even during severe drought stress, providing enhanced access to water and photosynthetic activity.



Chandrasekaran, 2024

42

42

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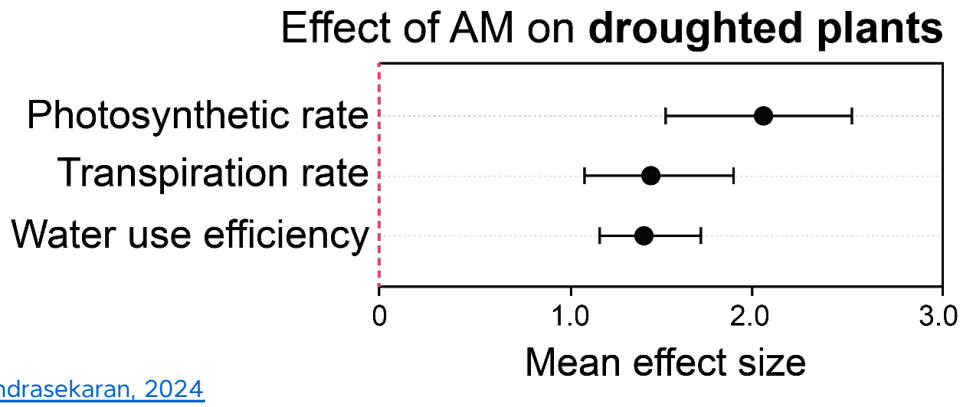

Chandrasekaran, 2024

43

43

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- increase absorptive root surface area
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- enhance drought tolerance
- suppress **pests** and **diseases**

44

44

- AM suppress root diseases by outcompeting pathogens for nutrient and shielding roots.

Rilling and Veresoglou, 2011

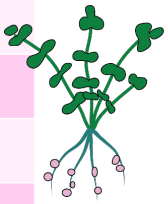
45

45

46

- What kinds of management decisions impact soil biology, and in what direction?

Management	Root Size or Activity	AM Benefits
Fertilization	?	?
Tillage	?	?
Fungicides	?	?
Bioinoculants or **biostimulants**	?	?

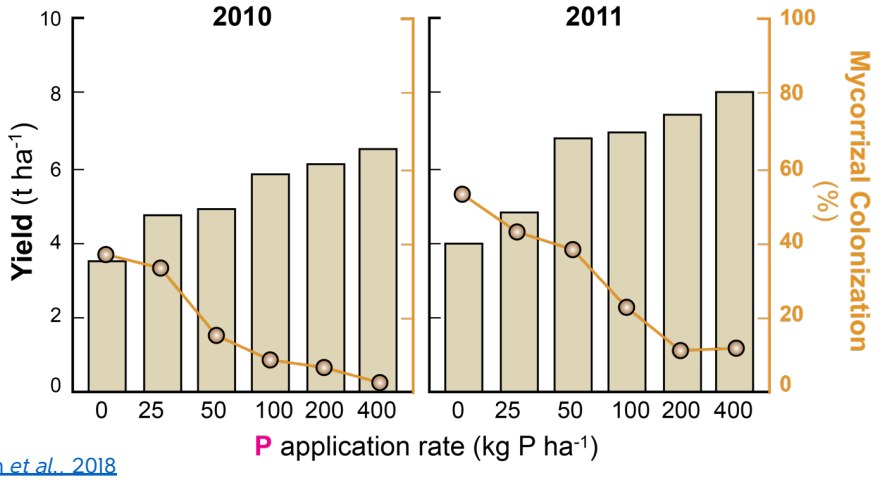


47

47

Fertilization

- AM associations are greatly reduced when **P** fertilizer is applied to fields.



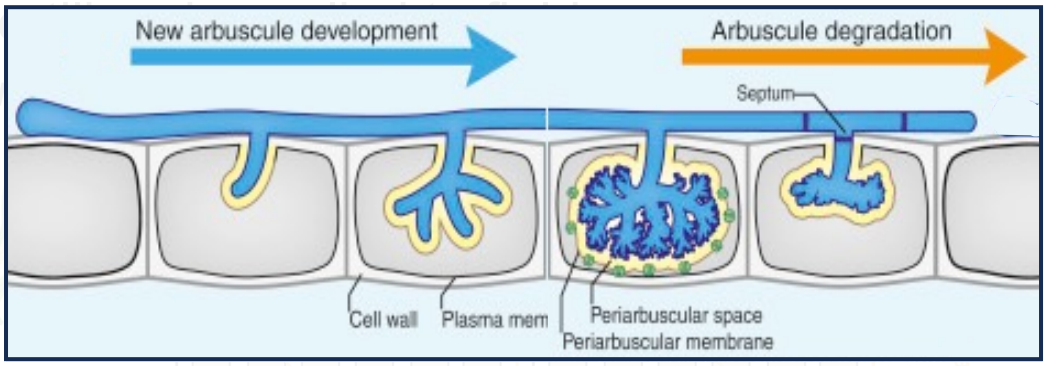
Ryan and Graham *et al.*, 2018

48

48

Fertilization

- AM associations are greatly reduced when P



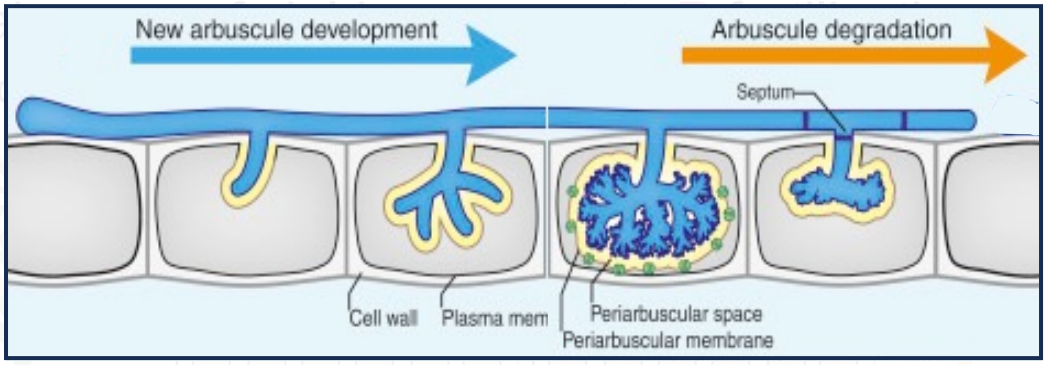
- Plants **evict AM** when they are not providing a benefit.

Ryan and Graham *et al.*, 2018

49

Fertilization

- AM associations are greatly reduced in corn in



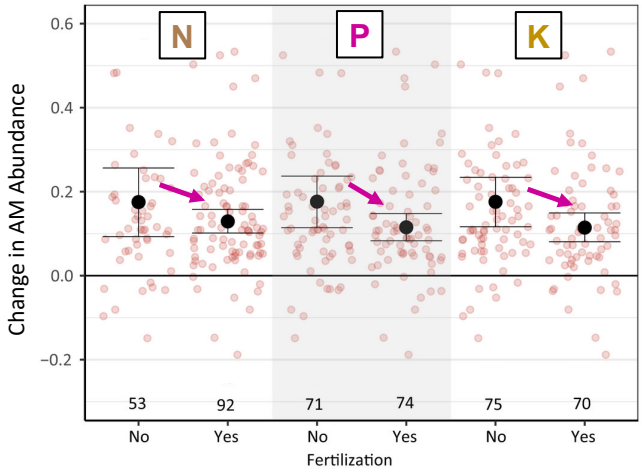
- Plants **evict AM** when they are not providing a benefit.

Ryan and Graham *et al.*, 2018

50

Fertilization

- Overall, mineral fertilizers tends to reduce the benefit of AM associations, particularly for **P**.



Zhang *et al.*, 2018

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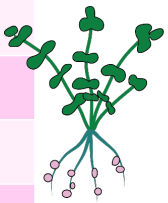
- What kinds of management decisions impact soil biology, and in what direction?

Management	Root Size or Activity	AM Benefits
Fertilization	increased	reduced
Tillage	**?**	**?**
Fungicides	**?**	**?**
Bioinoculants or **biostimulants**	**?**	**?**



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Tillage

- Reduced tillage can improve the abundance of AM and increase root colonization.

Carrara *et al.*, 2018

53

53

Tillage

- Overall, higher tillage intensity reduces AM associations, even for occasional tillage.

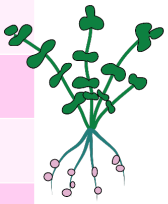
Bowles *et al.*, 2016

54

54

- What kinds of management decisions impact soil biology, and in what direction?

Management	Root Size or Activity	AM Benefits
Fertilization	increased	reduced
Tillage	increased / variable	reduced
Fungicides	**?**	**?**
Bioinoculants or **biostimulants**	**?**	**?**



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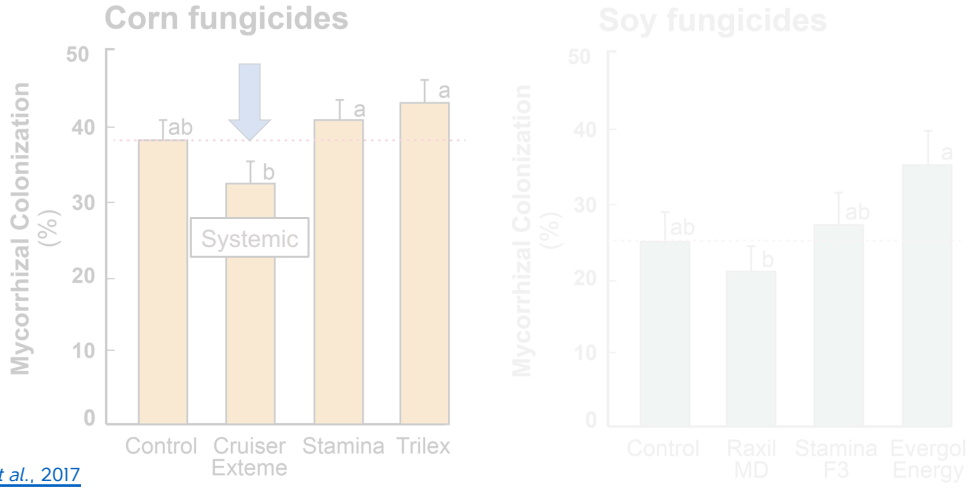
Fungicides

- Impact of fungicide is minor and varies by ingredient & application (*ex.* seed vs. foliar)



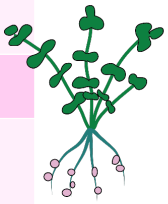
Cameron *et al.*, 2017

56

56

- What kinds of management decisions impact soil biology, and in what direction?

Management	Root Size or Activity	AM Benefits
Fertilization	increased	reduced
Tillage	increased / variable	reduced
Fungicides	minimal	minimal (except for systemic fungicides)
Bioinoculants or **biostimulants**	**?**	**?**



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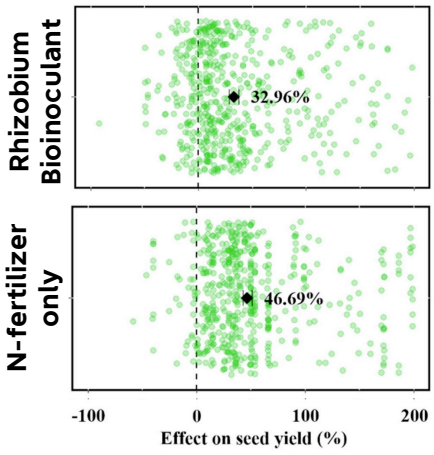
Bioinoculants

- Bioinoculants are living microbes that provide nutrients to plants



Santos Sousa *et al.*, 2022

58

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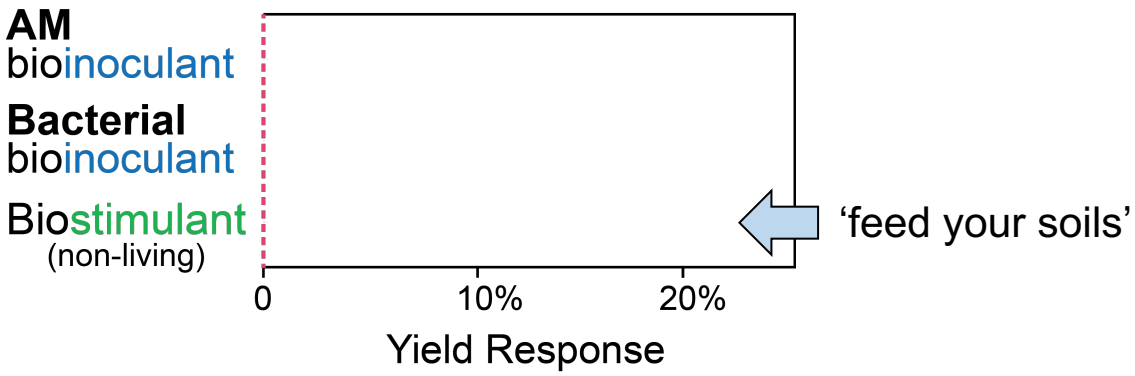
Biostimulants

- Biostimulants do not contain microbes.
- The application of biostimulants yields a similar increase in yield as bioinoculants.



Li *et al.*, 2020

59

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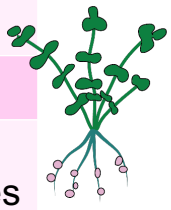
- What kinds of management decisions impact soil biology, and in what direction?

Management	Root Size or Activity	AM Benefits
Fertilization	increased	reduced
Tillage	increased / variable	reduced
Fungicides	minimal	reduced by systemic fungicides
Bioinoculants or **biostimulants**	minimal	increased



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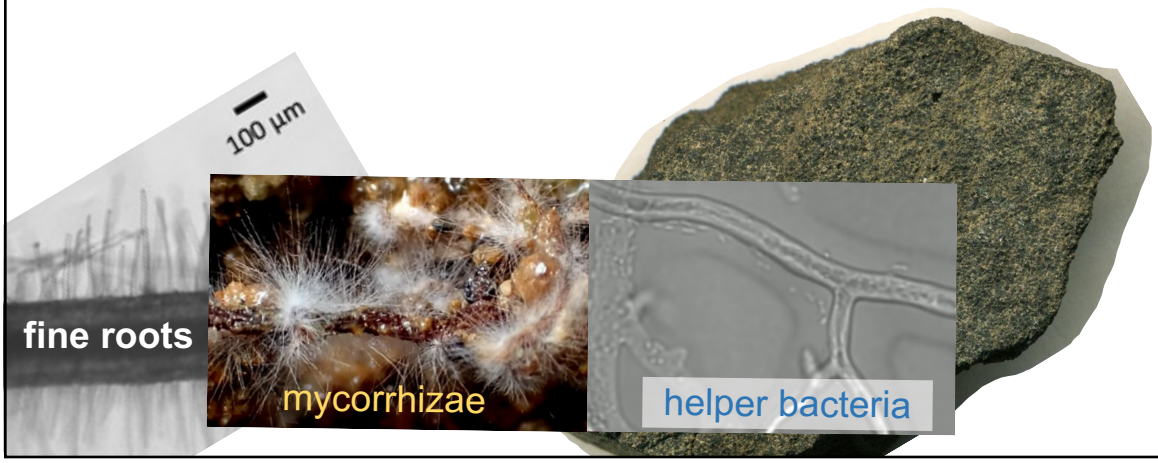
Take-aways

1. Mycorrhizae and helper bacteria can provide a substantial supply of nutrients (*ex.* P, K, N) in exchange for plant sugar.



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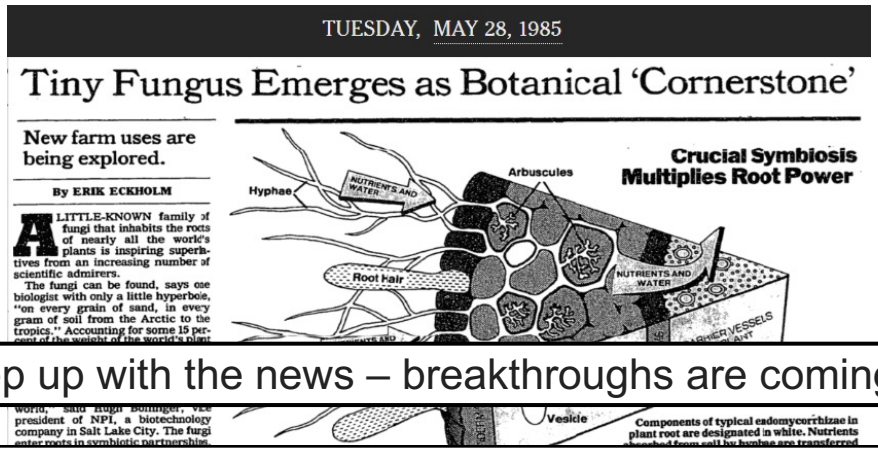
Take-aways

2. There are always trade-offs: consider the biology, don't obsess over it.


TUESDAY, MAY 28, 1985

Tiny Fungus Emerges as Botanical 'Cornerstone'

New farm uses are being explored.

By ERIK ECKHOLM

A LITTLE-KNOWN family of fungi that inhabits the roots of nearly all the world's plants is inspiring superlatives from an increasing number of scientific admirers.

The fungi can be found, says one biologist with only a little hyperbole, "on every grain of sand, in every gram of soil from the Arctic to the tropics." Accounting for some 15 per-

Crucial Symbiosis Multiplies Root Power

Hyphae
Arbuscules
Root hair
Vesicle
NUTRIENTS AND WATER

Components of typical endomycorrhizae in plant root are designated in white. Nutrients

president of NPI, a biotechnology company in Salt Lake City. The fungi

Keep up with the news – breakthroughs are coming

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Take-aways

3. Manage for root and AM health with balanced fertilization, reduced tillage, and feeding soils with organic matter.

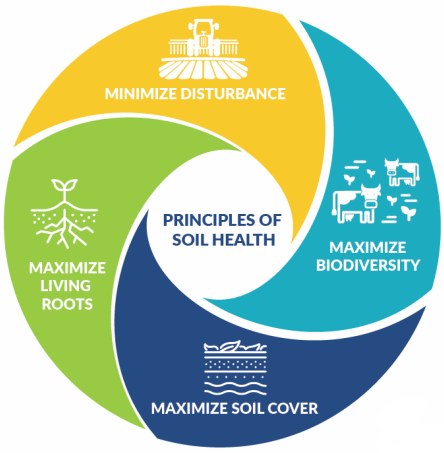

image source

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Take-aways

4. Do I need bioinoculants?
   - It depends on whether you have sizeable populations.
   - Add an AM bioinoculant to a batch of seed and monitor results.
   - After 1st year, consider using a biostimulant to keep the AM active

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Questions?
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Agronomy

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