Root-rhizosphere interactions

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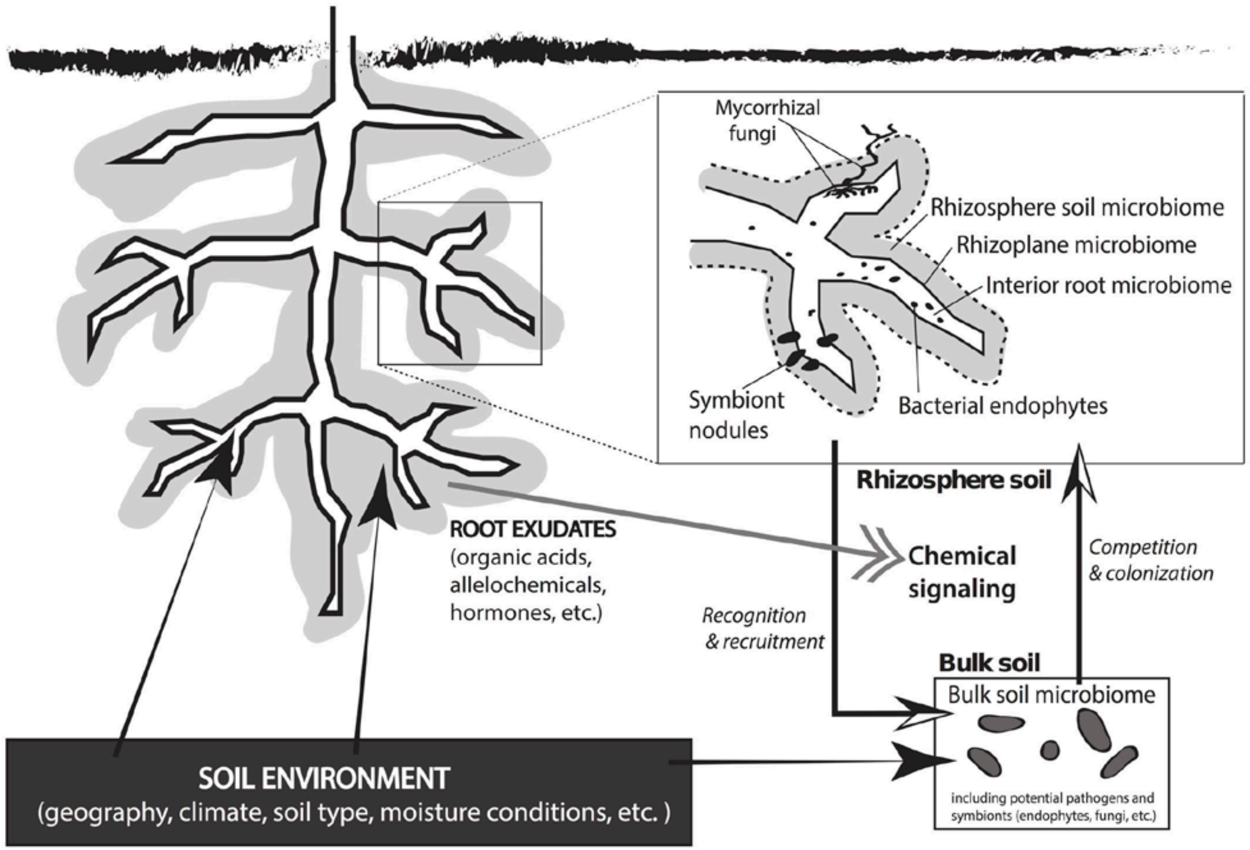
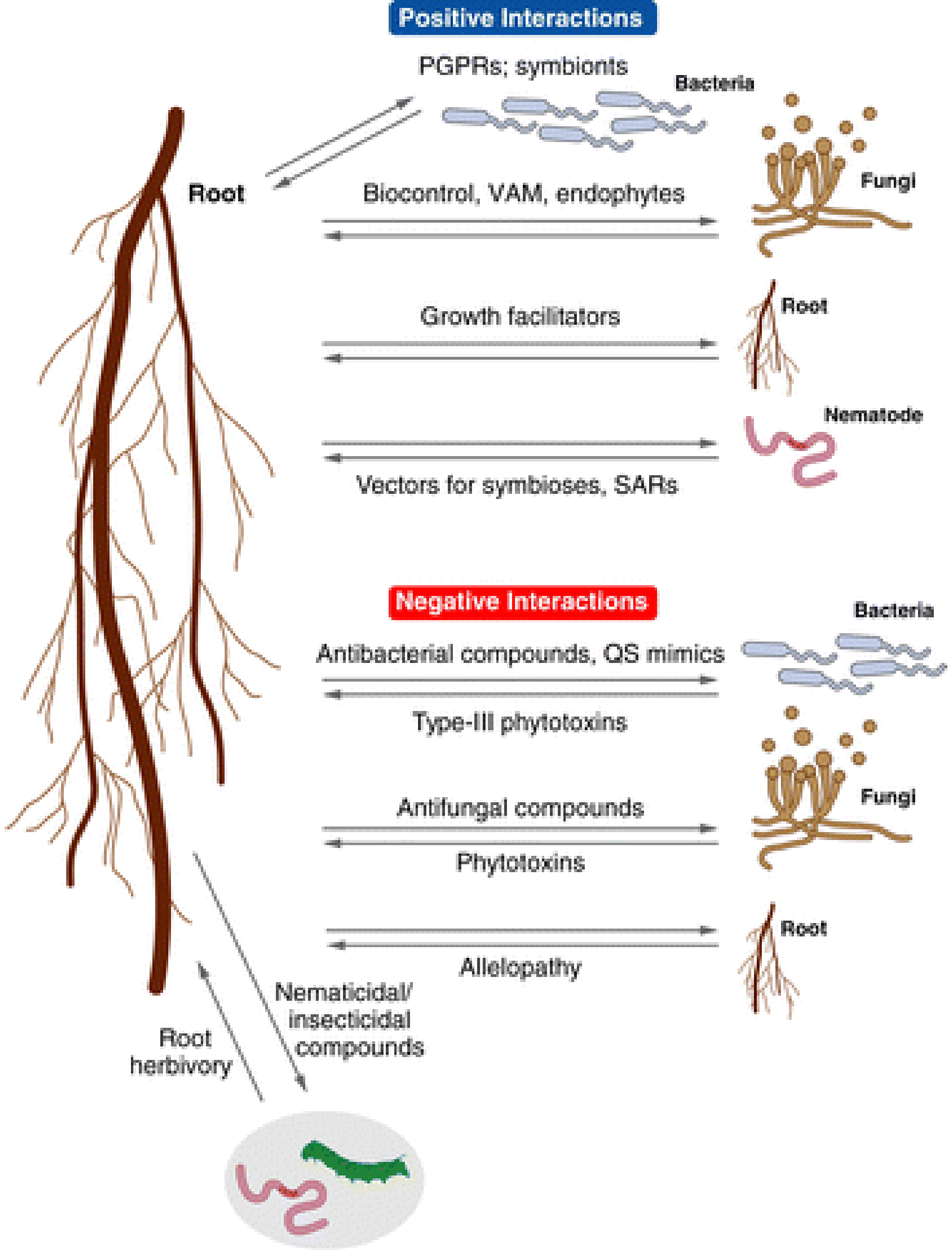
Rhizosphere

- Zone of soil around roots that is affected by the presence of the roots
- Zone with
  - Altered water content (generally more moist) than bulk soil
  - Enhanced microbial activity
    - Stimulated by carbon rich compounds released by roots
    - Direct signaling between plants & microorganism
- Mycorrhizal sphere
  - Expanded zone that includes the soil area influenced by the presence of a root associated mycorrhizal fungus

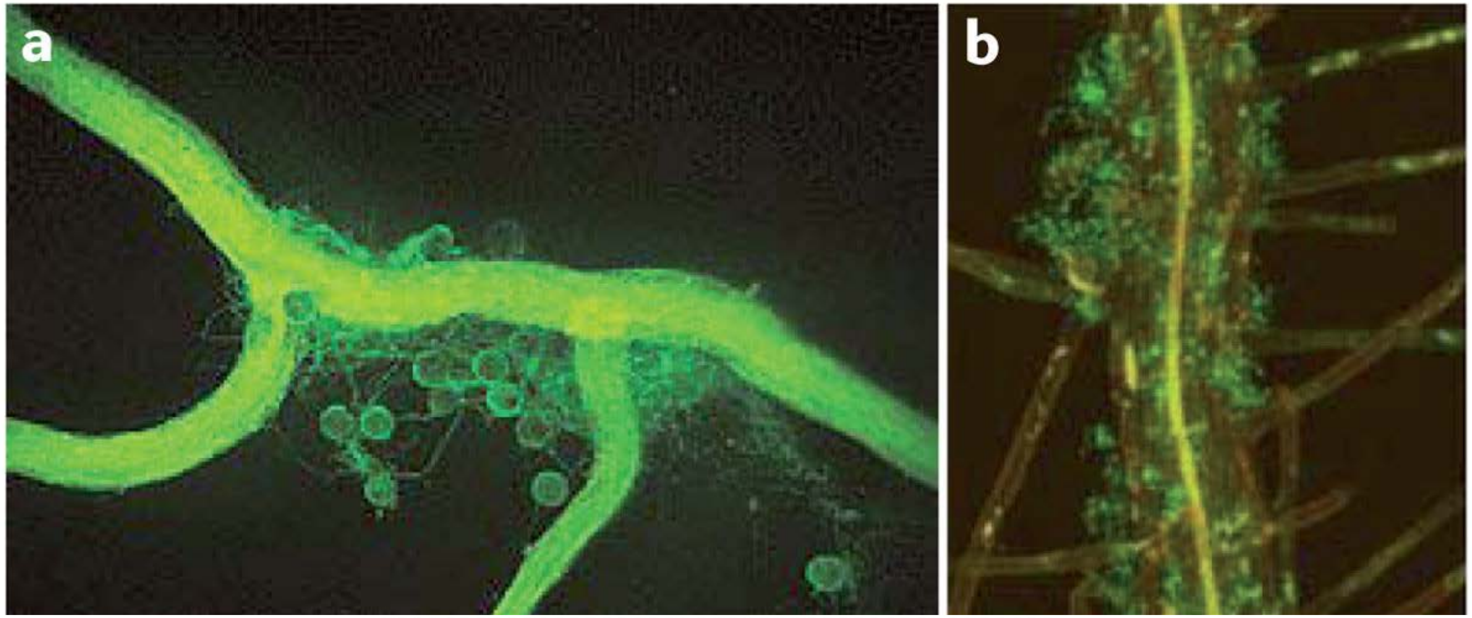


Coats et al. 2014

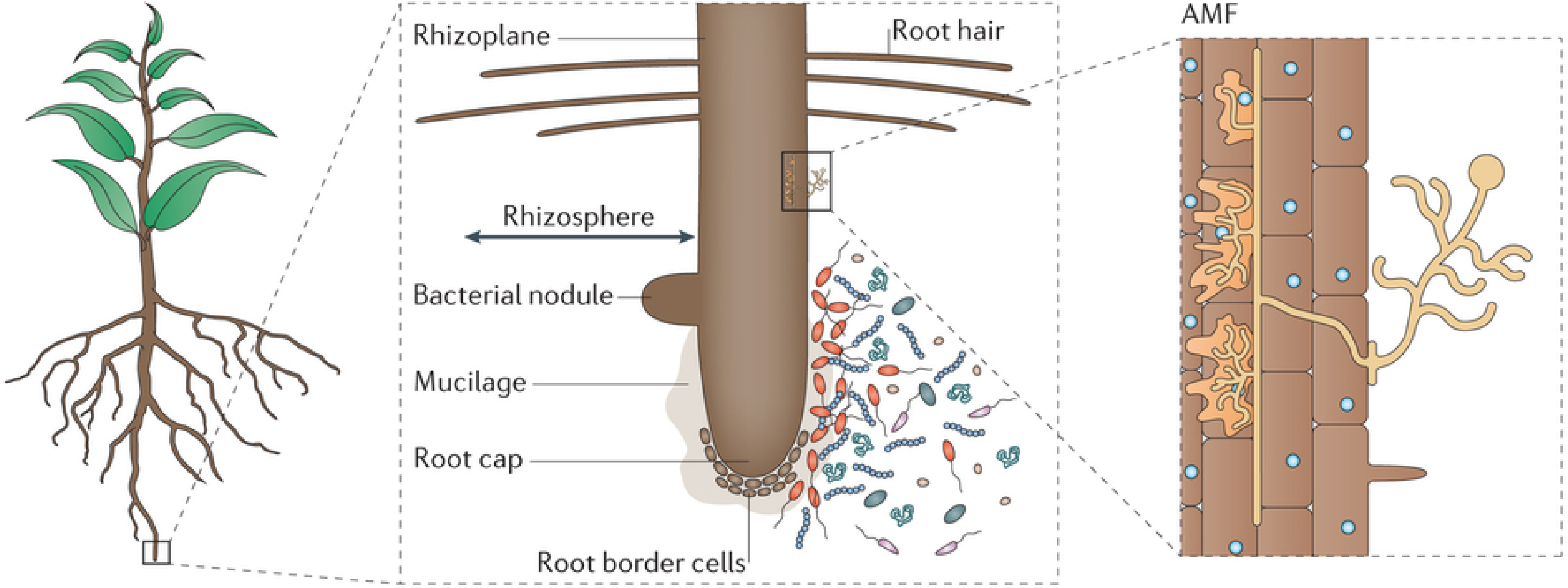


Bais HP, et al. 2006.
Annu. Rev. Plant Biol. 57:233–66

Mycorrhizal hyphae and spores on a corn root



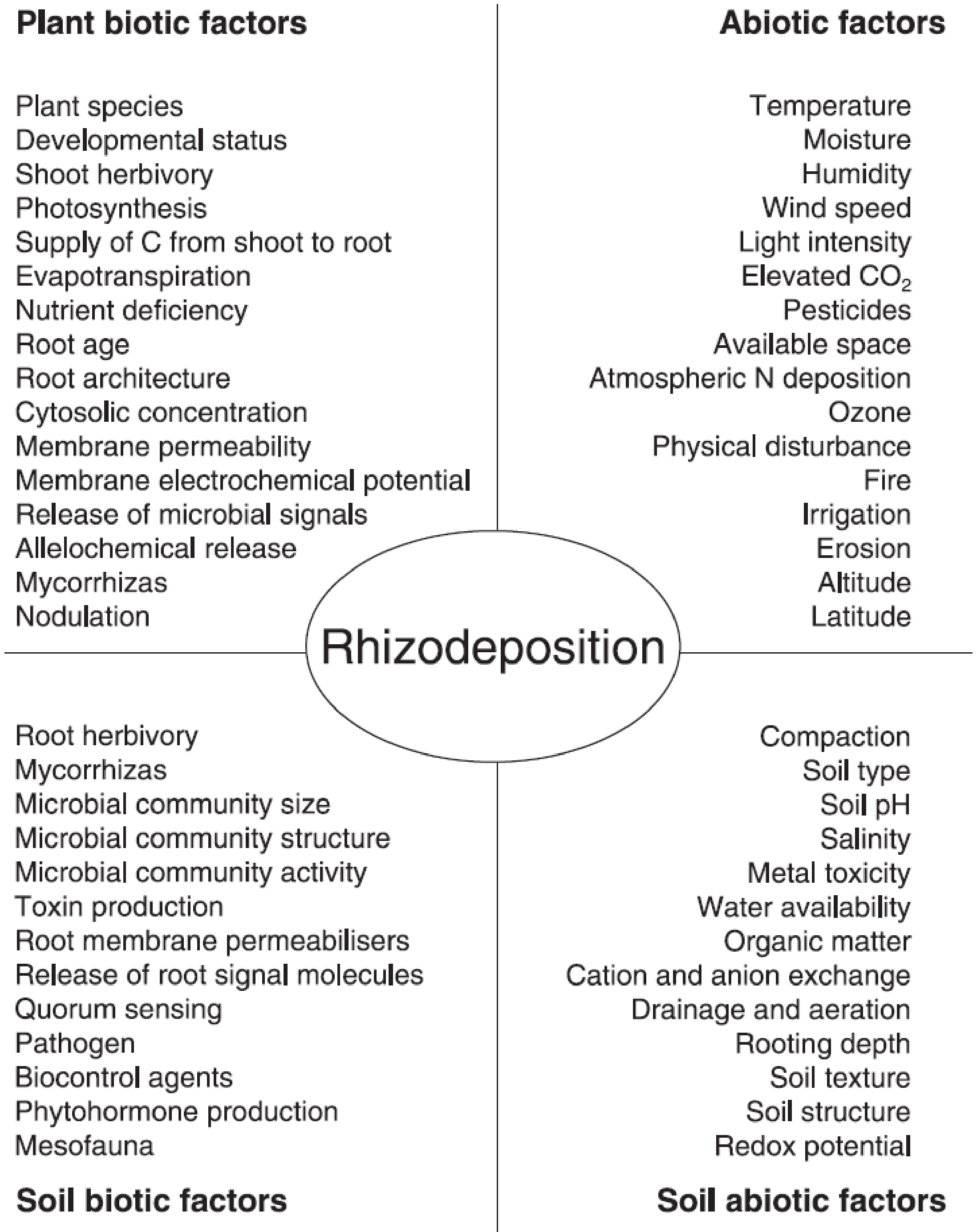
Plant growth promoting bacteria (PGPB) on Arabidopsis roots



Nature Reviews | Microbiology

Philippot et al. 2013

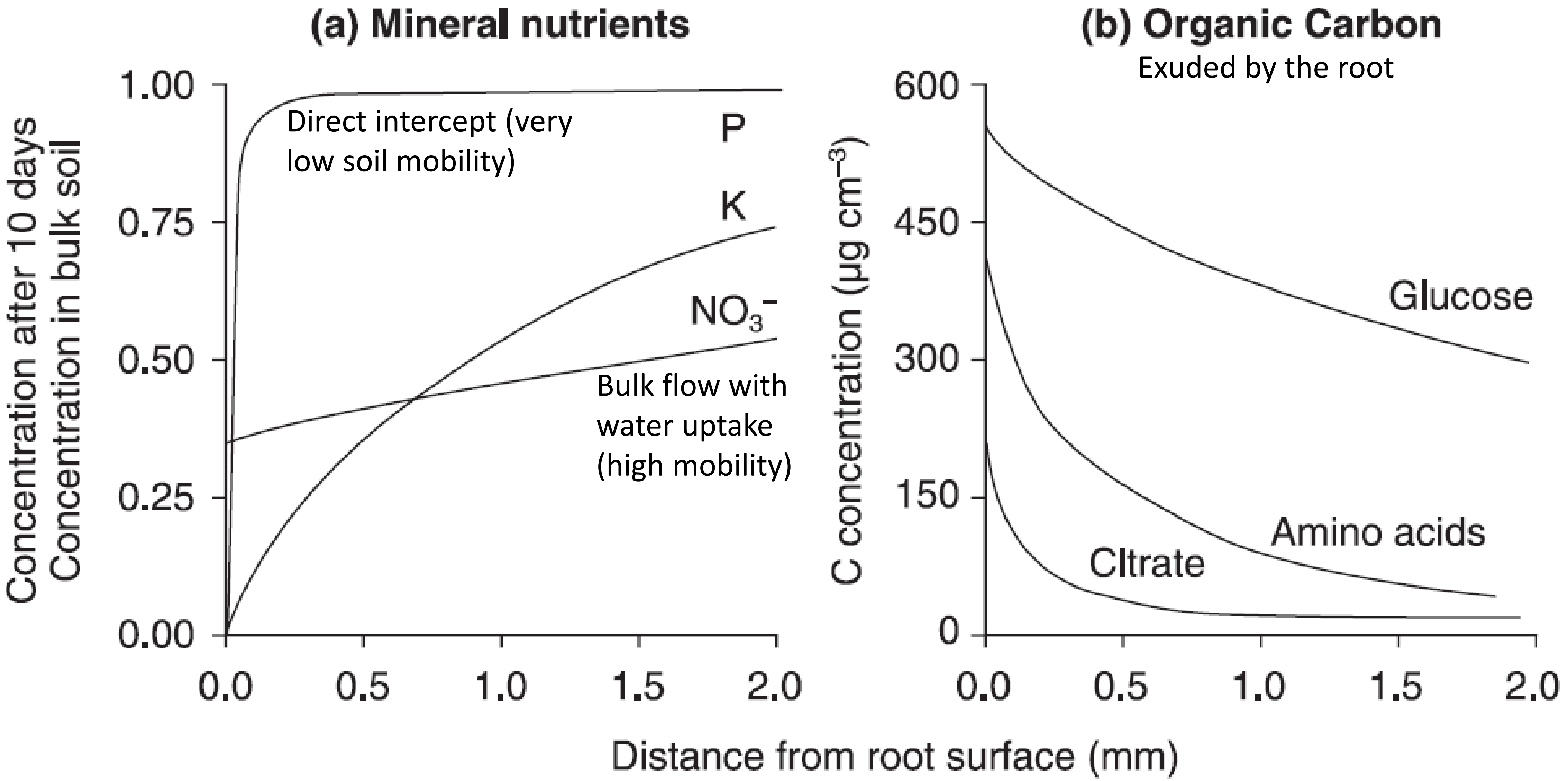
Rhizodeposition



Jones et al. 2004

Component	Function	Component	Function
Phenolics	Nutrient source Chemoattractant signals to microbes Microbial growth promoters Nod inducers/inhibitors in rhizobia Resistance inducers against phytoalexins Chelators of poorly soluble mineral nutrients (e.g. Fe) Detoxifiers of Al Phytoalexins against soil pathogens	Root border cells	Produce signals that control mitosis Produce signals controlling gene expression Stimulate microbial growth Release chemoattractants Synthesize defense molecules for the rhizosphere Act as decoys that keep root cap infection free Release mucilage and proteins
Organic acids	Nutrient source Chemoattractant signals to microbes Chelators of poorly soluble mineral nutrients Acidifiers of soil Detoxifiers of Al Nod gene inducers	Enzymes	Catalysts for P release from organic molecules Biocatalysts for organic matter transformation in soil
Amino acids and phytosidero phores	Nutrient source Chelators of poorly soluble mineral nutrients Chemoattractant signals to microbes	Purines	Nutrient source
Vitamins	Promoters of plant and microbial growth Nutrient source	Sugars	Nutrient source Promoters of microbial growth

Jones et al. 2004



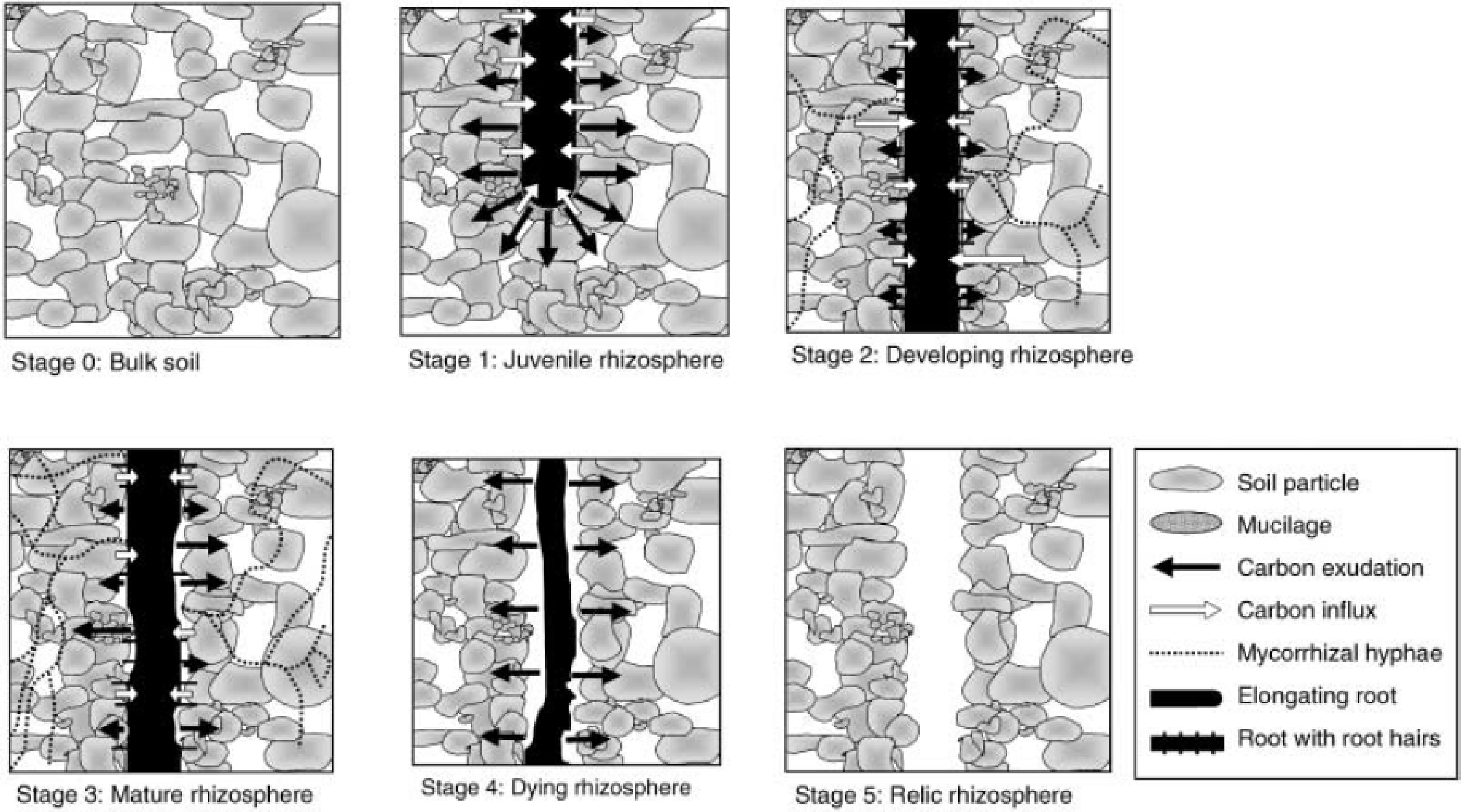
Jones et al. 2004

Table 2 The most important mechanisms for enhancing nutrient mobilization in the rhizosphere

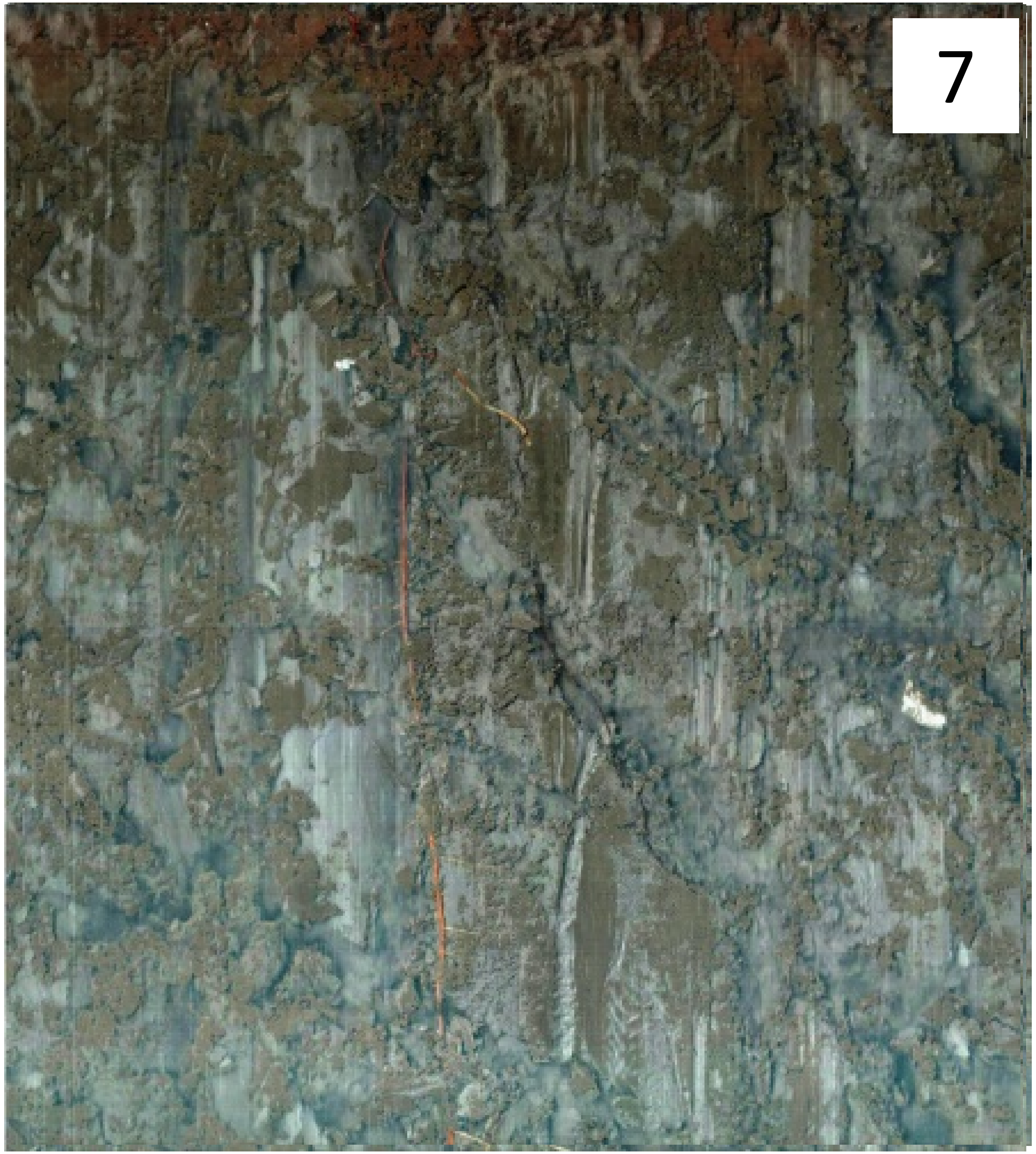
	pH change	Redox change	Metal complexation	Biotic	Root morphology	Mycorrhizas	
N				+ + +	+ + +	+ + +	N
P	+ + + ↘		+ +	+ + +	+ + +	+ + +	P
K						+ +	K
S				+ +			
Mg						+ +	
Ca					+ + +	+	
Fe	+ + ↘	+ + + ↘	+ + +		+ + +		
Mn	+ + + ↘	+ + + ↘	+ + +		+ + +		
B							
Cl							
Zn	+ ↘		+ + +		+ + +		
Cu			+ + +				
Mo	+ ↗						

+, low; + +, important; + + +, very important. The arrows show the change direction of the parameter for increasing availability of the nutrient.

Physically engineering the soil - biopores



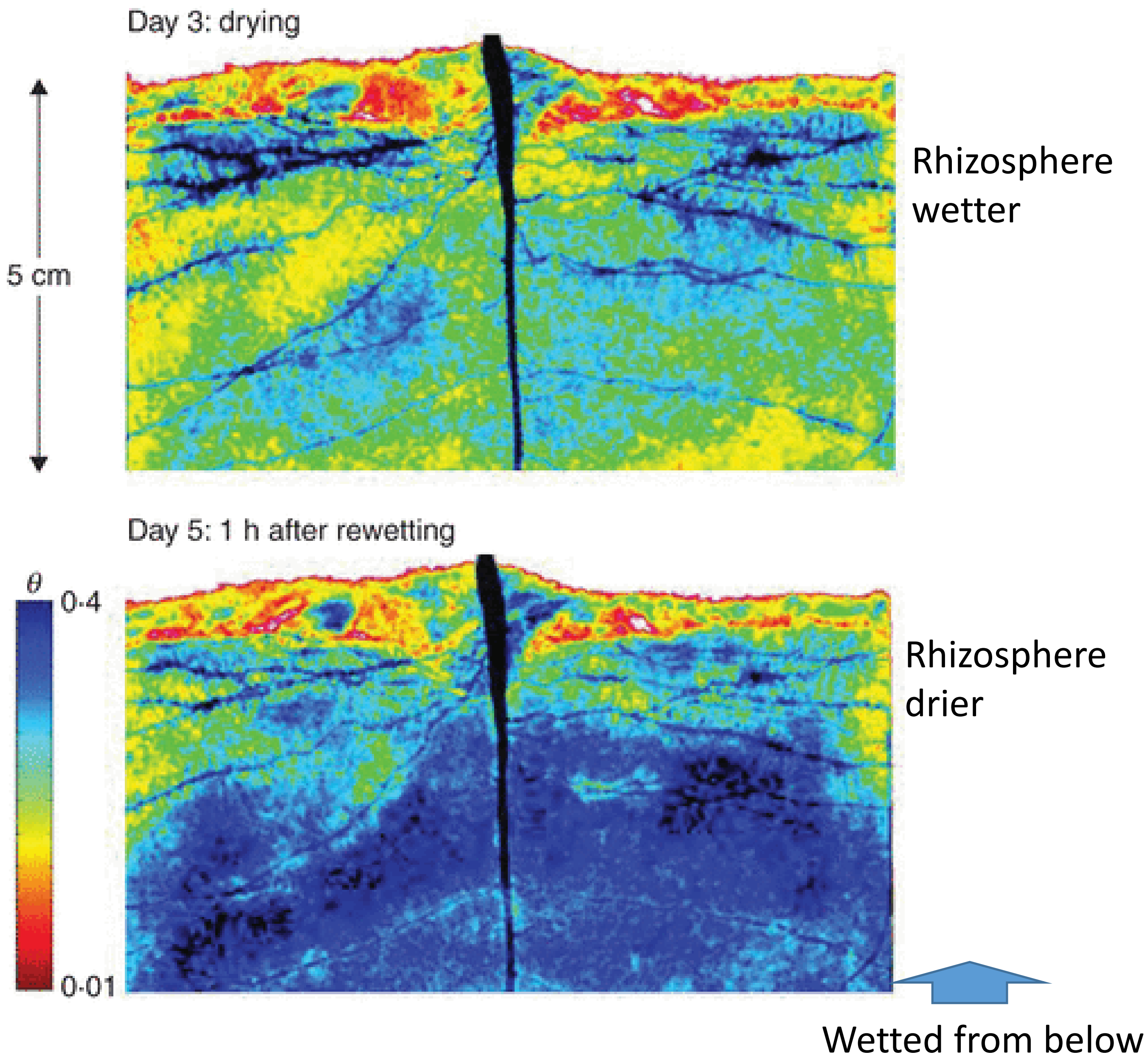
Jones et al. 2004



One week interval

- fine laterals appear and disappear
- higher order root turns brown

Roots modify rhizosphere water content compared to the bulk soil



Mucigel exuded by root caps and microorganisms can hold up to 50 times its dry weight in water. In a moderately dry soil, if mucigel was 0.1% of dry soil mass – it would increase localized soil gravimetric water content by 5%

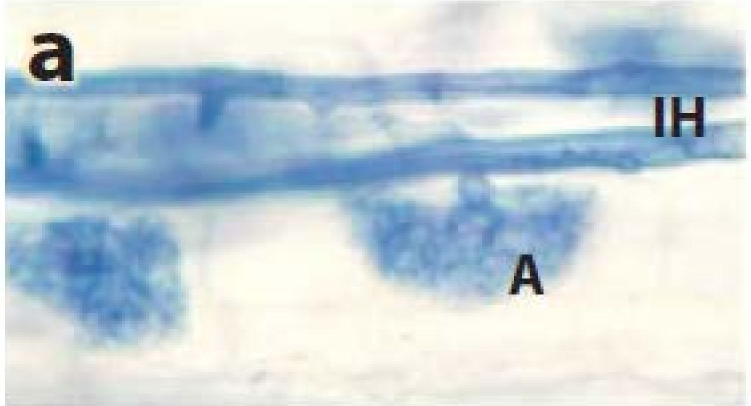
Also:

- Alters pH of soil (affects nutrient availability)
- Binds soil particles together
- Encourages bacterial growth by providing a food source

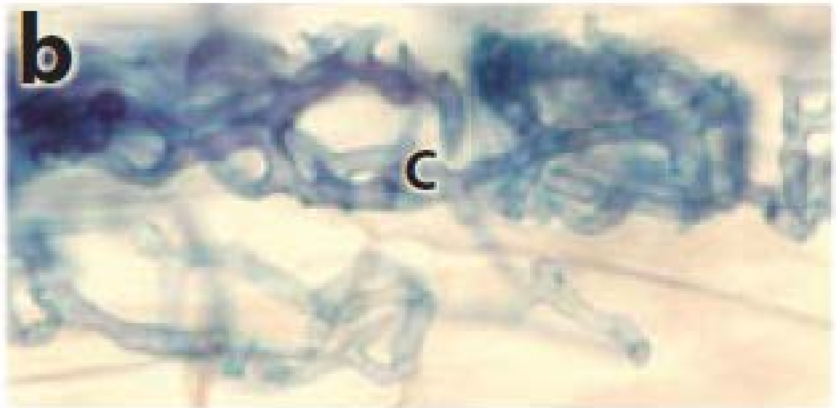
Carminati and Vetterlein, 2013

Mycorrhizae

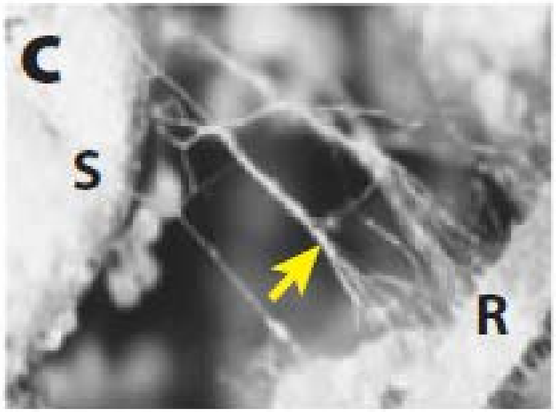
Biotrophic mutualistic symbiosis: two dissimilar organisms living together, obtaining nutrients from the living cells of their partner, beneficial to both



Extracellular hyphae & arbuscles inside cortical cells
Fungus: *Glomus intraradices*



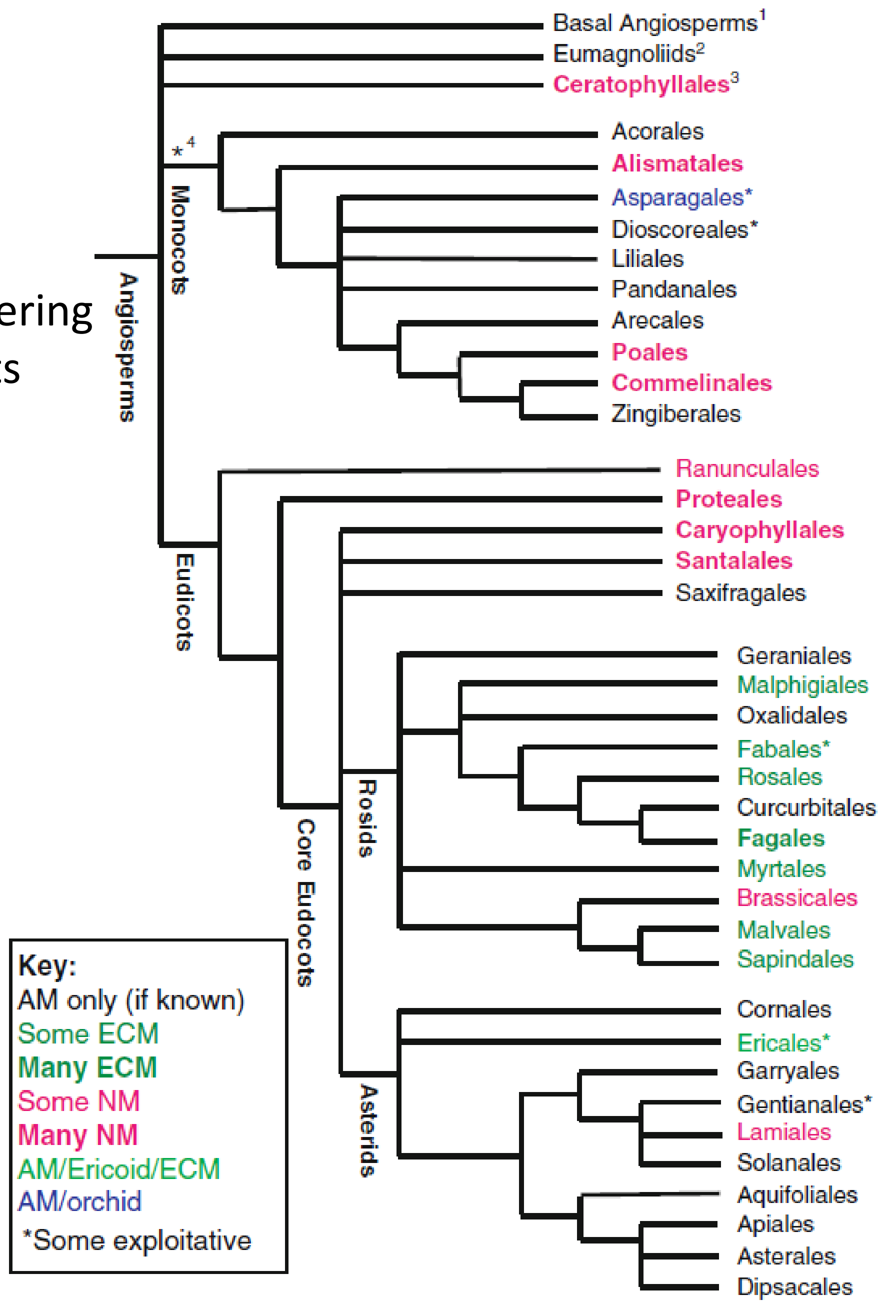
Intracellular hyphal coils
Fungus: *Gigaspora rosea*



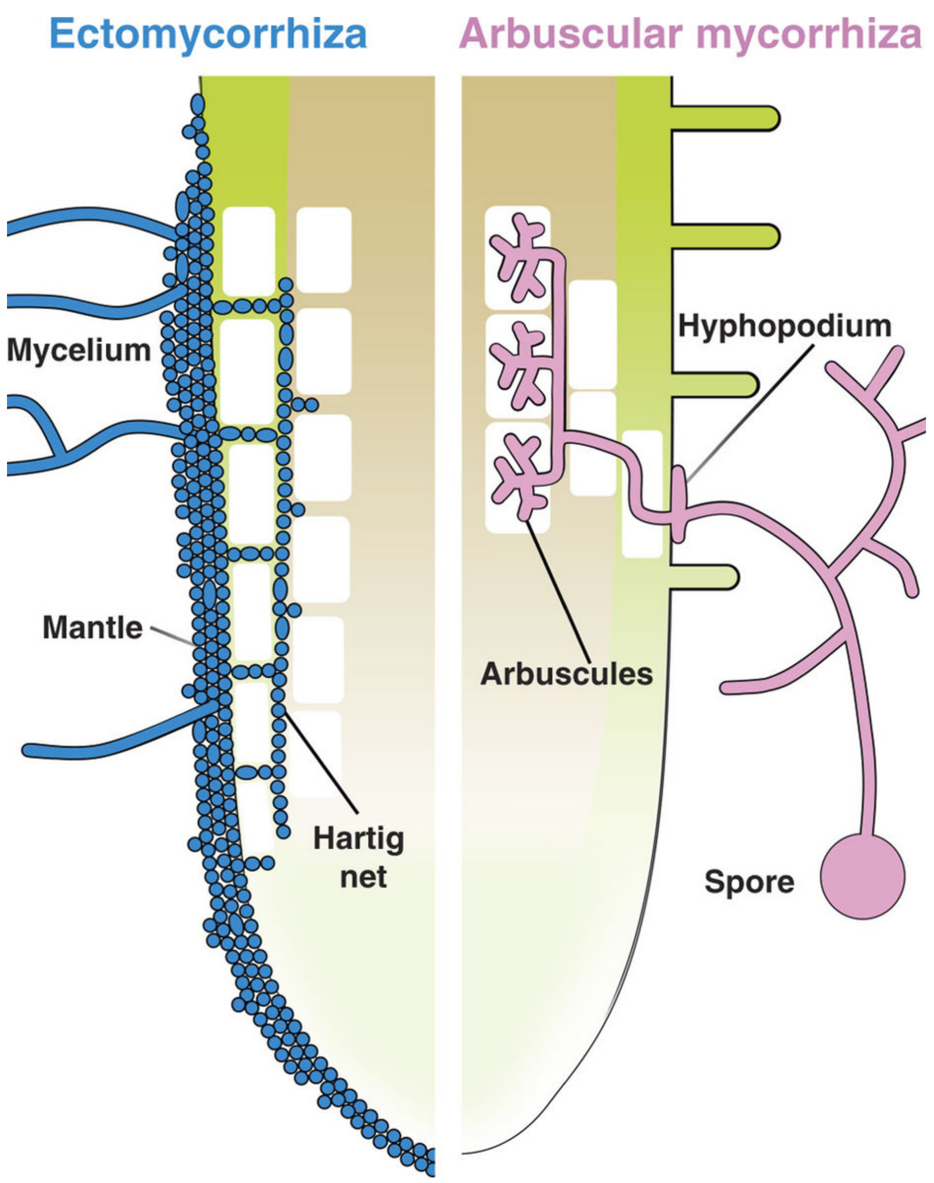
Fungal mycelium connecting a root (R) with a soil particle (S)

Smith & Smith, 2011

Flowering plants

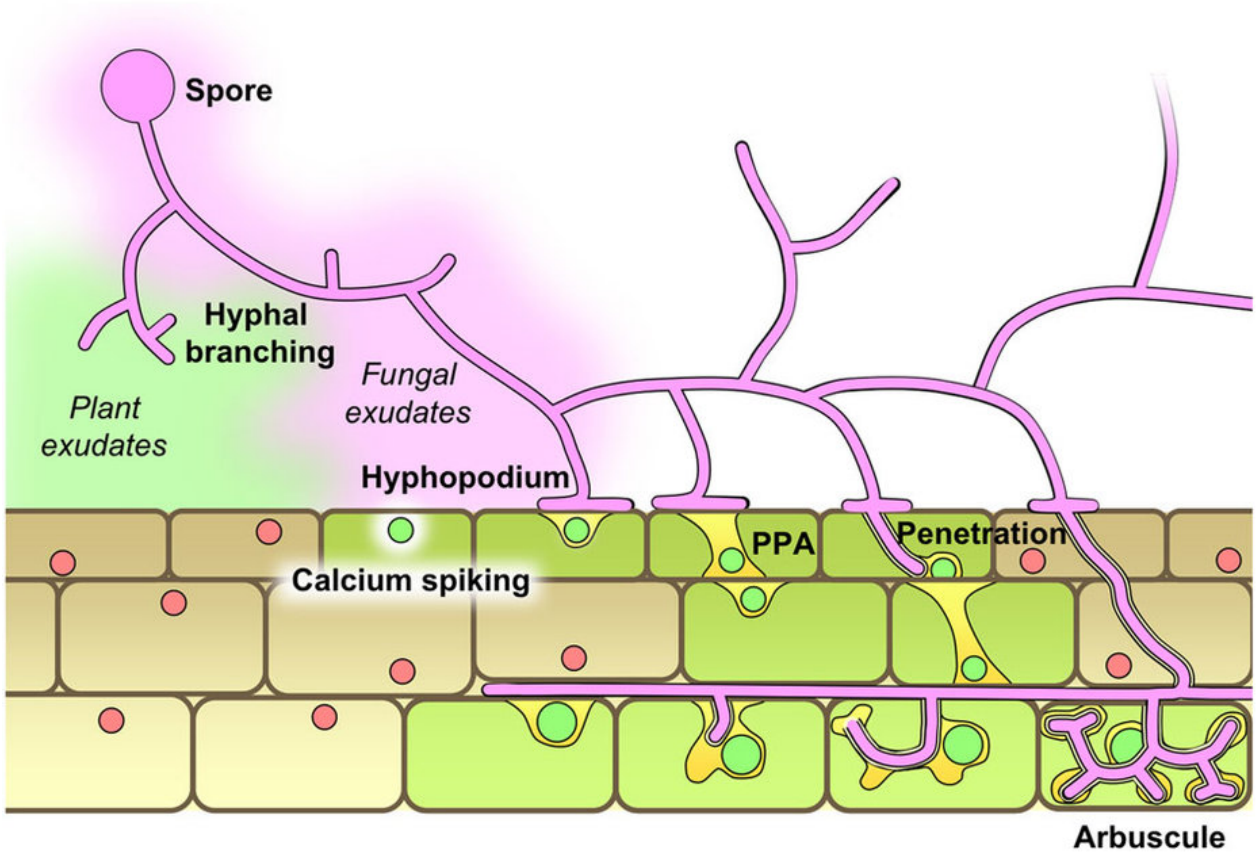


Lambers et al.2009



Bonfante & Genre, 2010

How does it work?

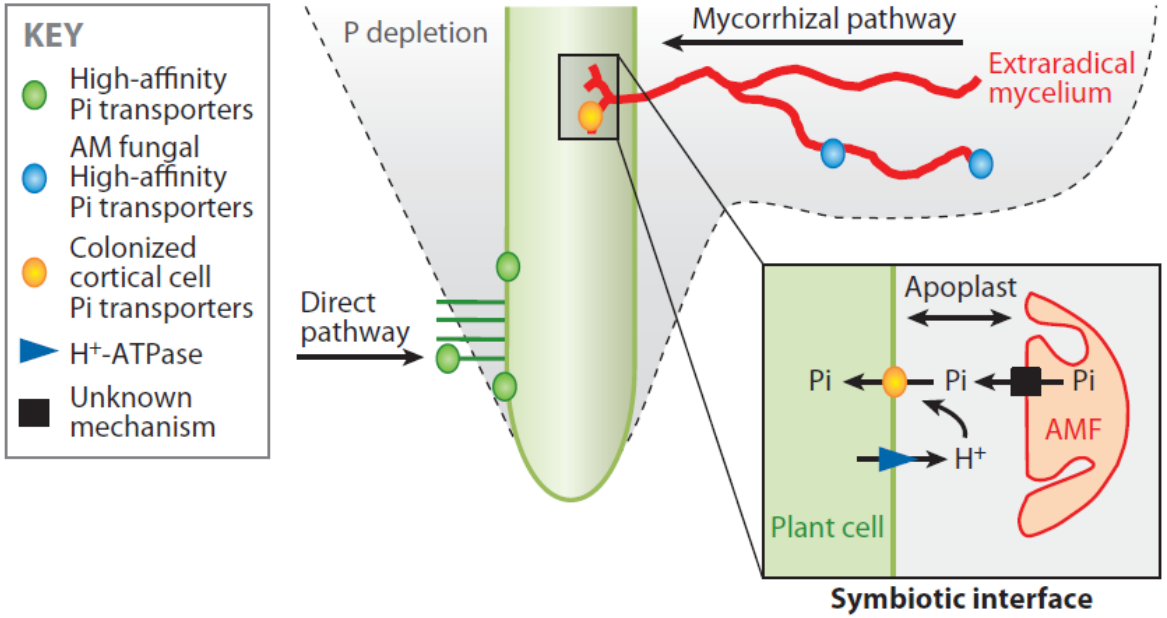


Bonfante & Genre, 2010

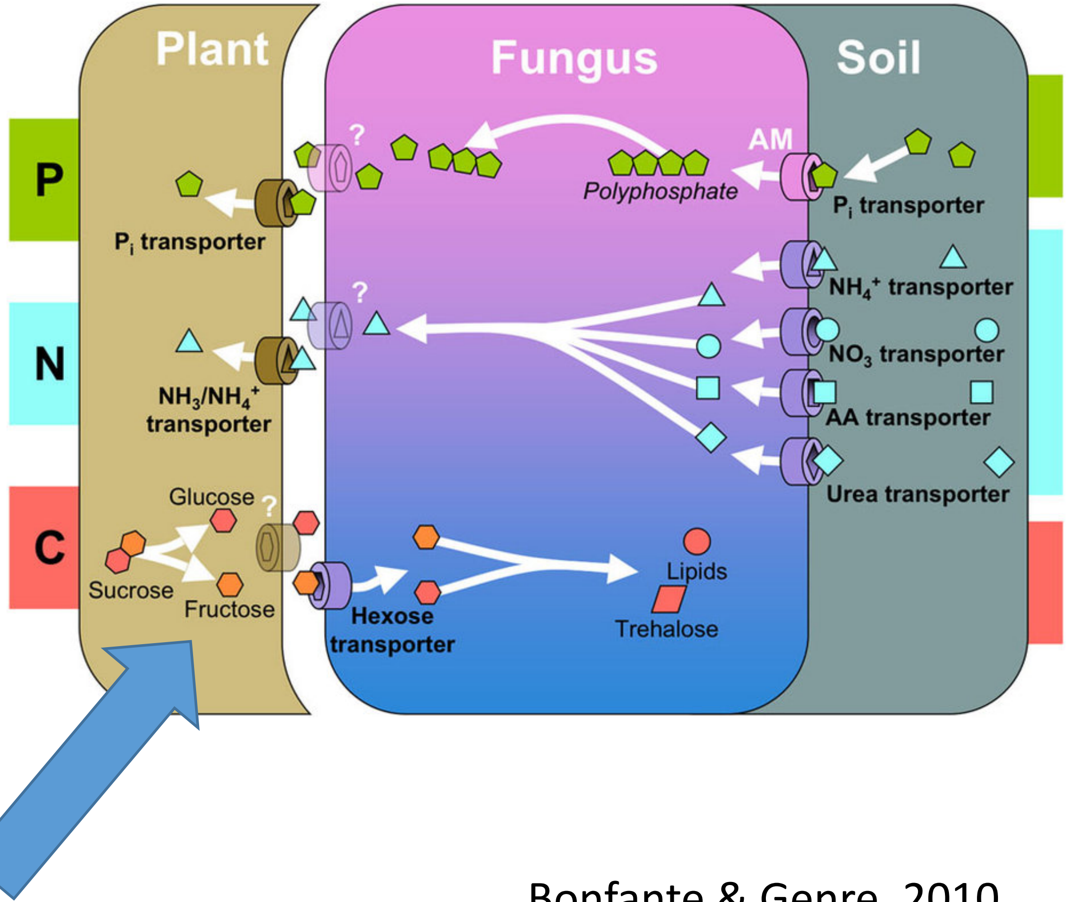
AM fungi produce spores, and once germinated, need a host to survive.

Communication requires both plant and fungal released chemical signals (strigolactones – also encourage germination of some parasitic weeds, *Striga* and *Orobanche* spp.)

Phosphorus & nitrogen



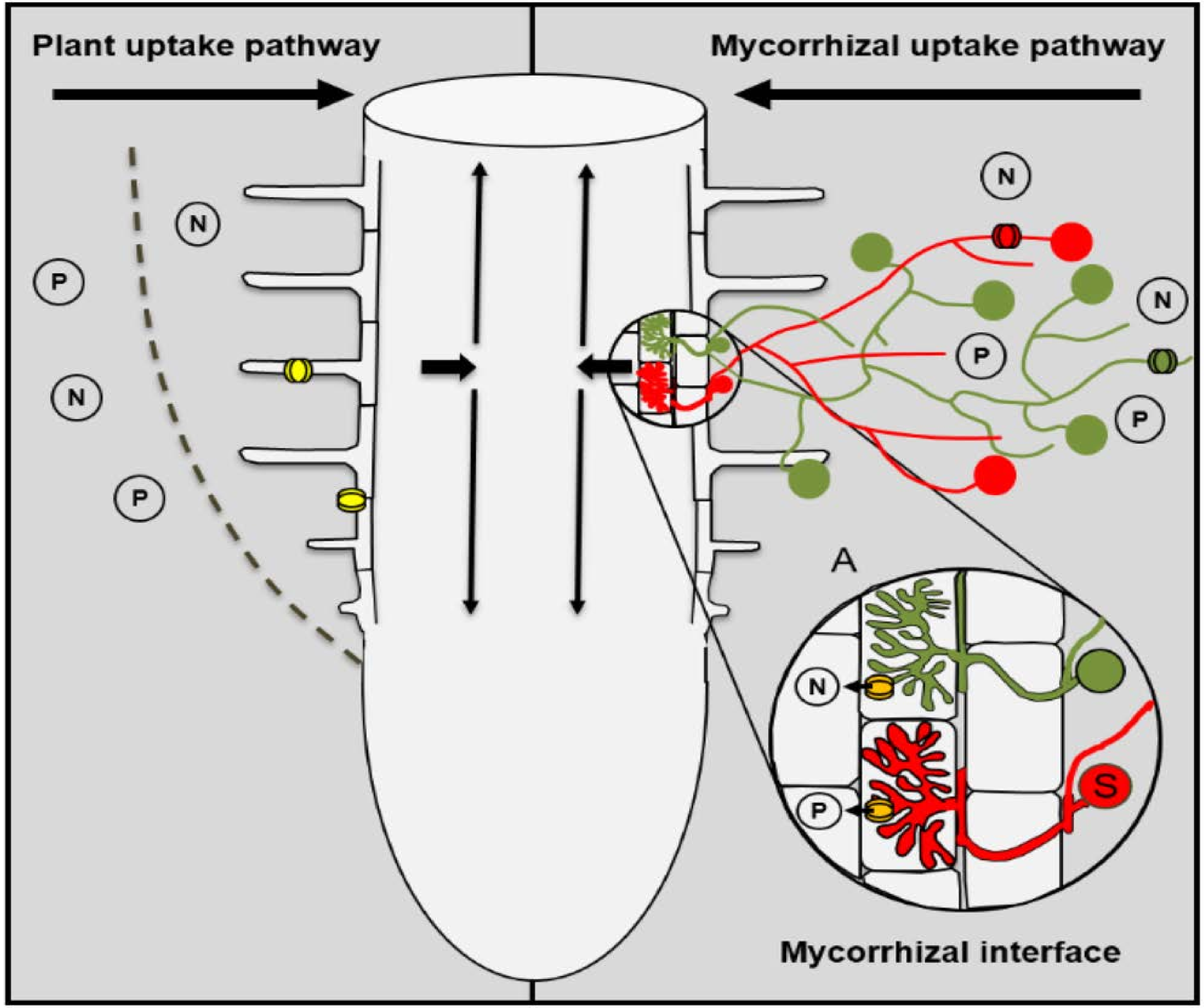
Fungus provides nutrients to the plant



Smith & Smith, 2011

Bonfante & Genre, 2010

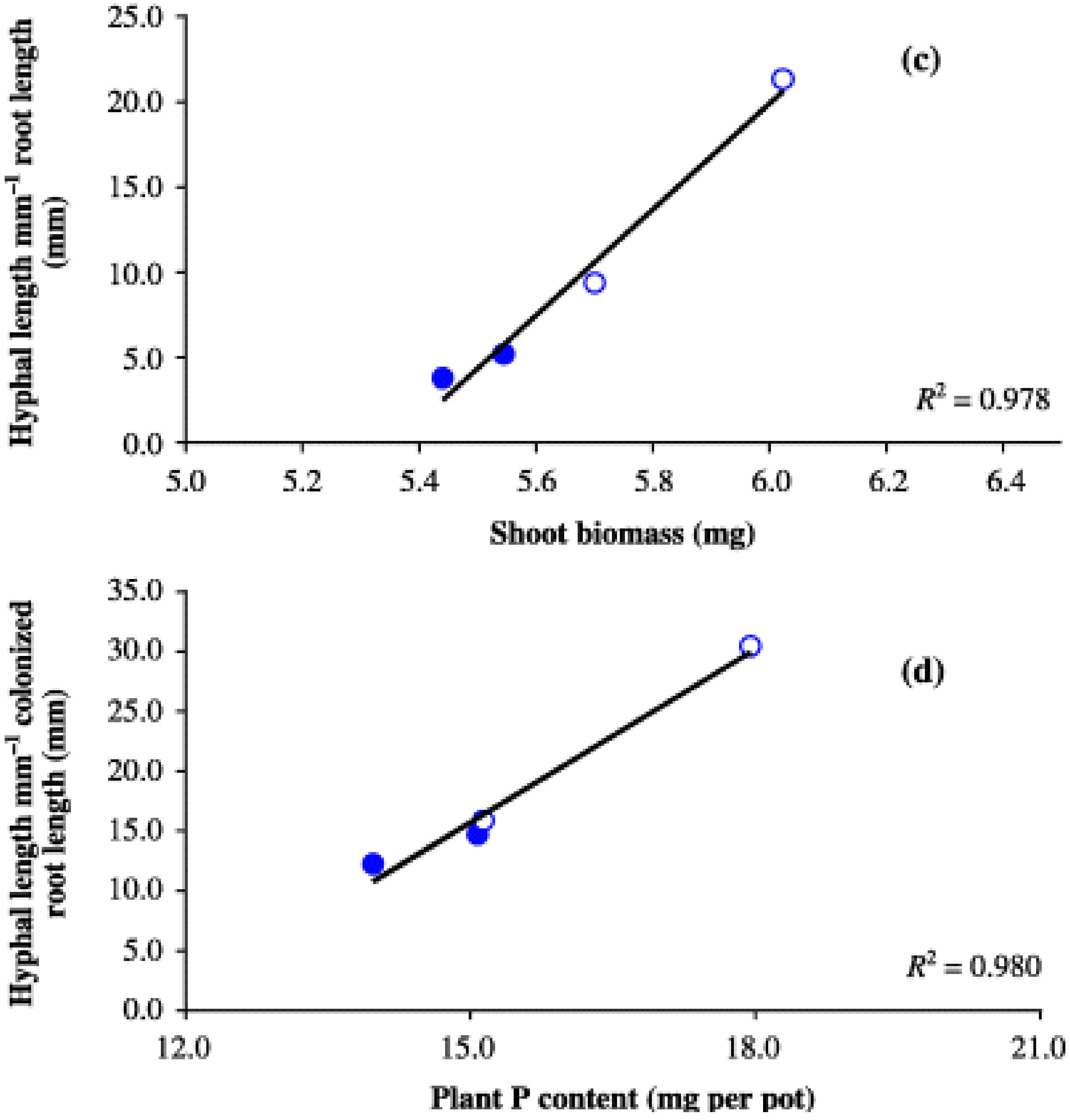
The fungus cannot photosynthesize and receives sugars (carbon) from the plant

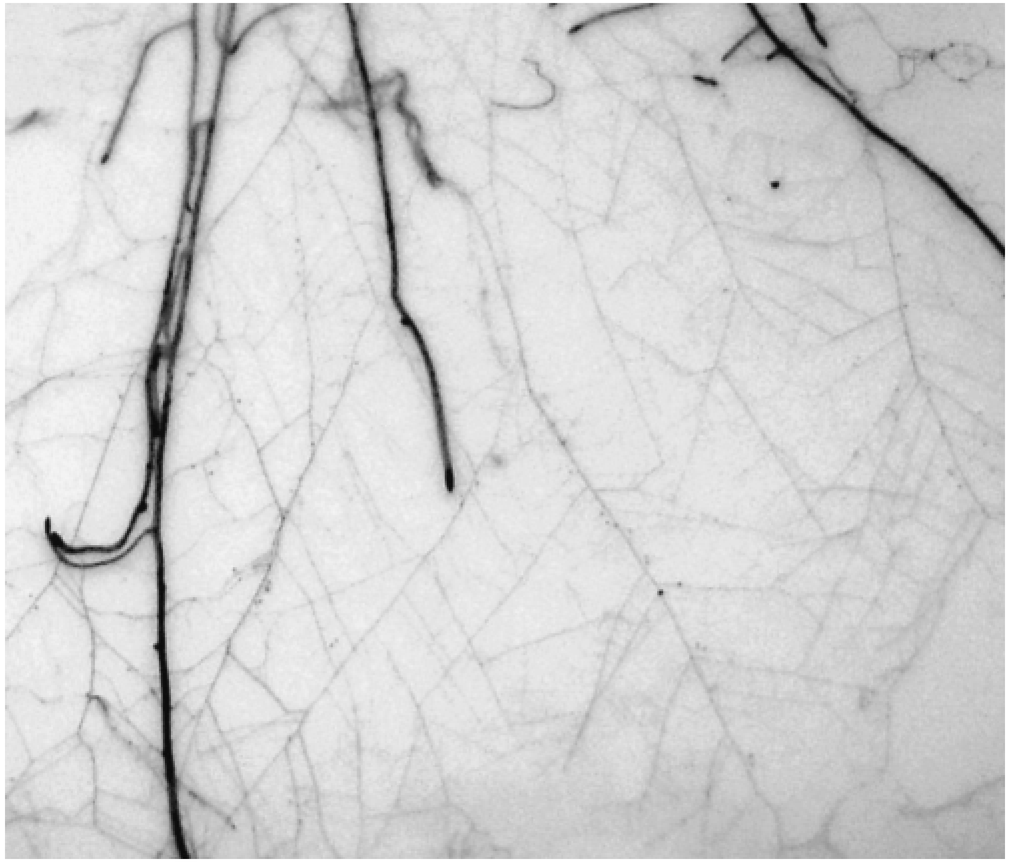


Greatly enhanced soil exploration and surface area for uptake – particularly important for immobile ion such as P

Colors indicates multiple fungal species

Bucking and Kafle, 2015



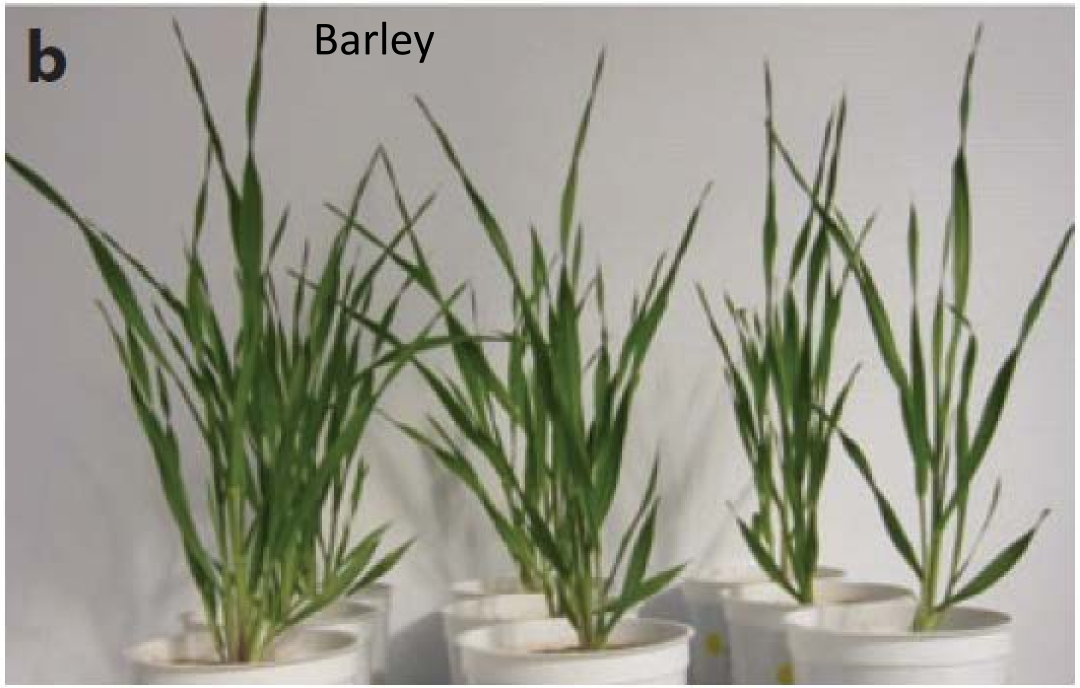


Medicago sativa
Alfalfa/Lucerne

Avio et al. 2006

Effects depend on host and fungal species, P supply AND environmental conditions

Clover with *Glomus mosseae*

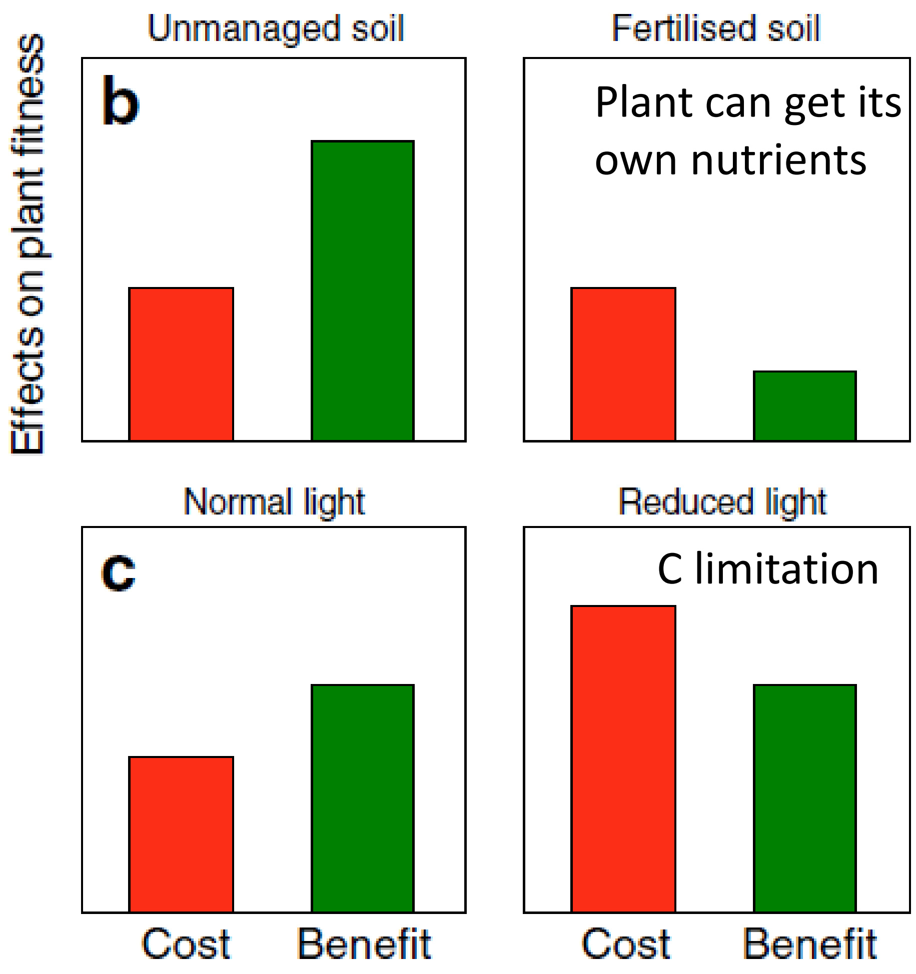


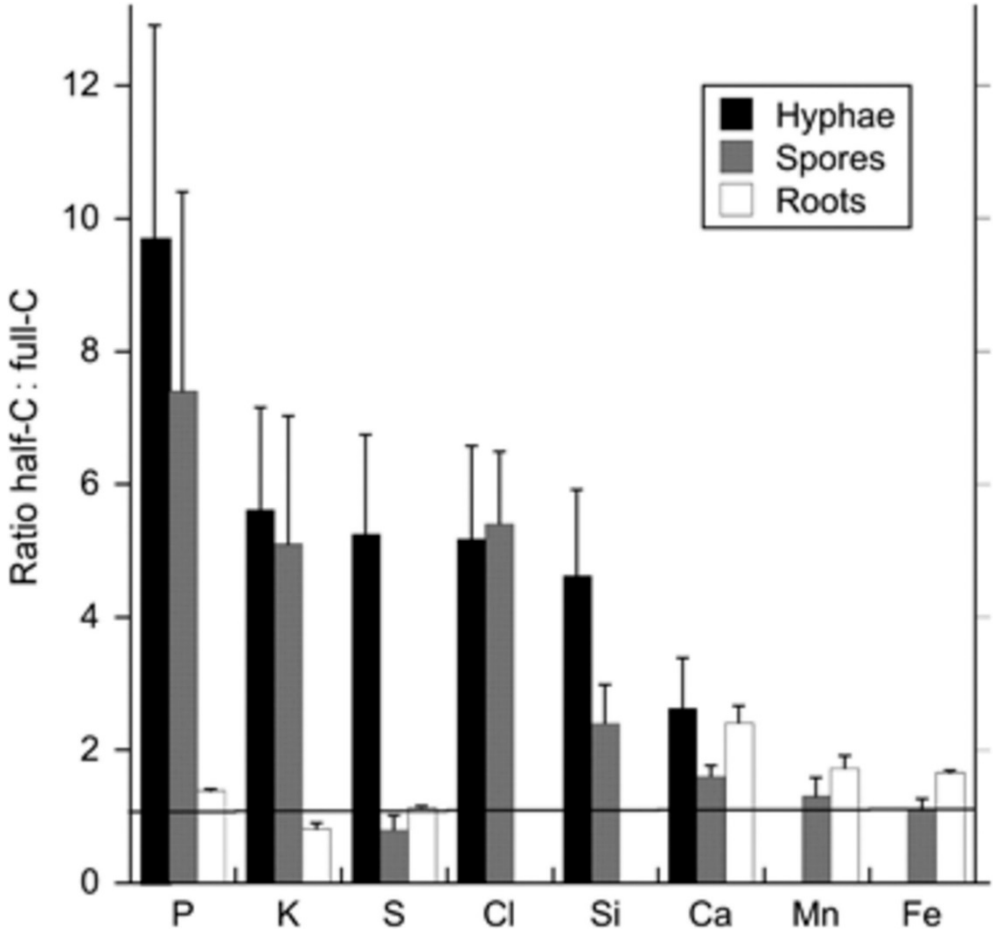
Mycorrhizal plants did worse than non-mycorrhizal plants, but differences in colonization did not lead to altered growth

Smith & Smith, 2011

Lambers et al. 2009

When the plant has less carbon available to give, the fungus will keep the nutrients!



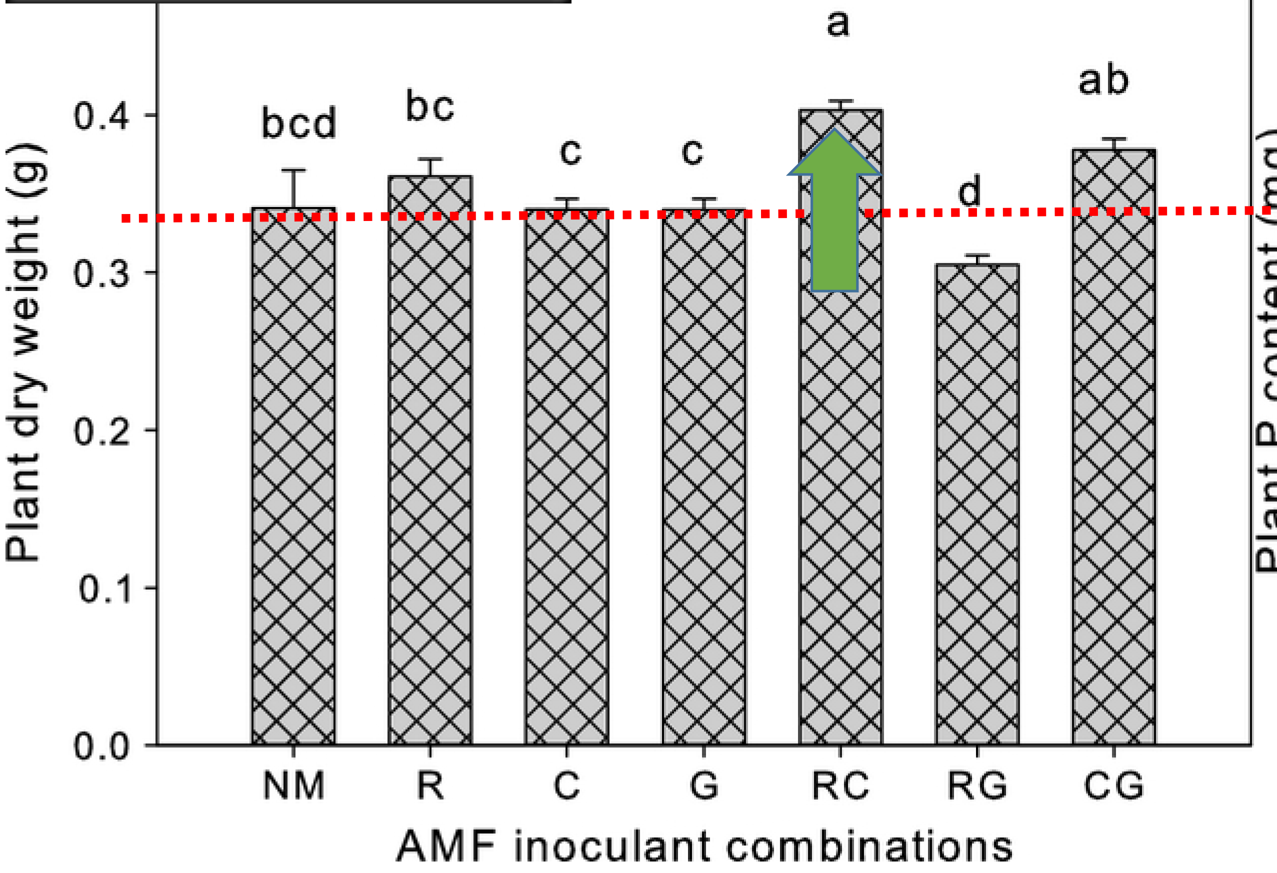


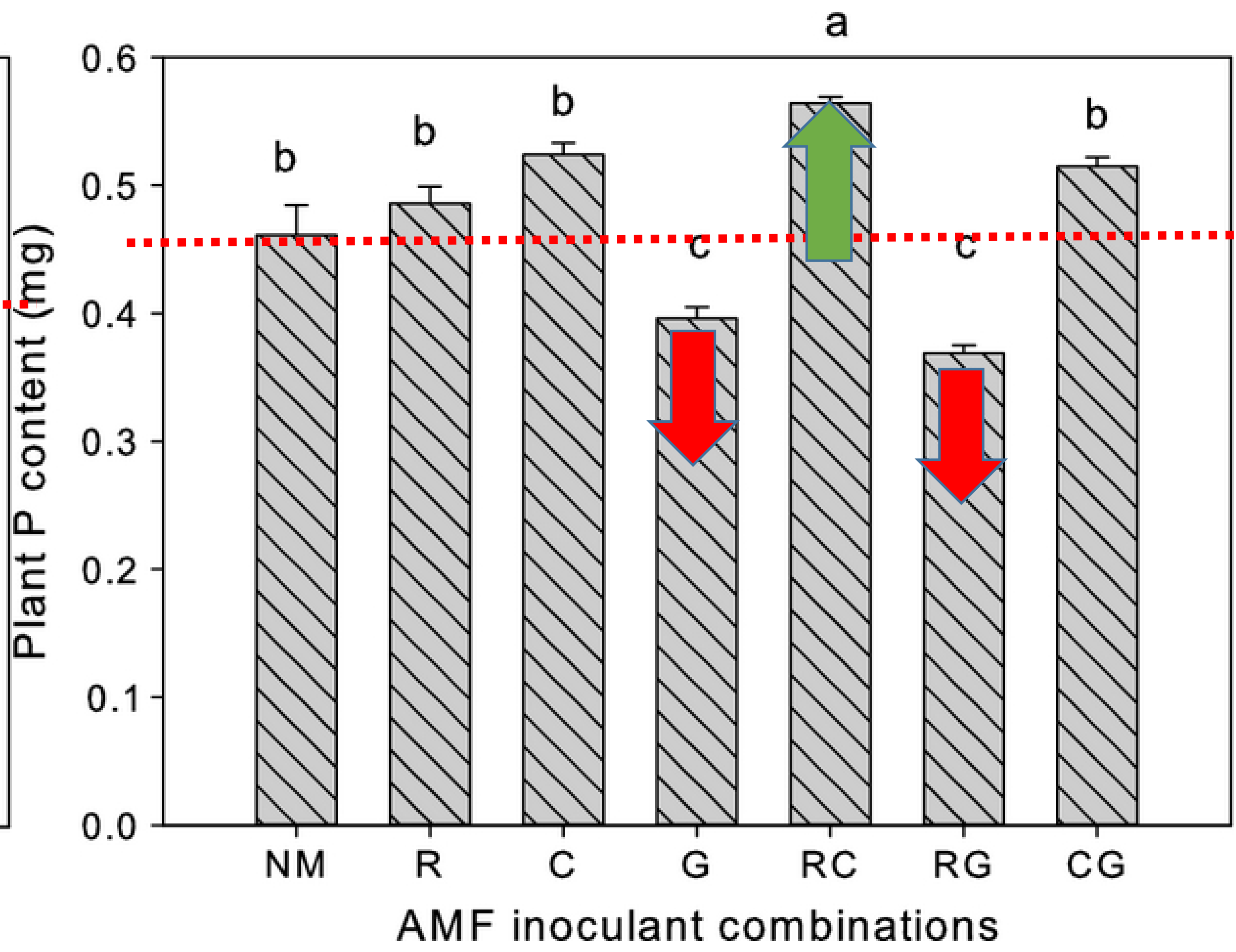
Hammer et al. 2011

Plant C cost (value of payment to the fungus) outweighs benefits only when nutrient supply is low, or the plant is not C limite

What if *WE* increase the number of fungal species?

Medicago trunculata (barrel clover)





Thonar et al. 2014

Bio/Organics Micronized Endomycorrhizal Inoculant

This inoculum contains a concentrated blend of multiple widely adapted strains of dormant spores of beneficial mycorrhizal fungi. Glomus brasilianum, G. clarum, G. deserticola, G. etunicatum, G. intraradices, G. monosporus, G. mosseae, Gigaspora margarita and others. - minimum 50 whole spores per cubic centimeter.

The species in this mix benefit nearly all food crops - grapes, citrus, fruits, nuts, berries, grains, beans, and most vegetables. (This fine powder replaces our previous granular product, BioBlend BASIC.)

Once in contact with the host plant, the fungus spreads throughout the root system and begins searching the surrounding soil for nutrients to bring to its host plant.

Mycorrhizae promote plant vigor, add disease resistance, and can increase yields while improving soil for future crops. As a rule, fertilizer inputs can be substantially reduced for mycorrhizal plants.

Most landscape and restoration plants use one or more of the species in this powdered blend.

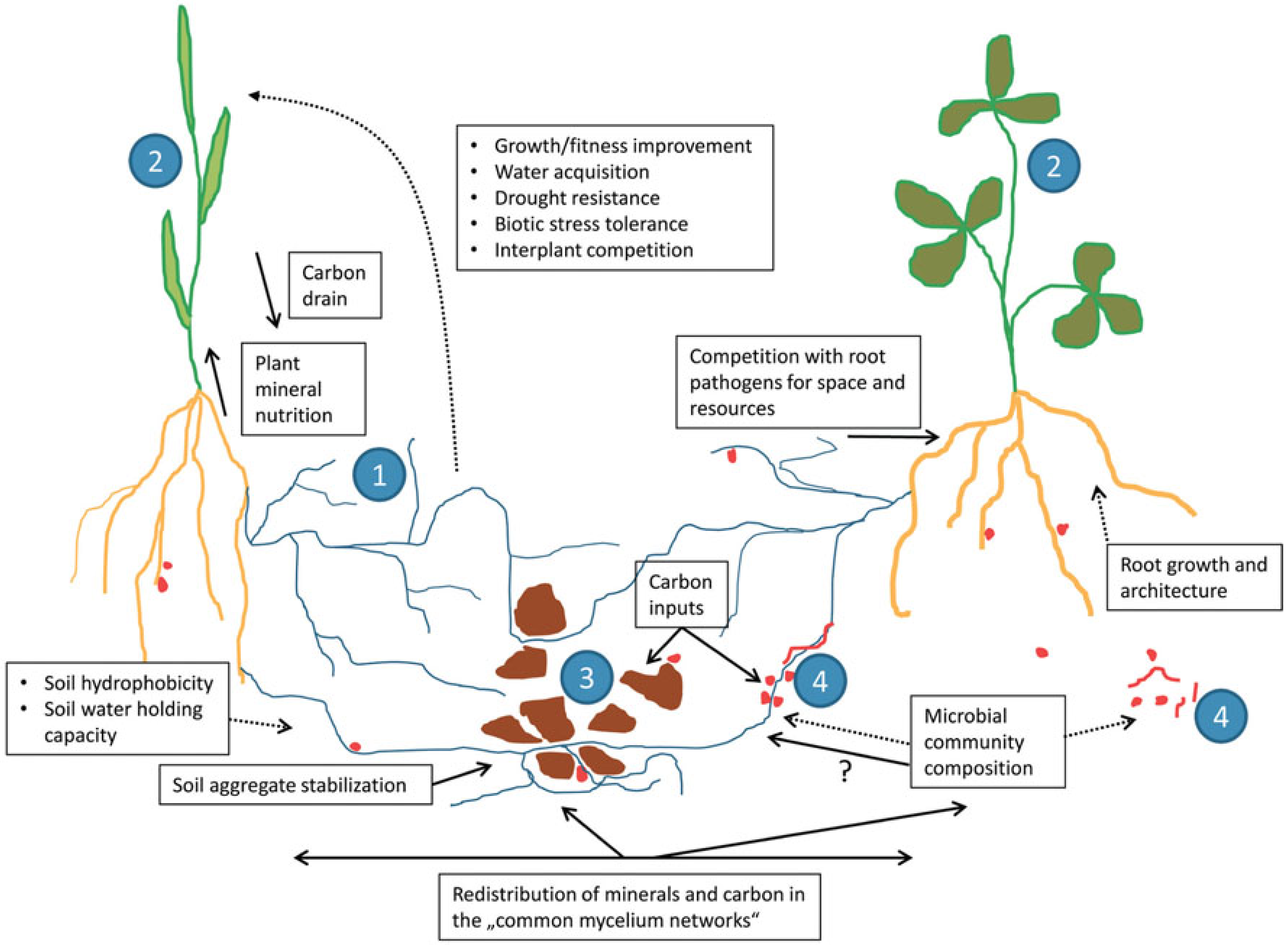
The main observed benefits are improved survival and growth rates, greater tolerance of problem soils, and a reduced need for water & fertilizer.

OMRI Listed
Organic Materials Review Institute

Sprinkle inoculant on roots of transplants, dust on seeds, or mix into water and apply as a soil drench to new plantings. For existing plants, these superior species are best introduced by inoculating roots of cover crops.

Studies have documented good effects on turf grass (including golf greens), ornamentals in poor urban soils, freeway and site restoration projects, plus flowerbeds. The powdered inoculant can be applied as a dust, mixed into water and applied as a drench, or injected to root zones.

Summary - mycorrhizae

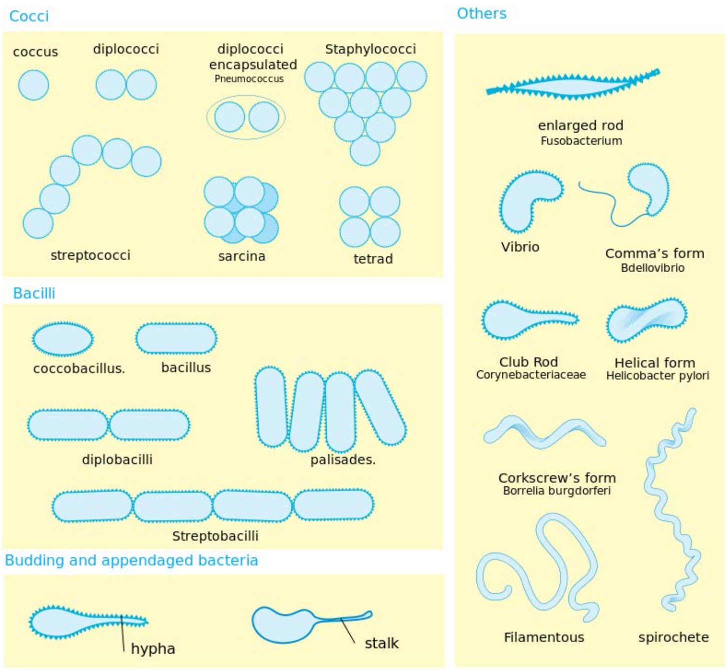


- Can be beneficial, but also negative for growth
- They also modify the environment and manipulate bacterial communities
- Provide P, N, possibly also K, water
- Induce systemic resistance
- Improve soil structure
- Outcompete some pathogens
- But be careful – they can work against each other & the plant as well

Jansa et al. 2014

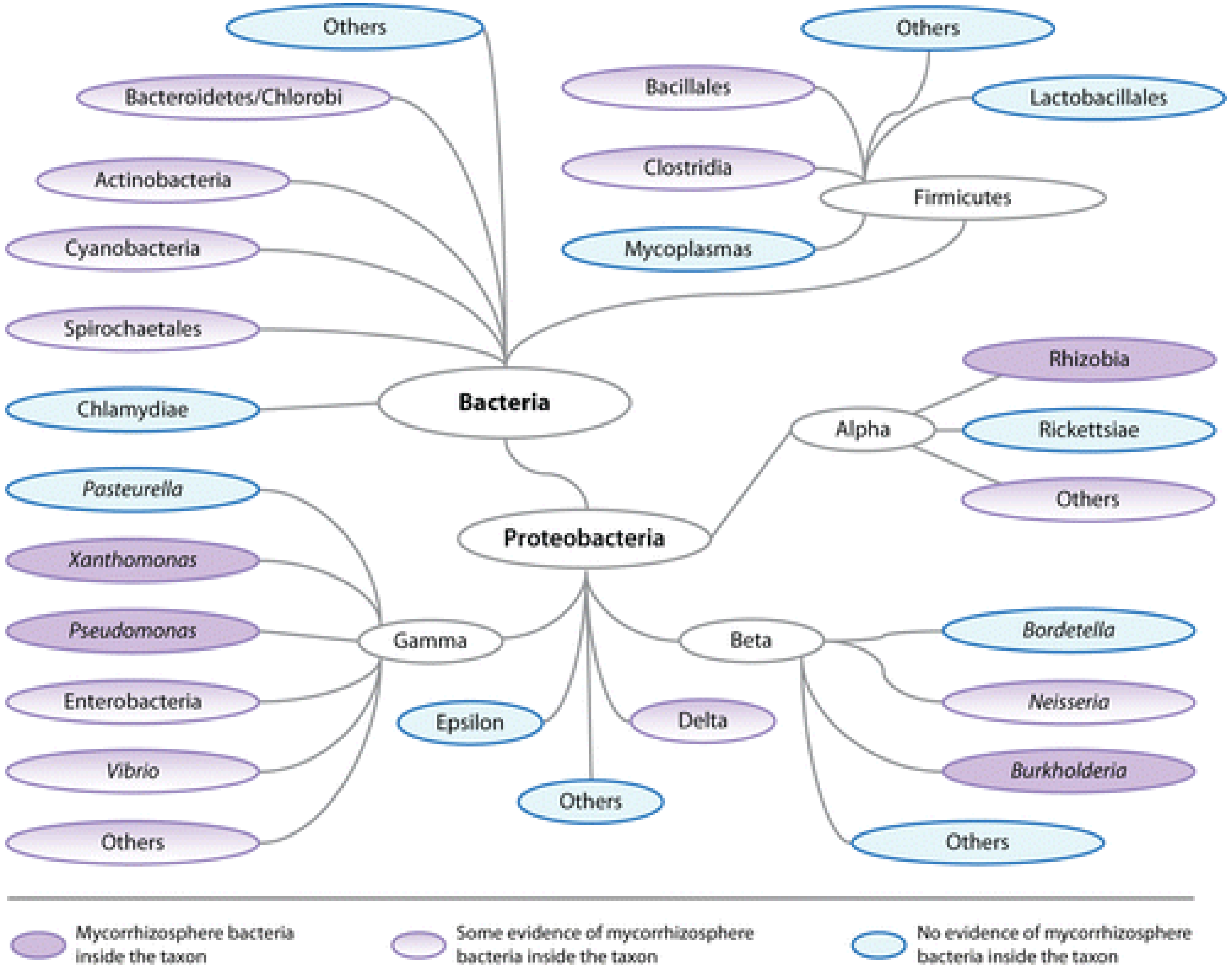
Bacteria

- Single celled organisms, some group together in chains or larger groups such as biofilms
- The ones of interest today require carbon from organic matter (e.g., living or dying or dead plant material/flesh, root exudates) to grow
- ~40 million bacterial cells in a gram of soil



Wikipedia

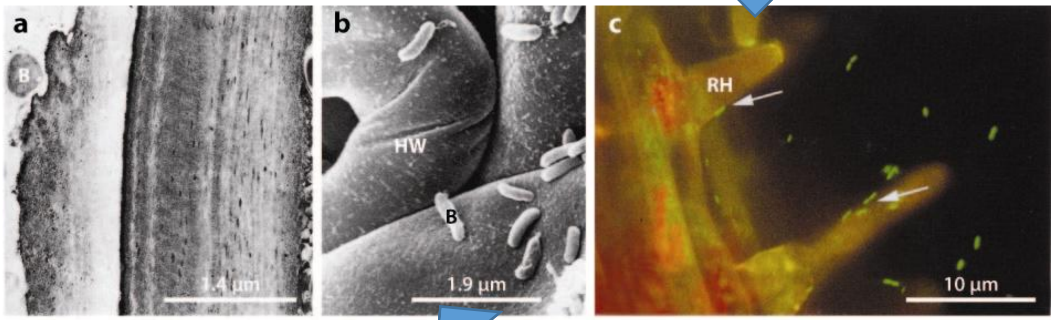
Mycorrhizosphere



Bonfante P, Anca I-A. 2009.
Annu. Rev. Microbiol. 63:363–83

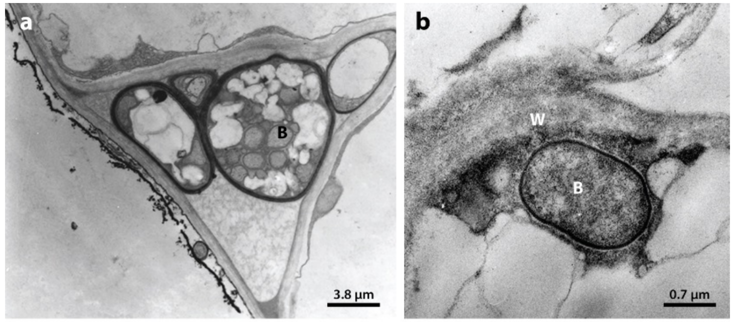
PGPB attached to root hairs

Bacteria "eating" the fungal cell wall



Bonfante P, Anca I-A. 2009.
Annu. Rev. Microbiol. 63:363–83

Plant growth promoting bacteria (PGPB) attached to hyphal wall



Bonfante P, Anca I-A. 2009.
Annu. Rev. Microbiol. 63:363–83

Bacterium like object growing inside fungal hyphae inside the root

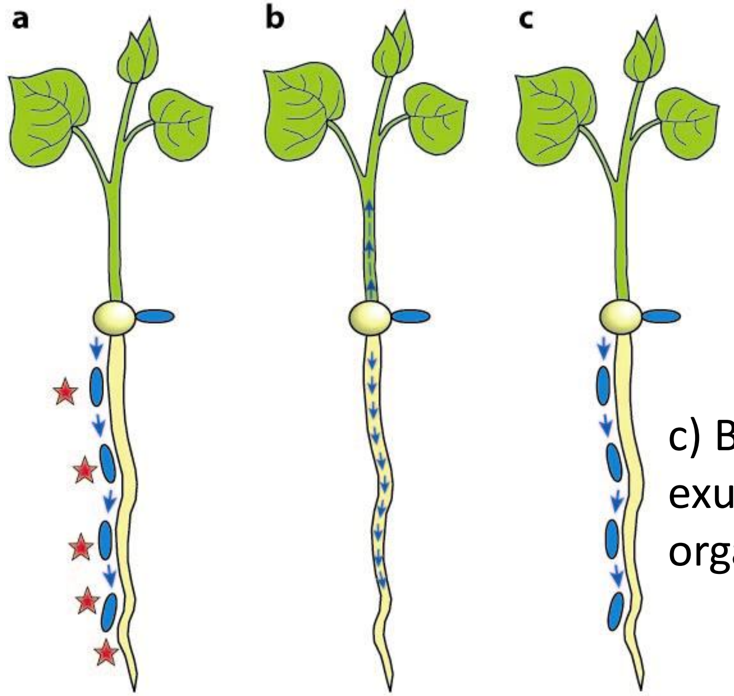
Are bacterial communities static?

- Take all disease (root rot) in wheat
- The outbreak stage (5 yr) was mainly characterized by the prevalence of *Proteobacteria*, notably *Pseudomonas* (*Gammaproteobacteria*), *Nitrosospira* (*Betaproteobacteria*), *Rhizobacteriaceae*, *Sphingomonadaceae*, *Phyllobacteriaceae* (*Alphaproteobacteria*), as well as *Bacteroidetes* and *Verrucomicrobia*.
- By contrast, suppressiveness (10 yr) correlated with the prevalence of a broader range of taxa, which belonged mainly to *Acidobacteria*, *Planctomycetes*, *Nitrospira*, *Chloroflexi*, *Alphaproteobacteria* (notably *Azospirillum*) and *Firmicutes* (notably *Thermoanaerobacter*)
- Bacterial community <u>changed with time</u> and suppressed the disease with each subsequent crop

Sanguin et al. 2009

Biological control of plant disease by external bacteria

a) Some bacteria may exude antibiotic molecules keeping harmful organisms away



c) Biocontrol bacteria acquire root exudates faster than harmful organisms, outcompeting them

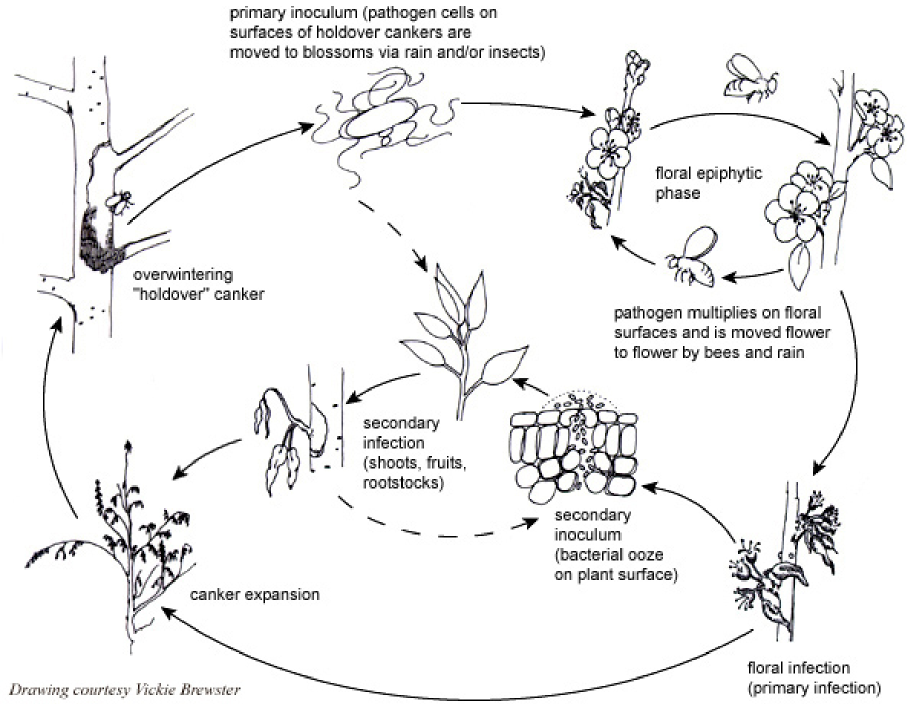
Lugtenberg B, Kamilova F. 2009.
Annu. Rev. Microbiol. 63:541–56

b) Induced systemic resistance “primes” the plant against attack by harmful organisms. Local colonization protects the whole plant – can also be induced by fungi

Induced systemic resistance (ISR)

- Addition of microbes to the soil has been shown to enhance plant defense against pathogen attack

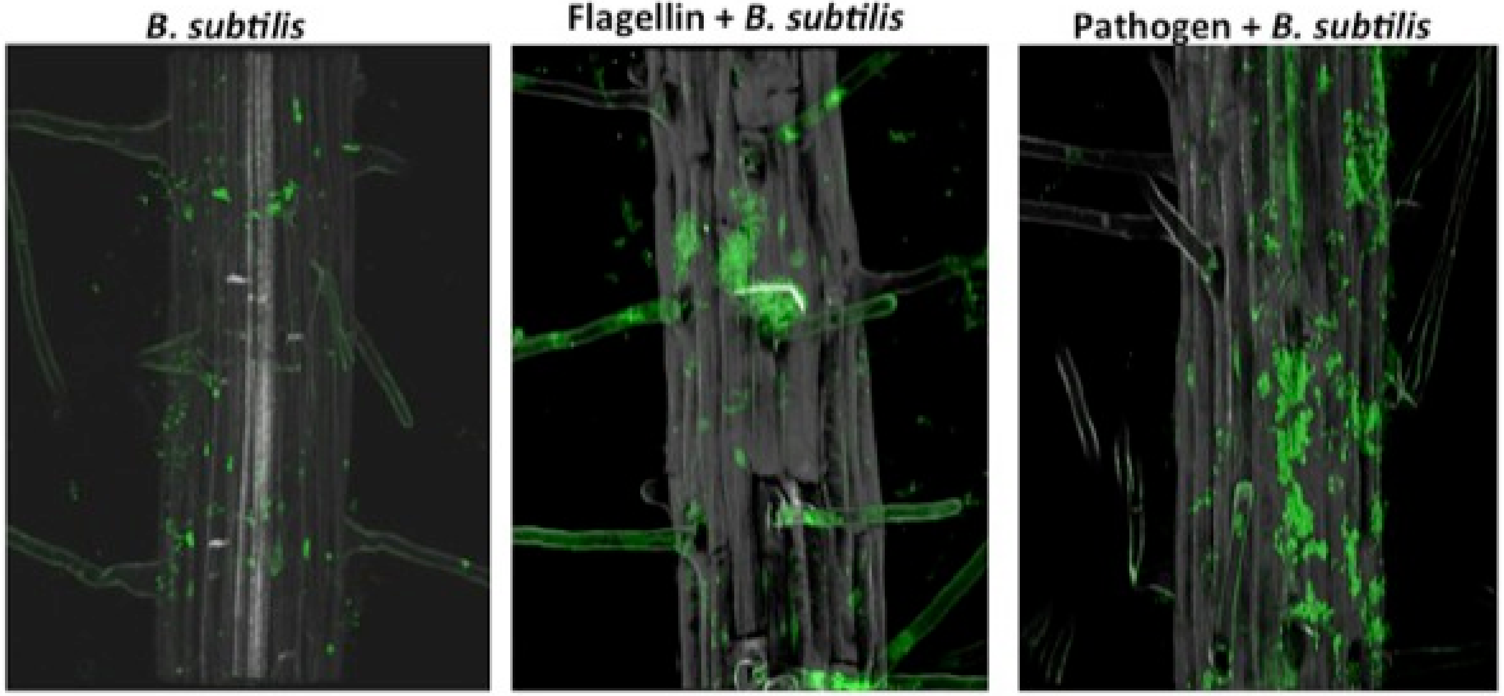
- What about bacteria entering the plant? Are they always bad?



Bacterial disease cycle

Sometimes the plant recruits bacteria for defense

B. subtilis is a benign bacteria that emits antimicrobial compounds

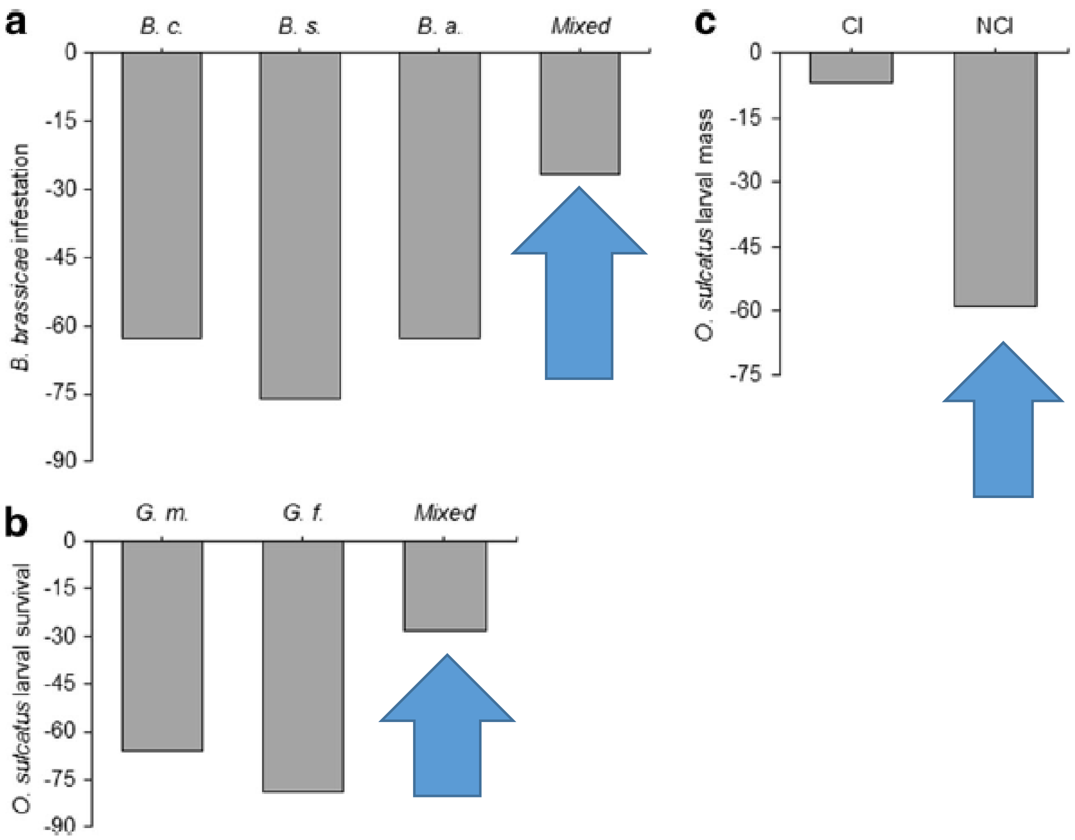


Flagellin is a protein associated with free moving (sometimes pathogenic) bacteria

More microbial diversity = better?

Different bacteria versus all combined

Impact of mycorrhizal diversity



NCI = non-commercial inoculant with indigenous mycorrhizae

Fig. 1 Effects of inoculation of individual vs. multiple microbial species and commercial vs. non-commercial inoculant on insect herbivores: individual species of a *Bacillus* most effectively reduced *Brevicoryne brassicae* field infestation; **b** *Glomus* significantly reduced *Otiorhynchus sulcatus* larval survival, than the mixtures of the same species. **c** Non-commercial inoculant containing indigenous mycorrhizal species reduced *O. sulcatus* larval mass more than the commercial mycorrhizal inoculant. The notations; *B. c.*, *B. s.*, *B. a.*, *G. m.*, *G. f.*, CI, and NCI represent *B. cereus*, *B. subtilis*, *B. amyloliquefaciens*, *G. mosseae*, *G. fasciculatum*, commercial (mixed) and non-commercial (mixed) inoculants respectively. In each case, the Y axis represents the percent reduction in insect performance on treated plants, compared to control (untreated plants)

J Chem Ecol (2016) 42:348–356

Plant Growth Promoting Rhizobacteria

Our wide range of Rhizobacteria are highly appreciated by our valuable clients. These fertilizers are widely used for soil and also enhance the growth of plants and crops. These fertilizers are offered in protective and attractive packings. However, these are formulated as per the requirement of clients.

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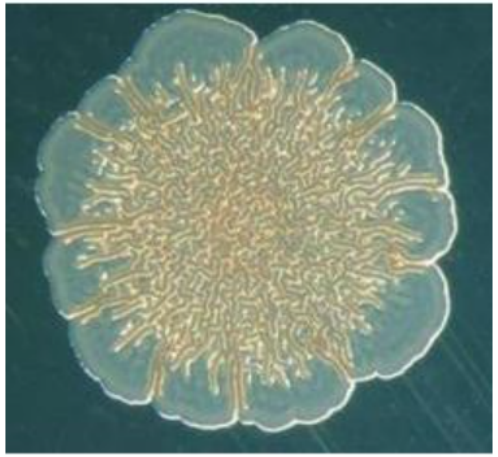
PGPR :

PGPR stands for PlantGrowth Promoting Rhizobacteria. Gmax PGPR is a combination of nitrogen fixing inoculants, Phosphate solubilizing inoculants, bio control inoculants and plant growth promoting inoculants. This combined formulation provides all the bio inoculants required for crops in a nutshell and enables the farmers for easy application.

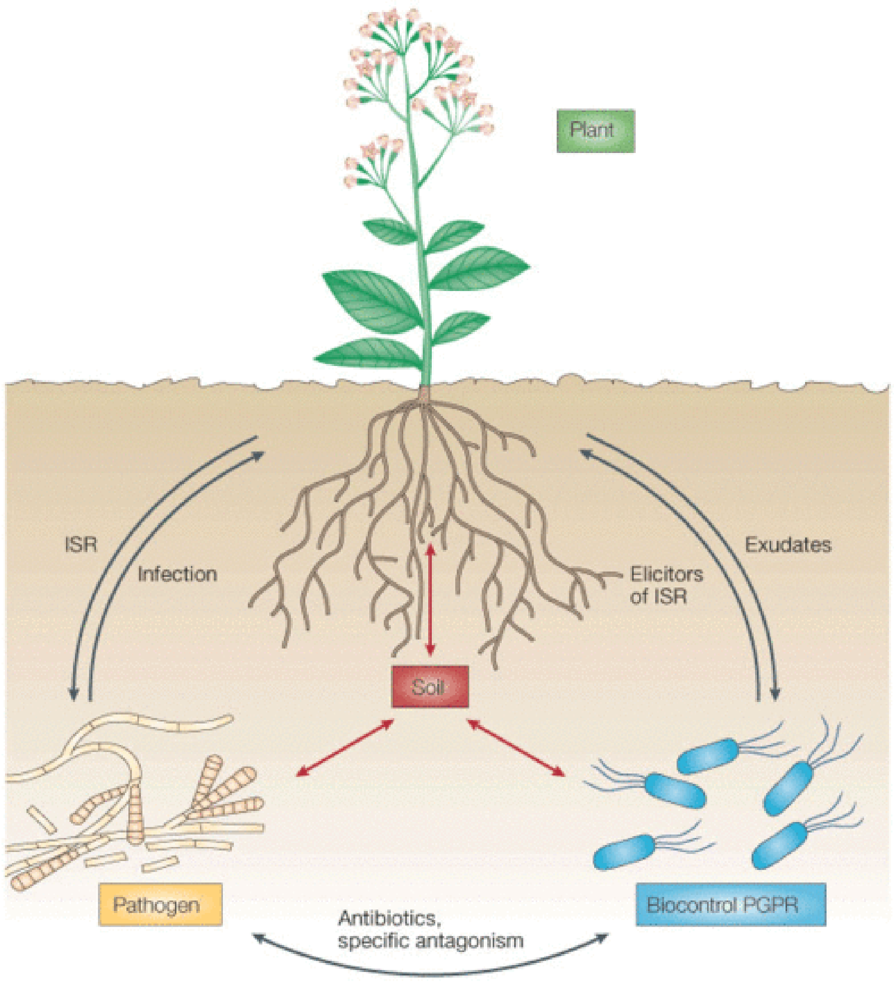


Brand name:*Gmax PGPR*

Product Details:

Technical:

Plant growth promoting bacteria - PGPB

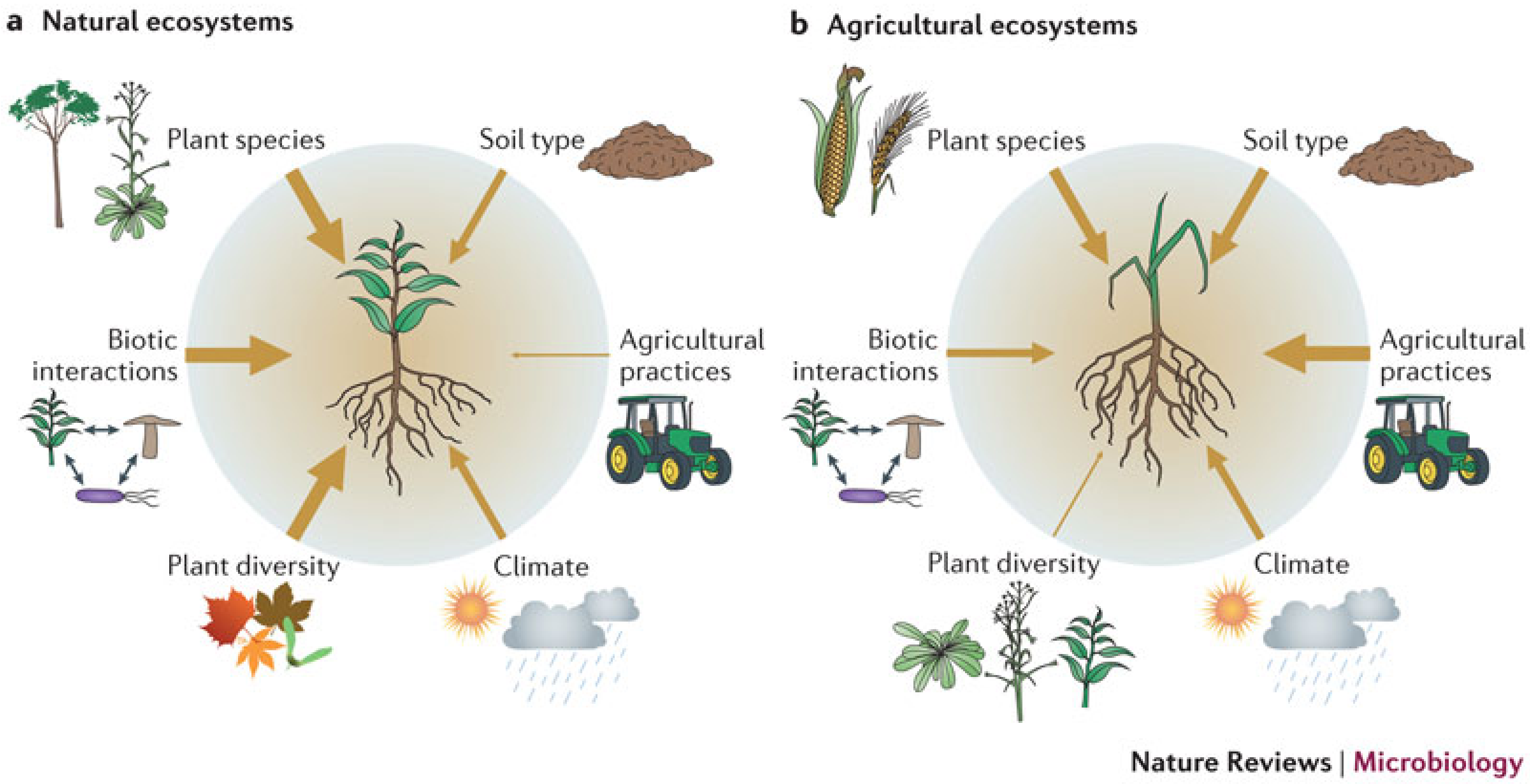


Nature Reviews | Microbiology

Plant growth promotion can work through:

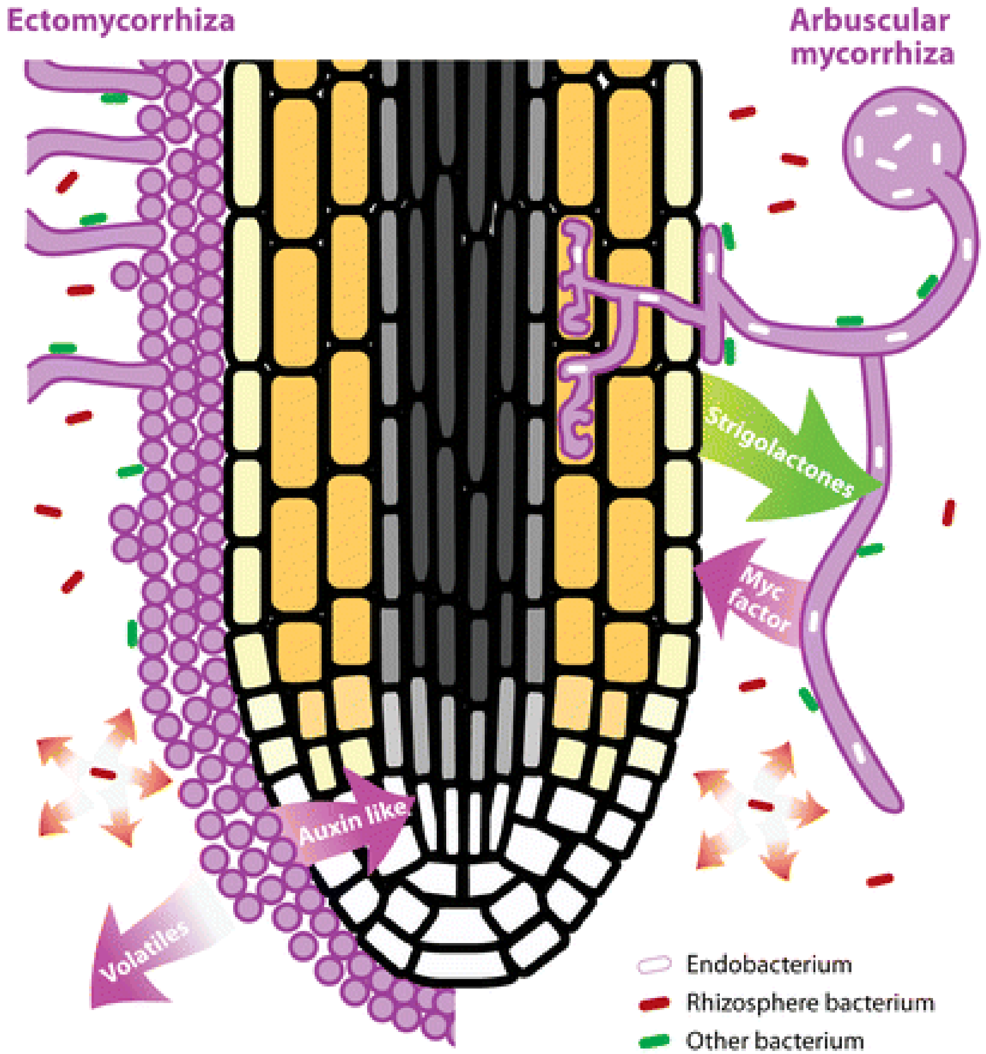
- Enhanced nutrient availability
- Suppressing pathogens in the soil, on the roots, or even in the plant, either through:
    - Release of antimicrobial compounds
    - Direct competition for nutrients
- Inducing systemic resistance (ISR)
- Inducing production of plant hormones that promote growth
- Nitrogen fixing symbiosis (root nodules)

Drivers of rhizosphere microbiota



Urban garden???

Philippot et al. 2013



Bonfante P, Anca I-A. 2009.
Annu. Rev. Microbiol. 63:363–83

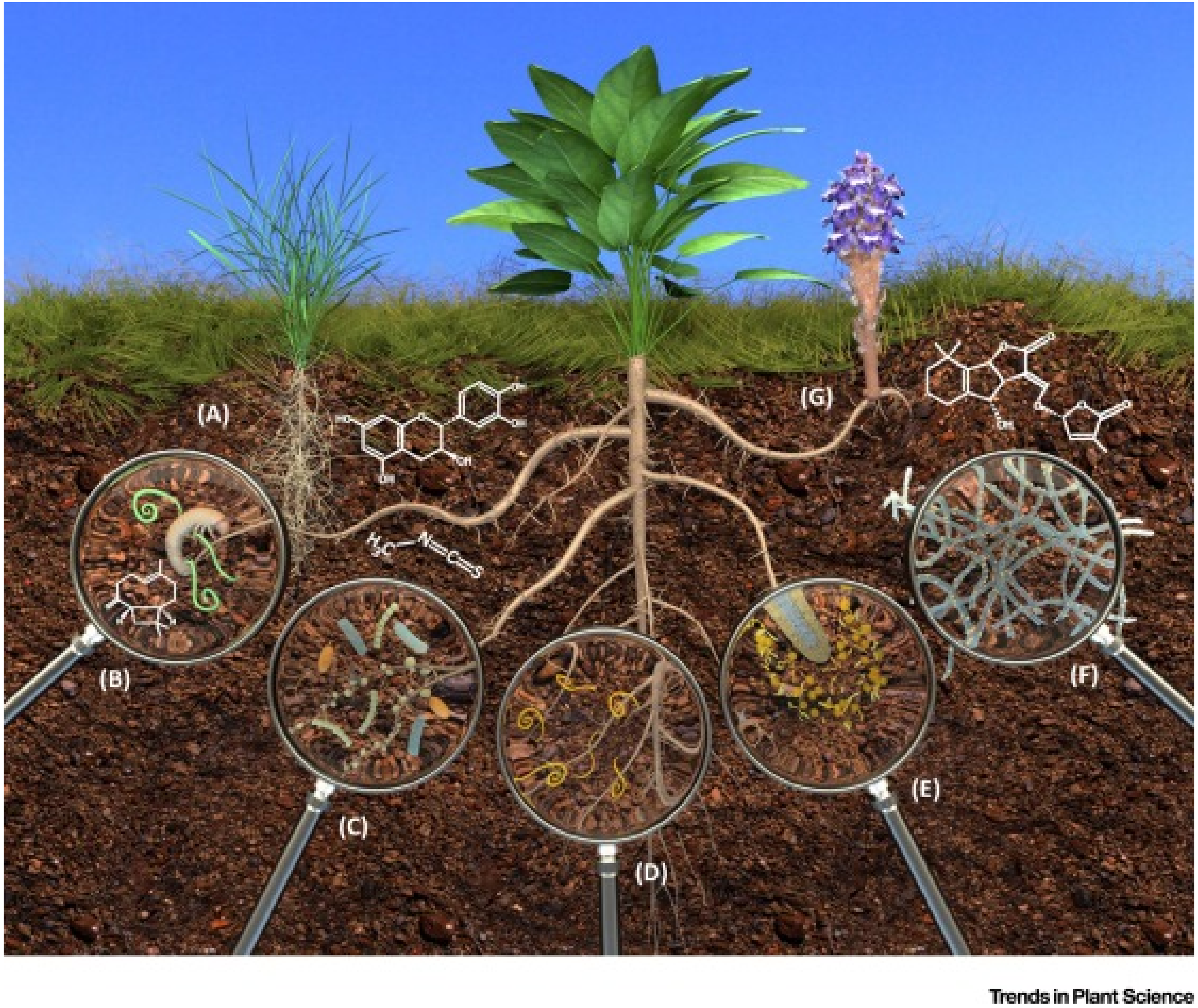
Role of the plant

Release exudates that promote a more conducive soil environment through:

- Providing C sources with a high N content
- Altering soil pH
- Engineering rhizosphere water content (sometimes even O_2)
- Emitting attracting signals (strigolactones)
- Providing C to beneficial funghi (mycorrhizae)

Best way to promote? Let the roots engineer the soil!

- Provide good root growth environment – provide organic matter, water holding capacity, macropores, moisture, oxygen
- Inoculate with native soil or soil from around thriving organisms
- Commercial product? – could work, but most likely dead. Expensive fertilizer. If alive – mixes may be antagonistic



Van Dam and
Bouwmeester, 2016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NOW WHEN I POUR MY COFFEE DREGS ON YOU, IT WILL LOOK LIKE WORK!
MUST... RUN...

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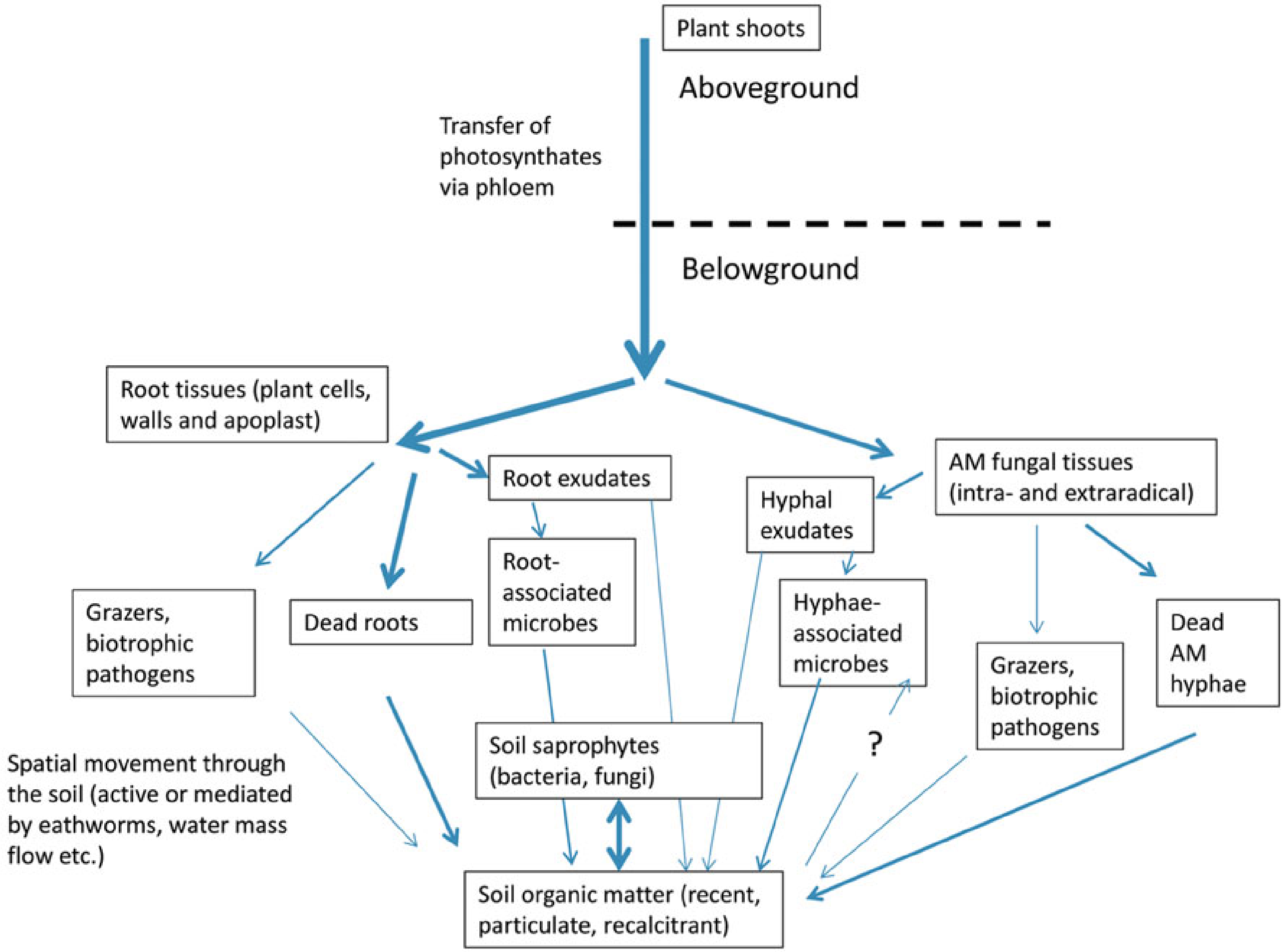
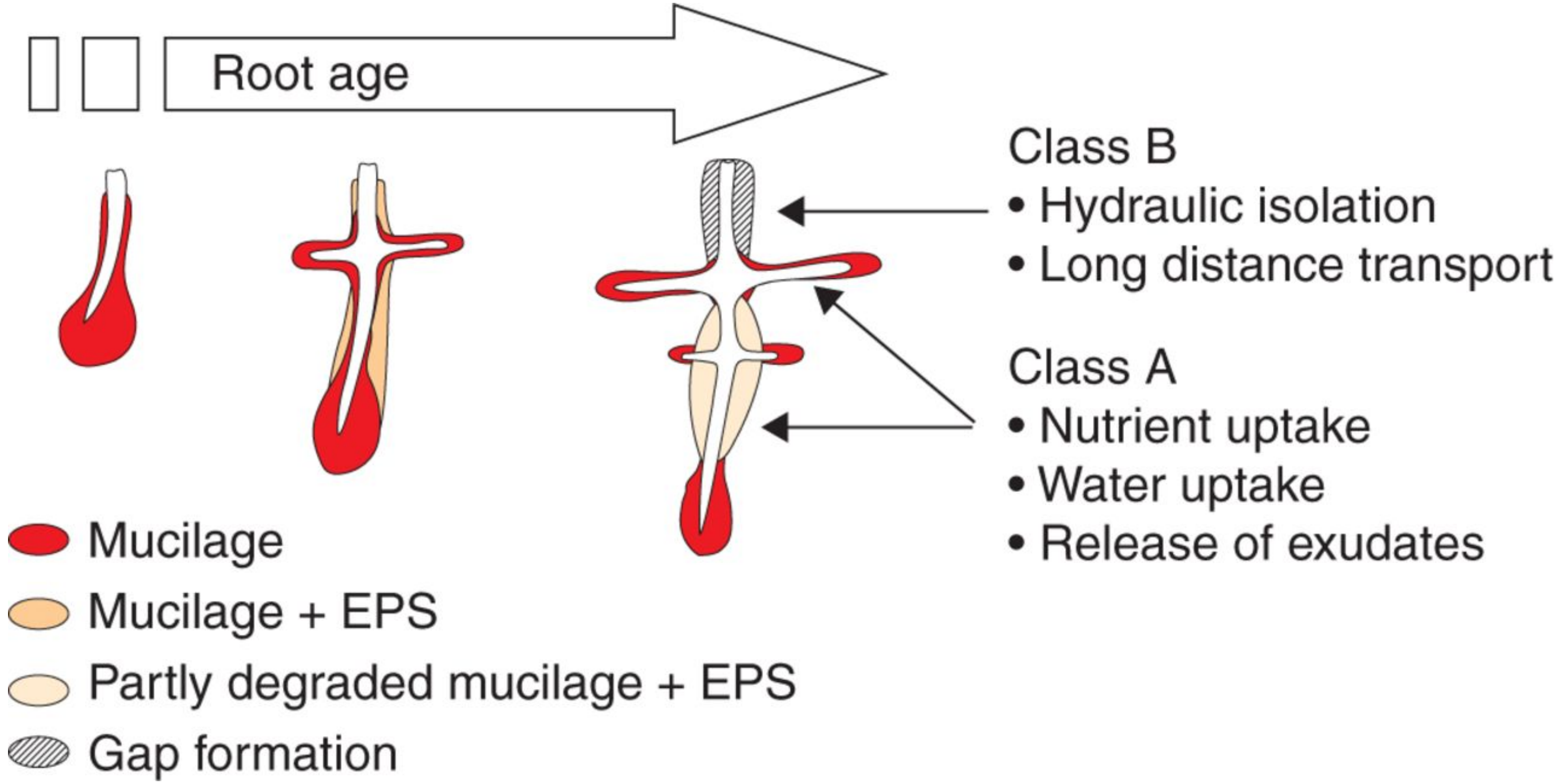
Belowground C allocation



Jansa et al. 2014

Diagram of the temporal and spatial development of roots and their rhizosphere from roots belonging to class A (having favourable properties for root water uptake) to roots belonging to class B (being hydraulically isolated from the surrounding soil).



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