Soil-plant-microorganism interactions in the rhizosphere - how do they affect nutrient uptake by plants?

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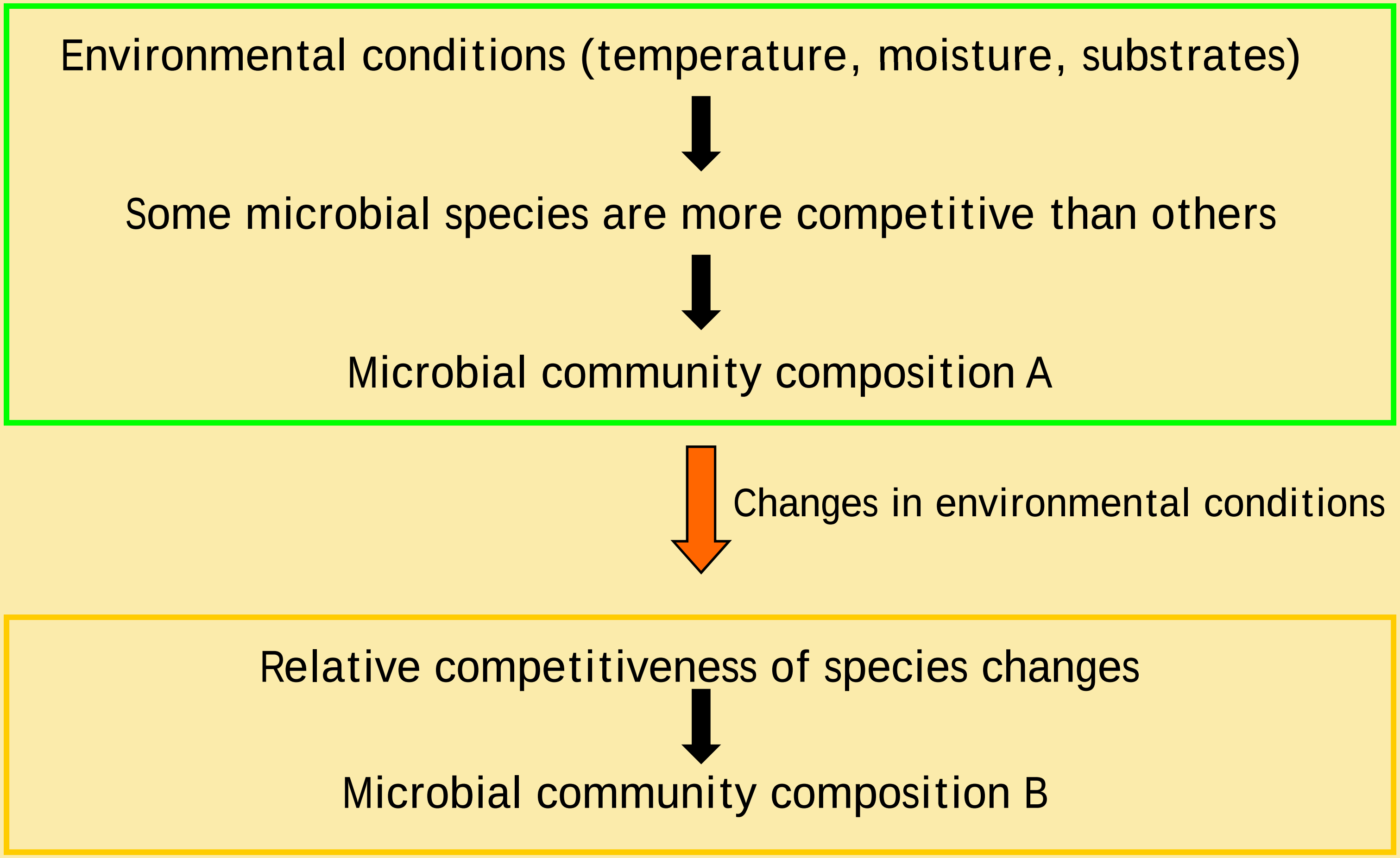
Soil microbial communities

- Total number of bacteria: 10^9 - 10^{10}/g soil
- Average number of bacterial genotypes: 3.8×10^6/g soil

- ➢ High number of genotypes → high diversity → strong competition
- ➢ The population density of a given genotype is not high
- ➢ Different species have different functions/capabilities/growth rates
- ➢ The function and importance of the vast majority of microorganisms in soil is unknown.
- ➢ Interactions among microorganisms are probably very important for functionality

Torsvik et al. 1990

Soil microbial communities



Environmental conditions (temperature, moisture, substrates)

Some microbial species are more competitive than others

Microbial community composition A

Changes in environmental conditions

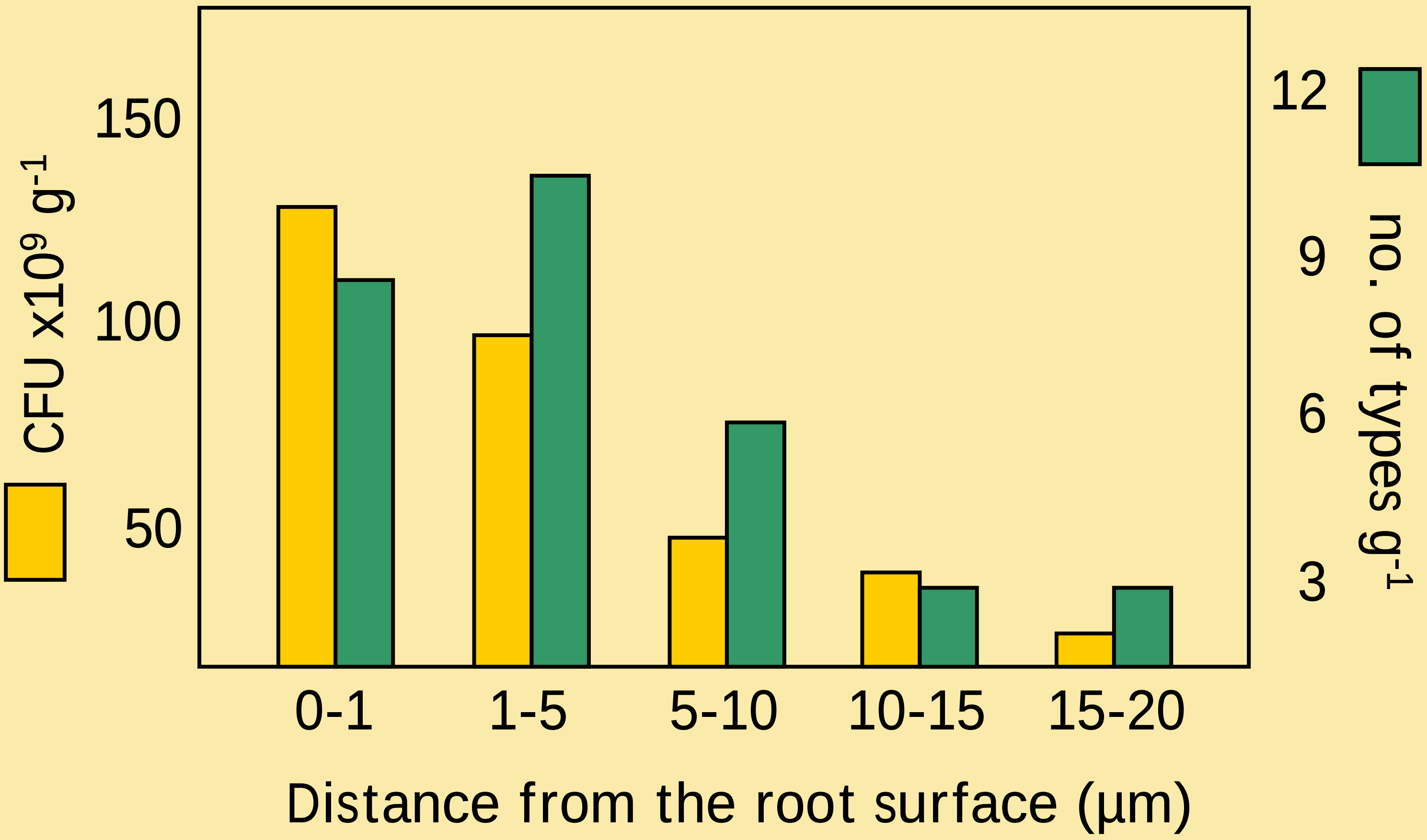
Relative competitiveness of species changes

Microbial community composition B

Soil microbial community composition is spatially and temporarily variable.

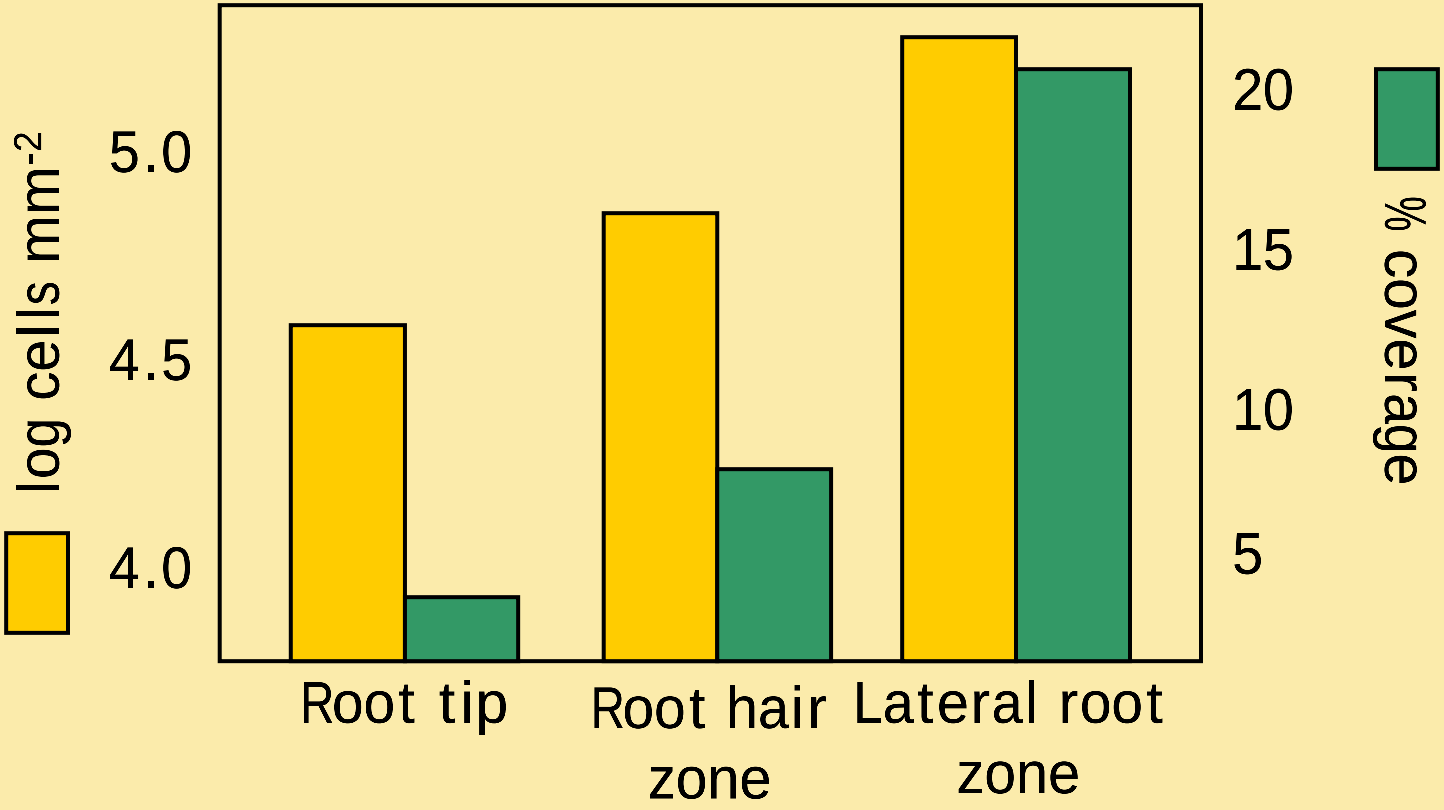
But changes in microbial community composition may or may not be associated with changes in function.

Microbial population density and number of types in the rhizosphere

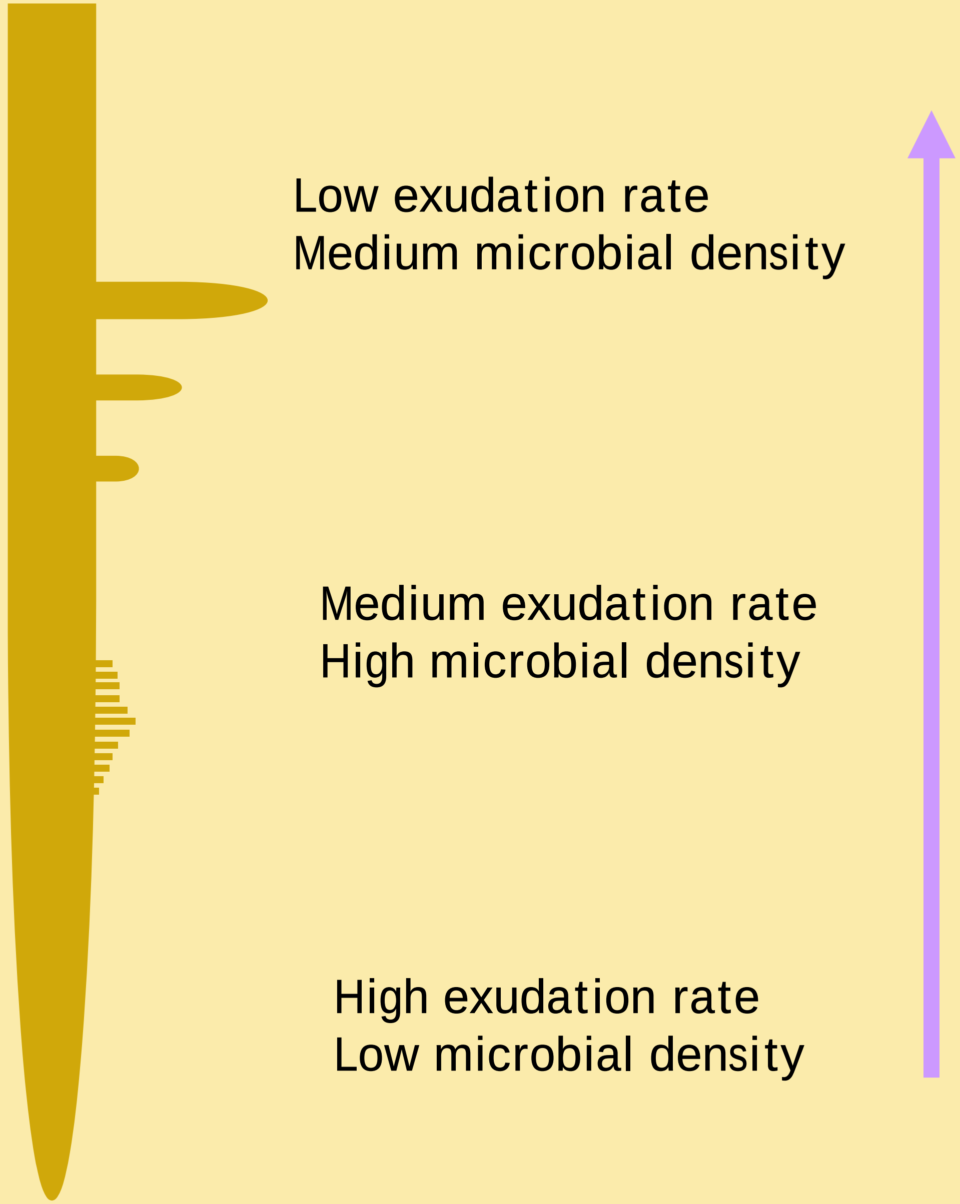


Foster 1986

Colonisation of the root surface in maize



Schönwitz and Ziegler 1989



Low exudation rate
Medium microbial density

Medium exudation rate
High microbial density

High exudation rate
Low microbial density

Changes in microbial community composition

Changes in function?

Soil-plant-microorganism interactions in the rhizosphere - how do they affect Fe and P uptake by plants?

Adaptation of microorganisms to low Fe availability

Fungi

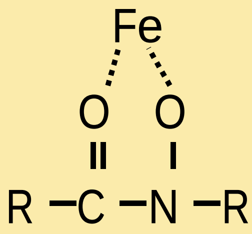
Bacteria

Production of siderophores

Solubilisation of Fe^{3+} by chelation
Diffusion to cell surface
Reduction of Fe^{3+} to Fe^{2+}
Uptake of Fe^{2+}

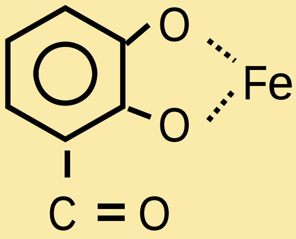
Microbial siderophores

Hydroxamates



Ferrichrome (*Penicillium*, *Aspergillus*)
Ferribactin
Pseudobactin } (*Pseudomonas*)
Pyoverdine
Ferrioxamine (*Streptomyces*)
Aerobactin (*E. coli*)

Catecholes



Enterobactin
Agrobactin (*A. tumefaciens*)
Pyocheline (*P. aeruginosa*)

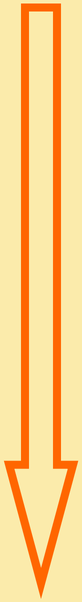
Others

Organic acids
Amino acids

Neilands 1984 a,b

Stability constants (K) of different chelators with Fe^{3+}

Chelate	Apparent stability constant
Mugeneic acid (phytosiderophore)	19.1
Rhizoferrin (fungal siderophore)	19.7
EDTA (ethylene diamine tetra acetic acid)	22.2
Ferrioxamine B (bacterial siderophore)	25.1



Strength of Fe binding (affinity)

Yehuda et al. (2000)

Effect of bacterial siderophore on Fe uptake of axenic maize

	Fe uptake nmol/g root dw
Ferrioxamine B	1.5
Phytosiderophore	81.2

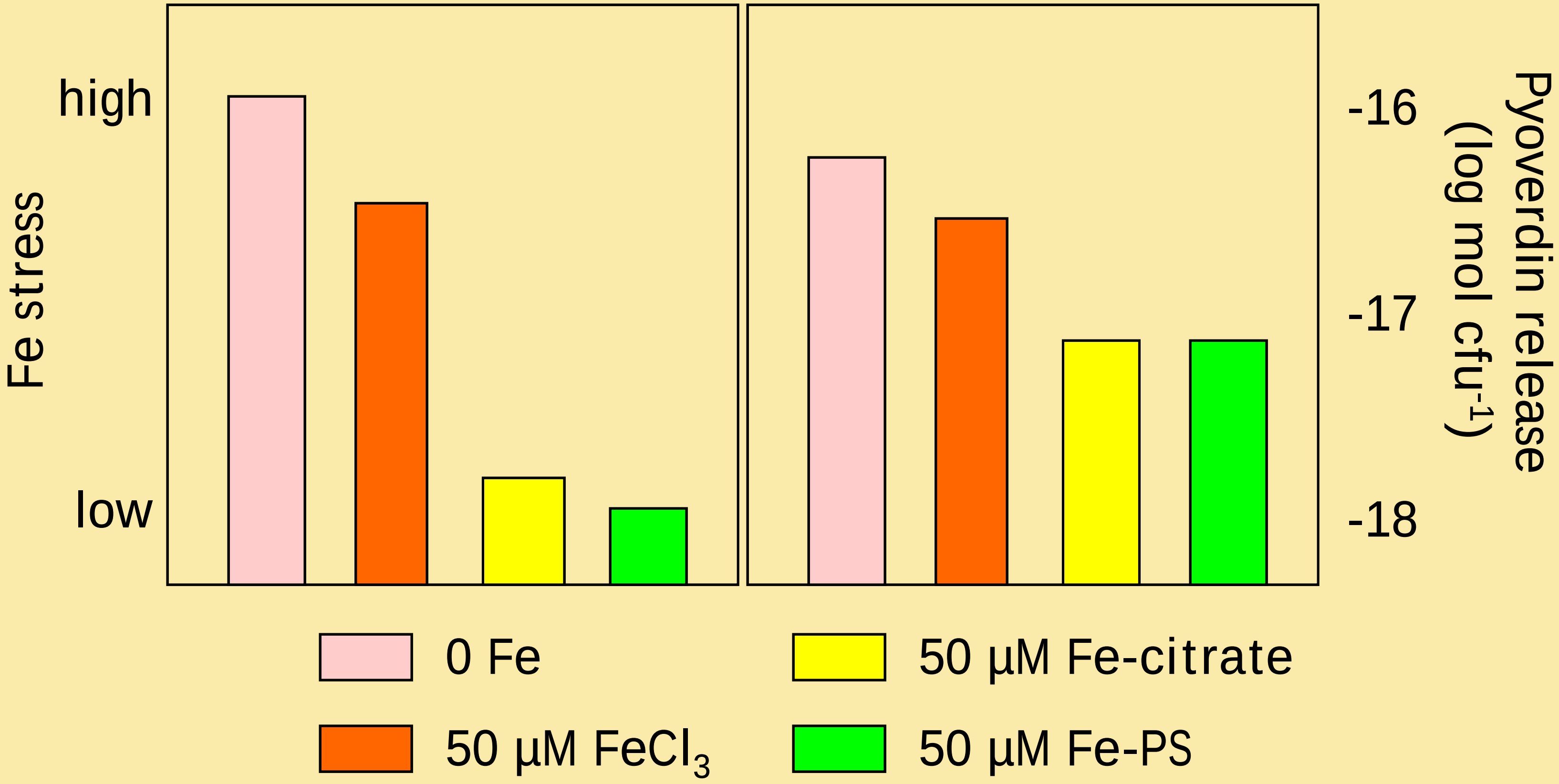
Crowley et al. 1992

Effect of microorganisms on the recovery of phytosiderophores from barley and sorghum

	Apparent phytosiderophore release nmol (pl. 5 h)$^{-1}$		
	sterile	unsterile	% of sterile
Barley	5000	3500	70
Sorghum	950	10	1

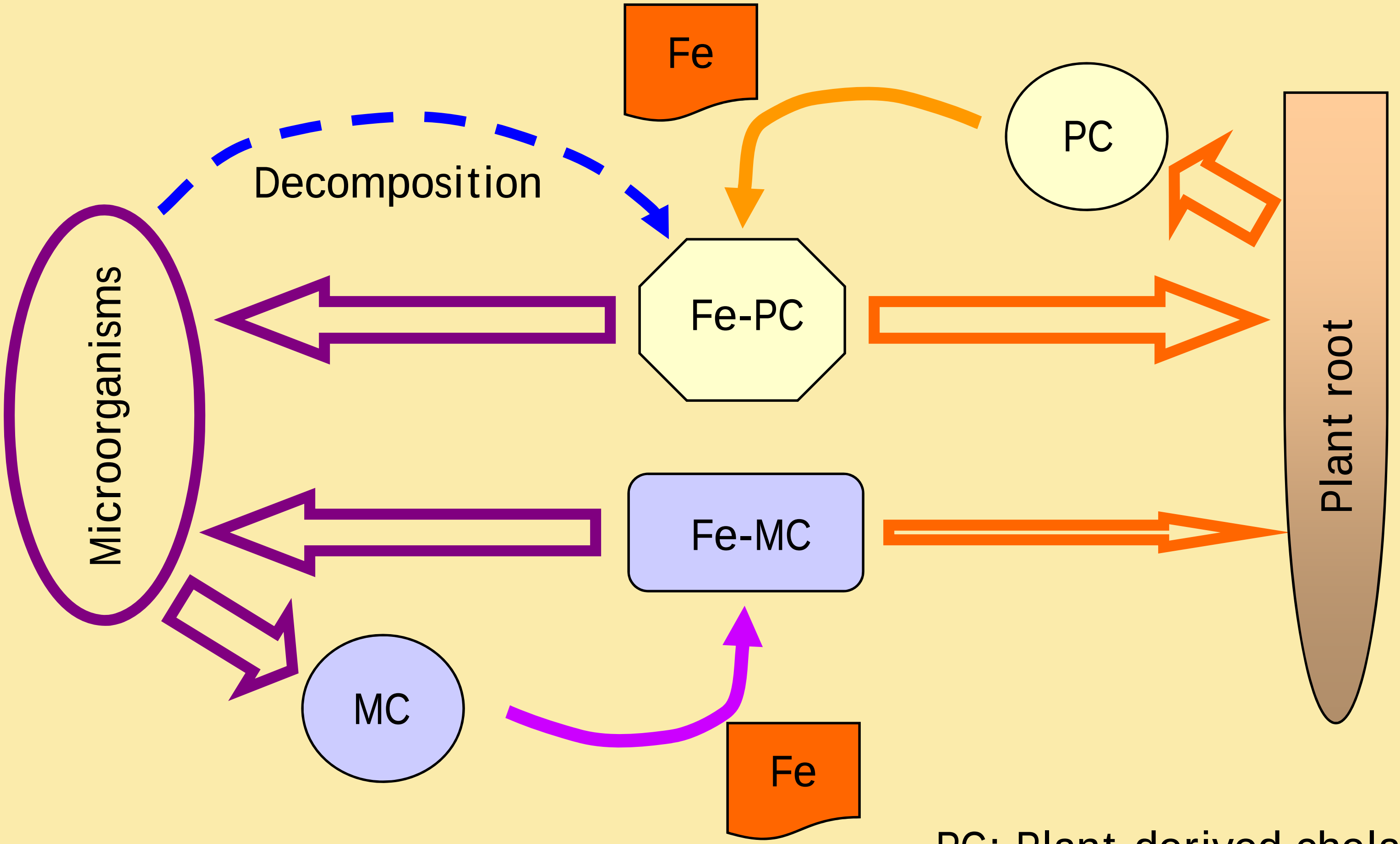
Von Wirén et al. 1995

Effect of Fe chelators on Fe stress and siderophore production of *P. fluorescens* Pf 5



Marschner and Crowley 1998

Competition or help?



Fe

Decomposition

PC

Microorganisms

Fe-PC

Plant root

Fe-MC

MC

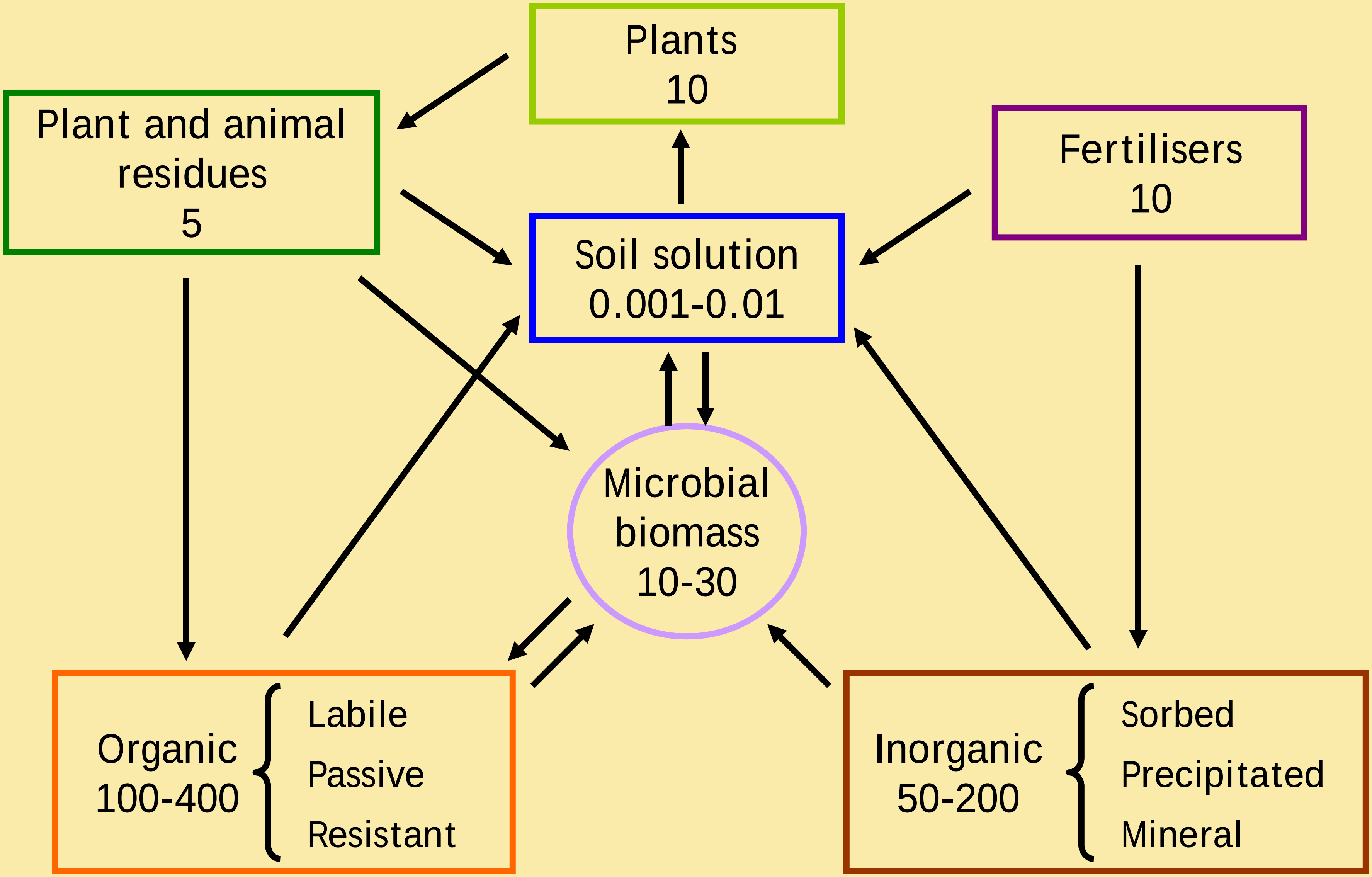
Fe

PC: Plant-derived chelator

MC: microbe-derived chelator

P fractions in soil

kg P ha^{-1} (0-10 cm)



Plants
10

Plant and animal residues
5

Fertilisers
10

Soil solution
0.001-0.01

Microbial biomass
10-30

Organic
100-400

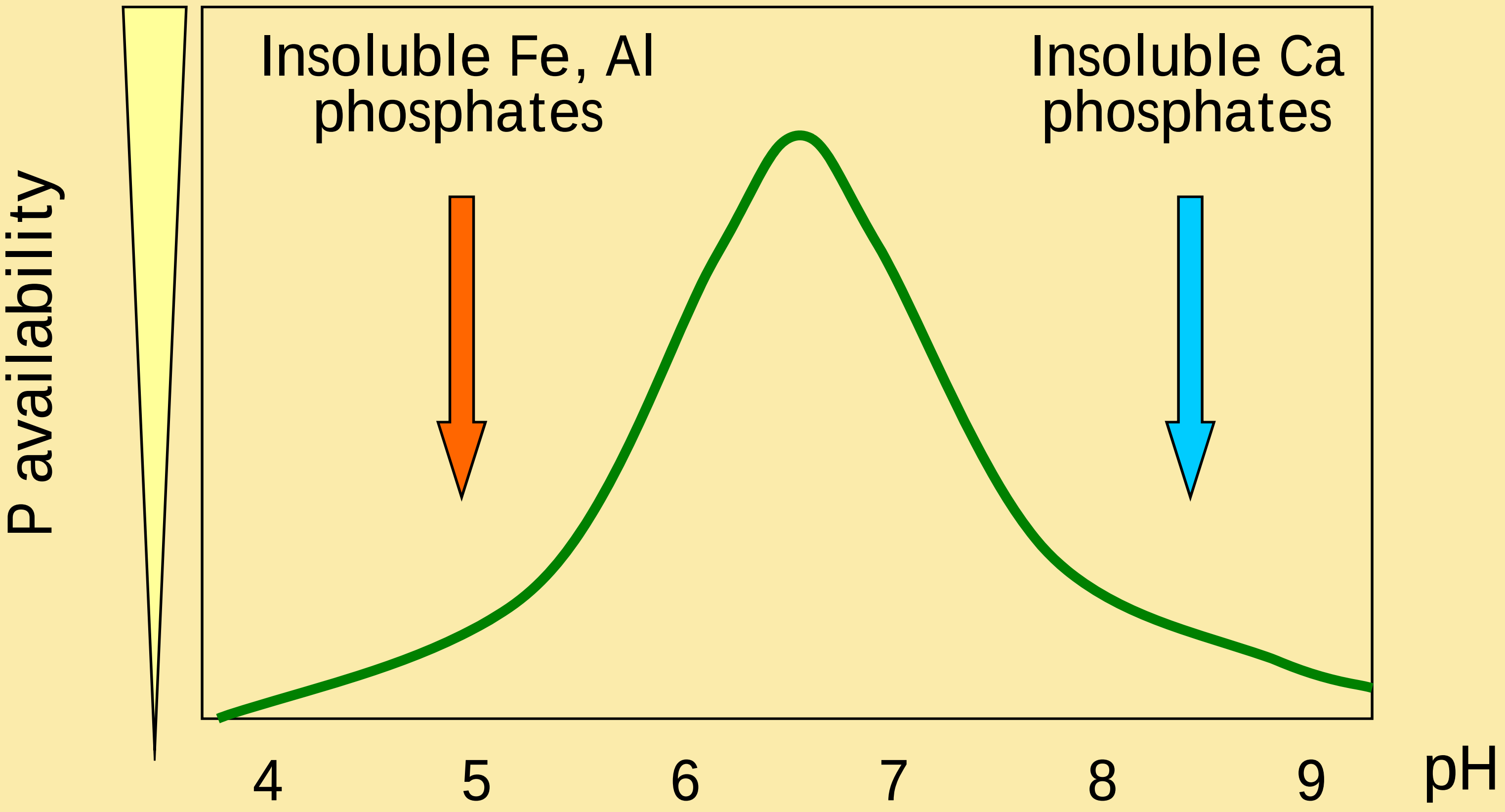
- Labile
- Passive
- Resistant

Inorganic
50-200

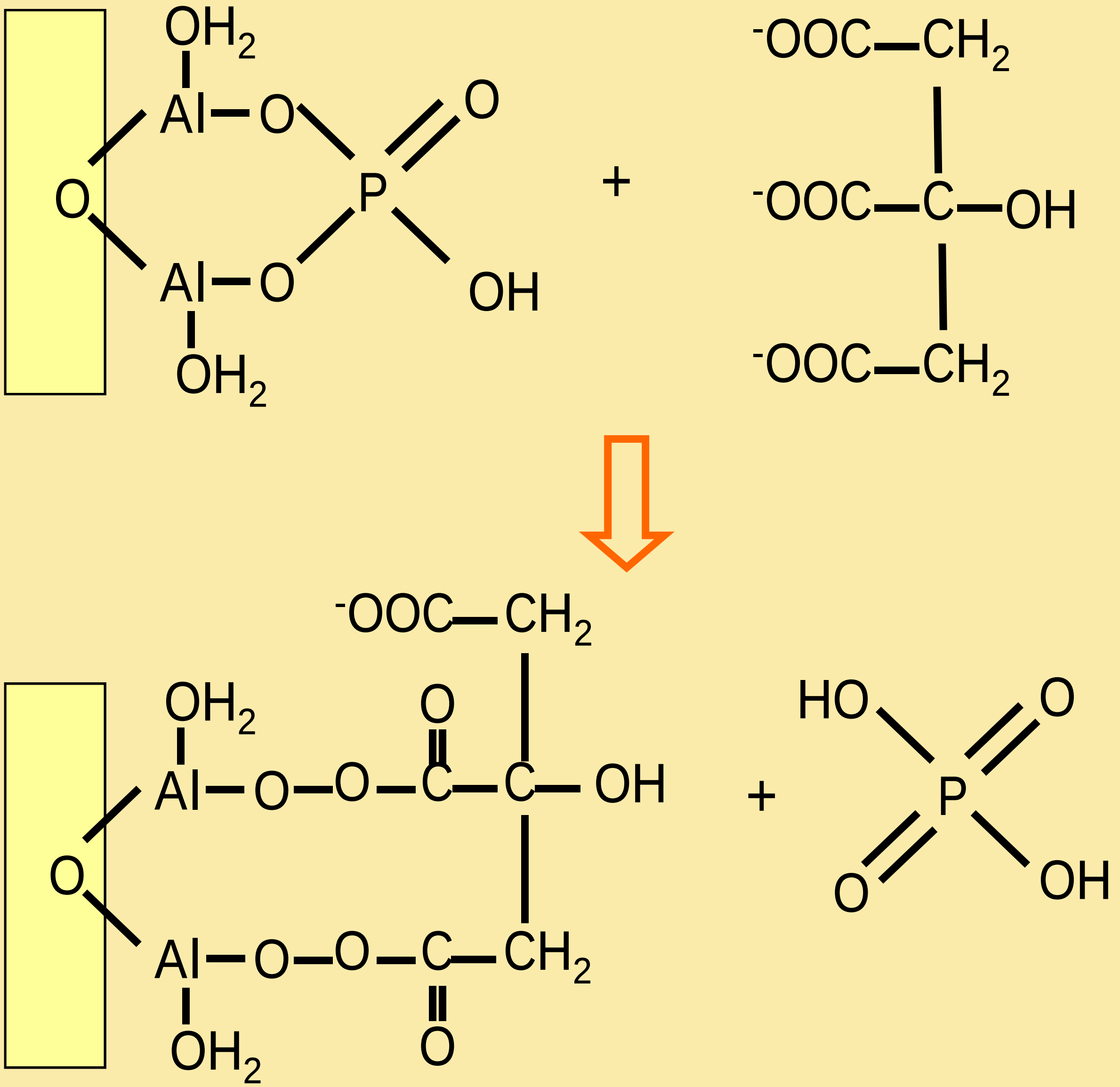
- Sorbed
- Precipitated
- Mineral

Richardson 1994

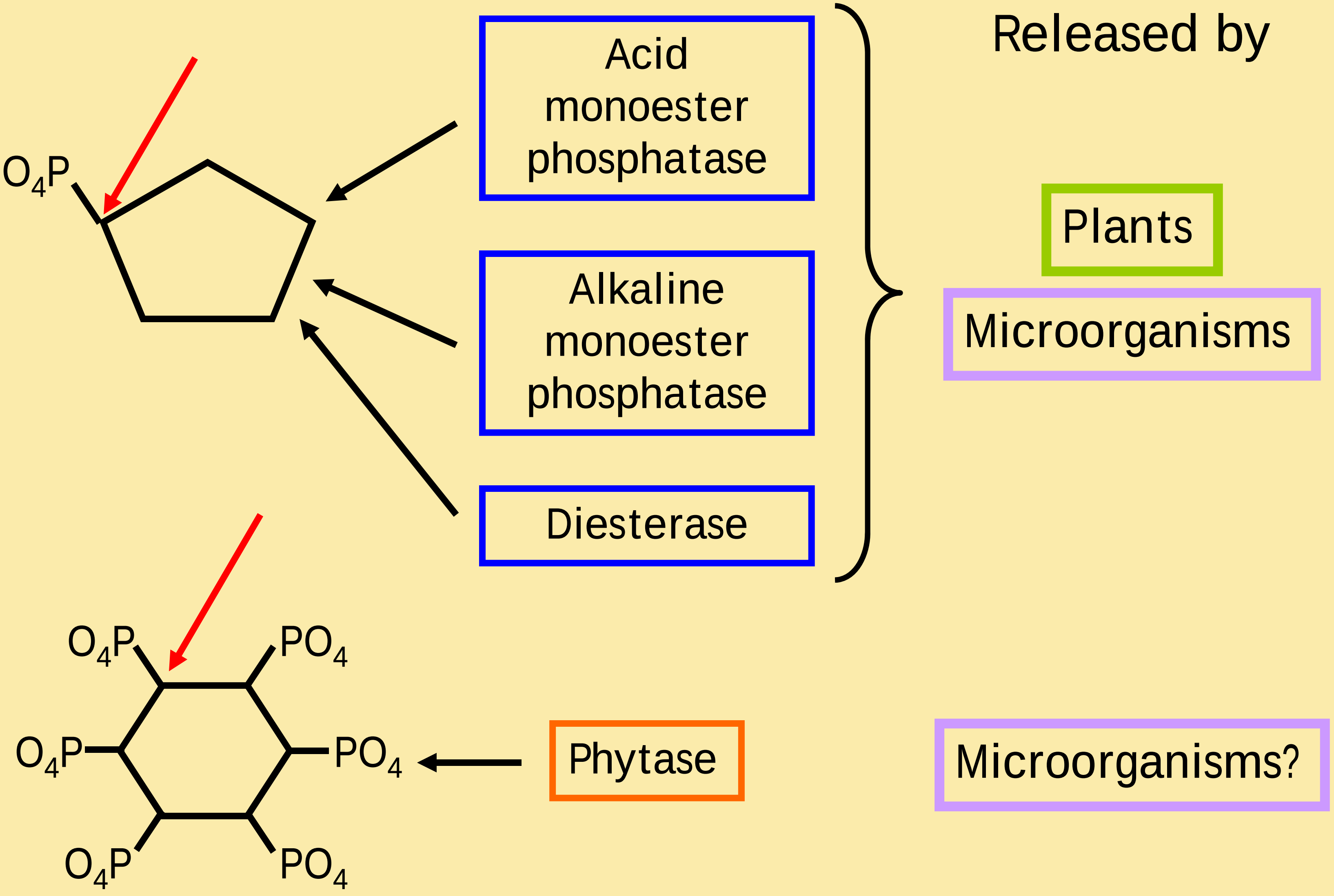
Solubilisation of inorganic P - changes in pH



Solubilisation of inorganic P – organic acid anions



Mineralisation of organic P



Acid monoester phosphatase

Alkaline monoester phosphatase

Diesterase

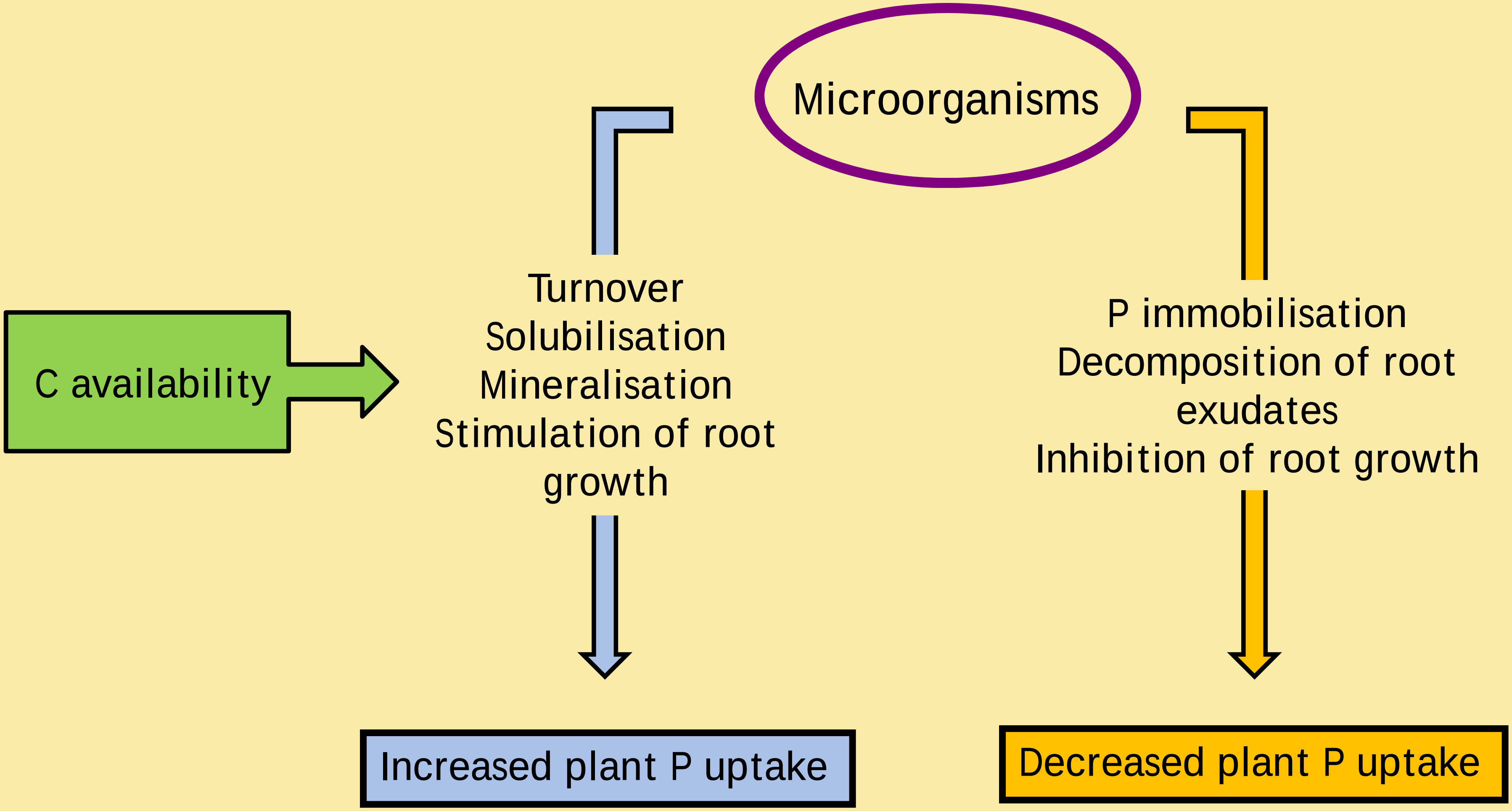
Released by

Plants

Microorganisms

Phytase

Microorganisms?



Microorganisms

C availability

Turnover
Solubilisation
Mineralisation
Stimulation of root growth

Increased plant P uptake

P immobilisation
Decomposition of root exudates
Inhibition of root growth

Decreased plant P uptake

Increasing P uptake

Solubilisation of Ca and Al-phosphate in vitro

	µg P solubilised/15 mg insoluble P	
	CaP	AlP
Bacillus sp.	27	8
Streptomyces sp.	14	0
Penicillium sp.	166	71
Aspergillus sp.	107	16

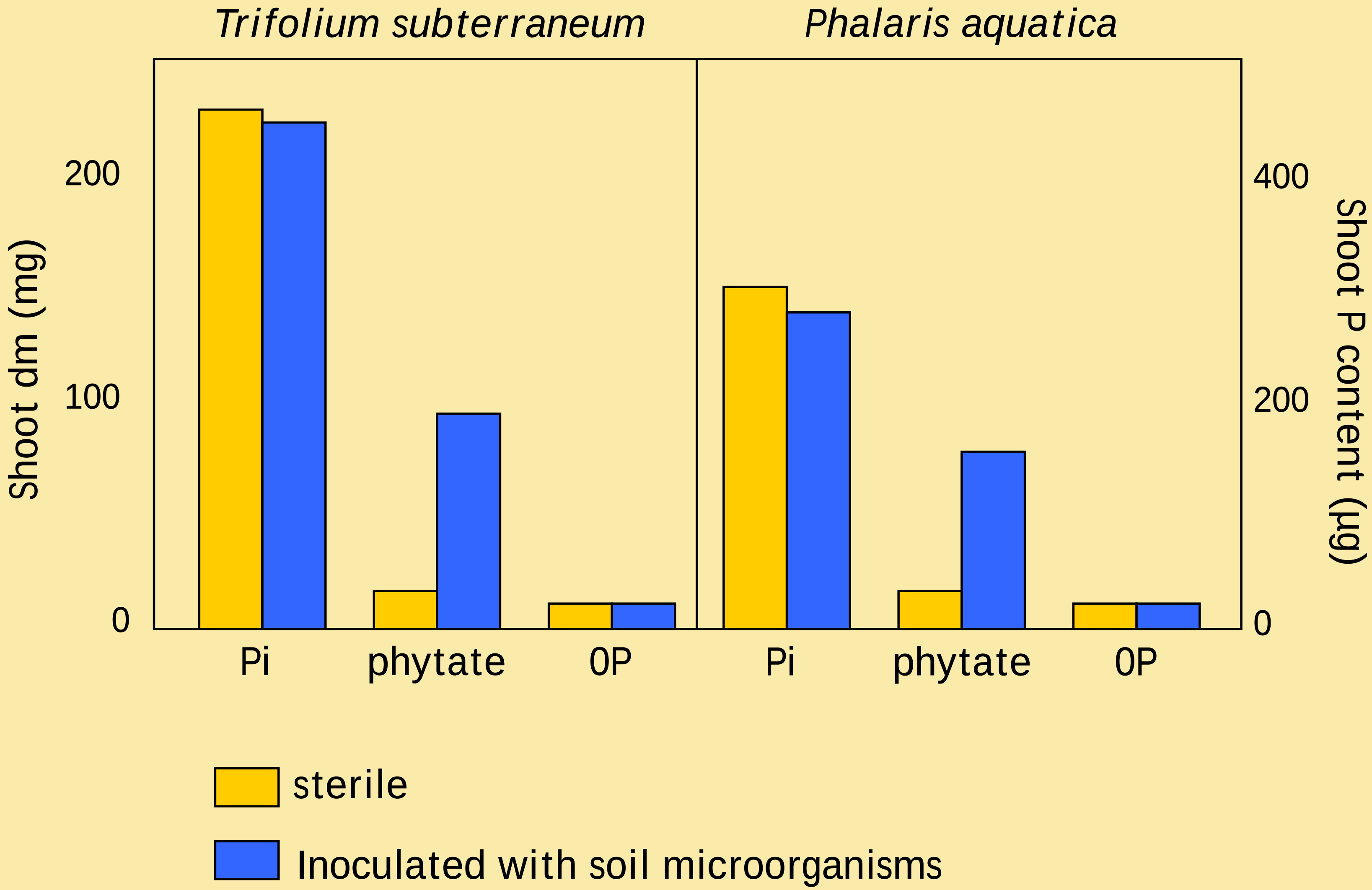
Banik and Dey 1983

Examples of microbial genera shown to solubilise P or produce phytase

P solubilisers	
Bradyrhizobium, *Rhizobium*	Antoun *et al.*, 1998
Gordonia	Hoberg *et al.*, 2005
Enterobacter	Kim et al., 1997
Rahella	Kim et al., 1997
Panthoea	Deubel *et al.*, 2000
Pseudomonas	Deubel et al. 2000; Hoberg et al. 2005
Aspergillus,Penicillium, Trichoderma	Barthakur 1978

Phytase producers	
Pseudomonas	Richardson and Hadobas 1997
Aspergillus, Emmericella, Penicillum	Yadav and Tarafdar 2003
Telephora,Suillus(ectomycorrhizal fungi)	Colpaert *et al.*, 1997
Peniophora	George et al., 2007

Growth and P uptake of *Trifolium* and *Phalaris* with inorganic P or phytate



Richardson et al. 2001

Azospirillum brasilense and root growth of wheat

	Shoot fw	Root length	Lateral roots	Root hair	
				density	length
	(g/plant)	(m/plant)	(no./plant)	(no./mm)	(mm)
Uninoculated	0.75	0.3	5	0.75	1.2
Inoculated	1.0	0.4	20	1.0	1.8

Martin et al. 1989

Mycorrhiza

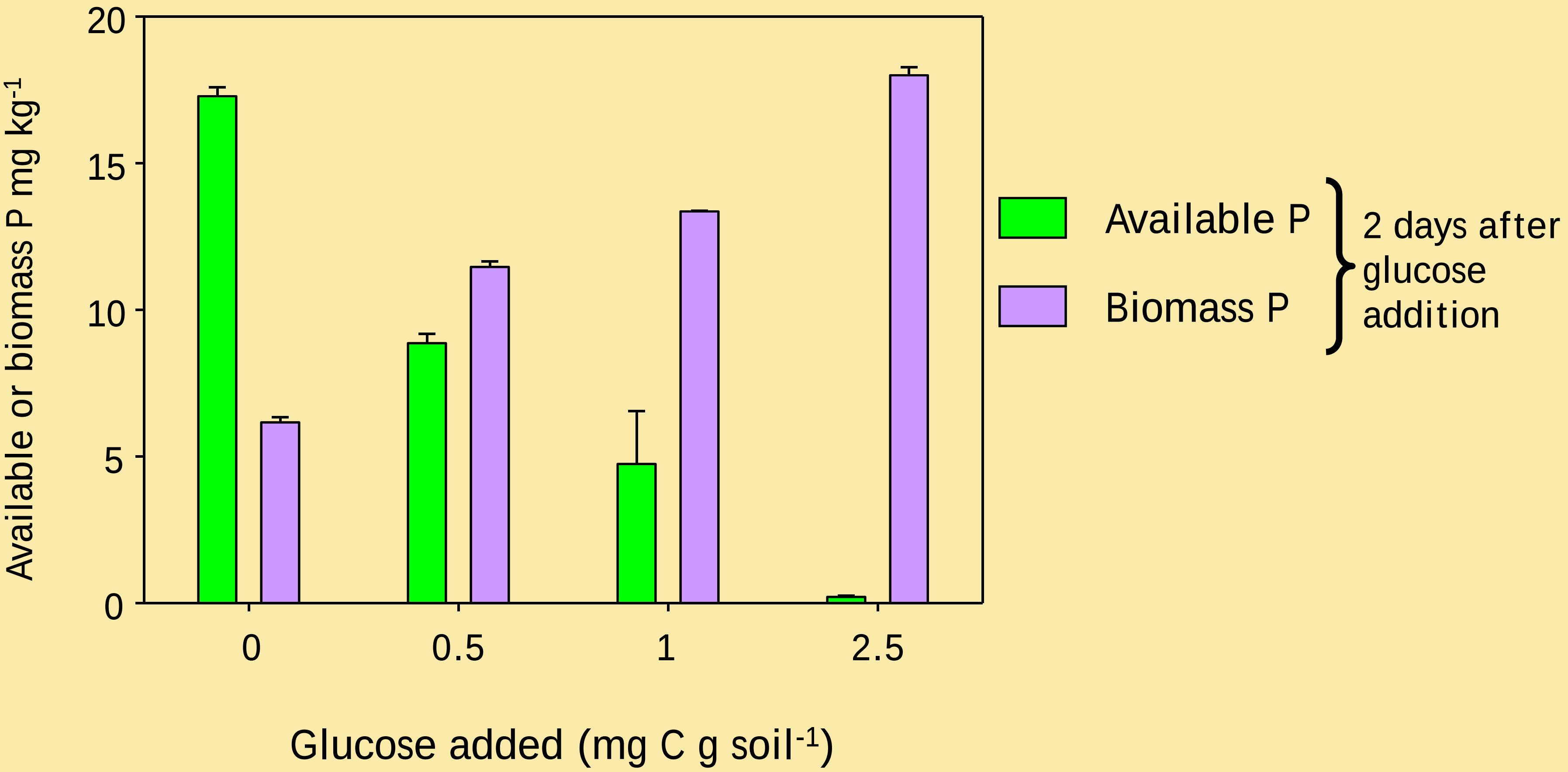
Solubilisation
Mineralisation
Stimulation of root growth
Increasing soil volume exploited (mycorrhiza)

↓

Increased plant P uptake

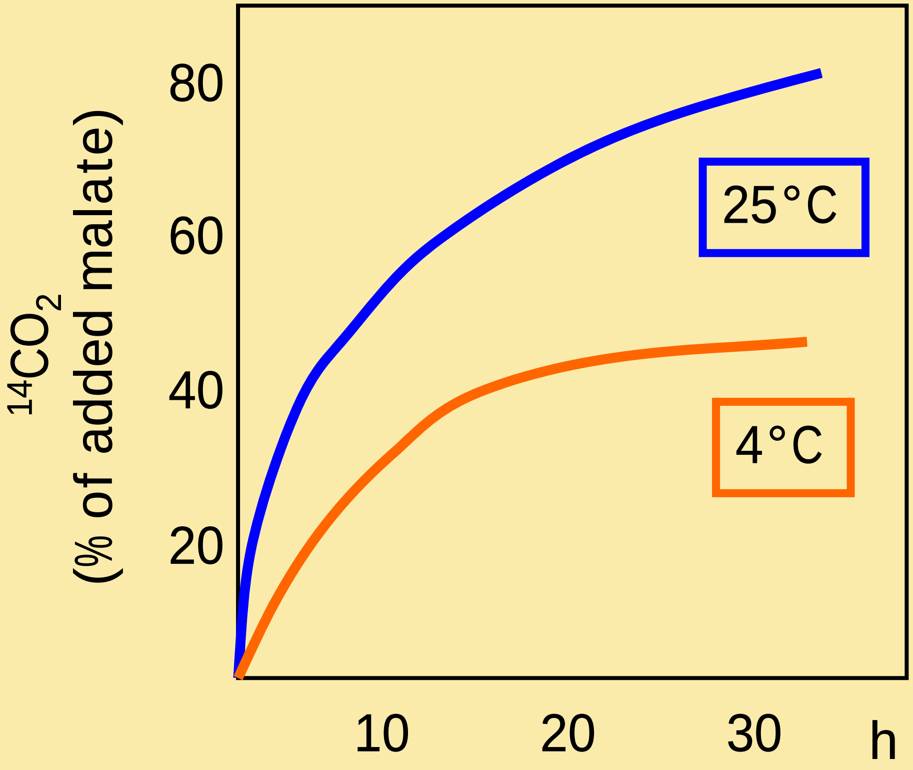
Decreasing P uptake

P immobilisation in the microbial biomass



Schmidt unpublished

Organic acid decomposition in soil



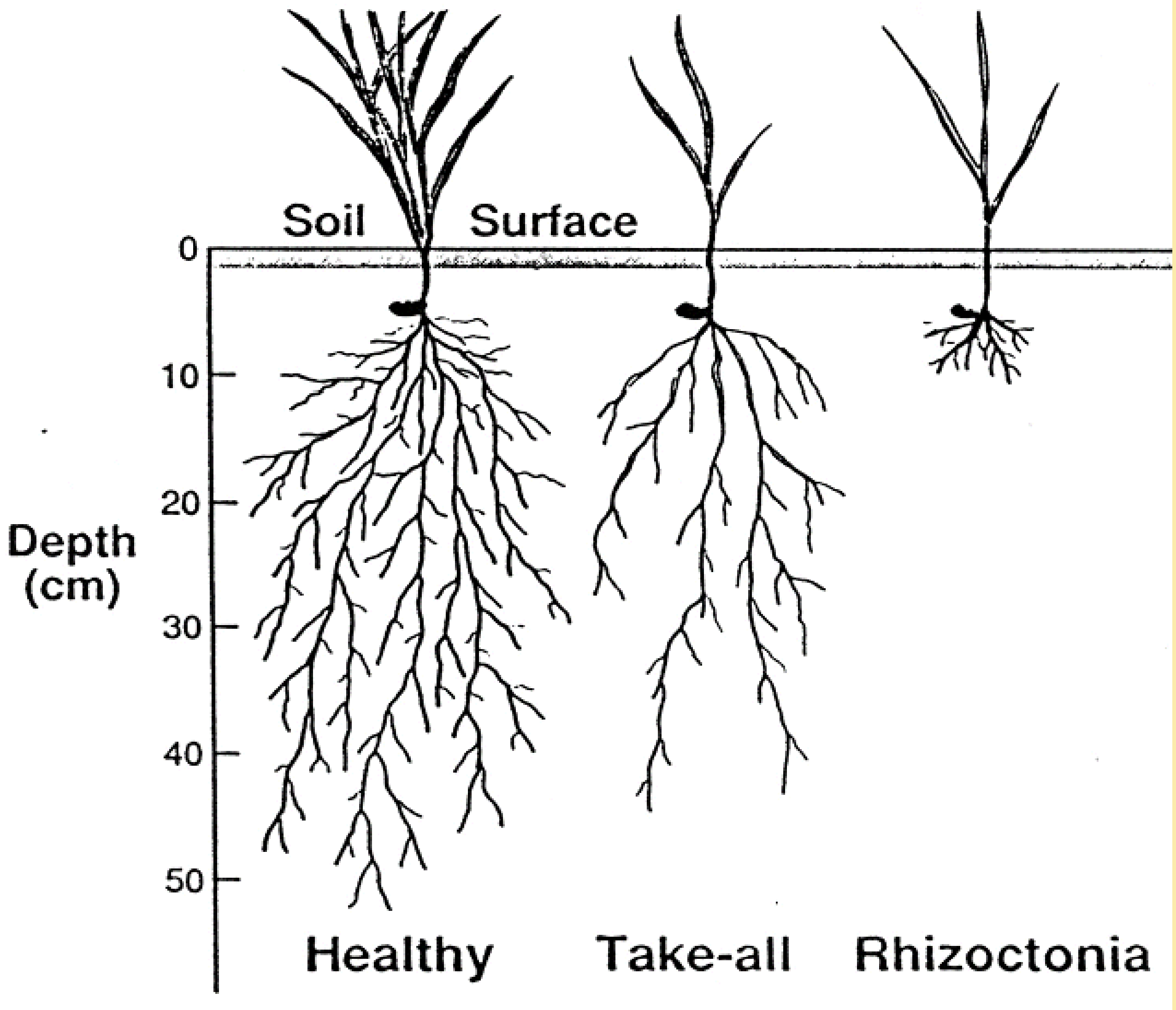
Half life of organic acids

Top soil 1-5 h

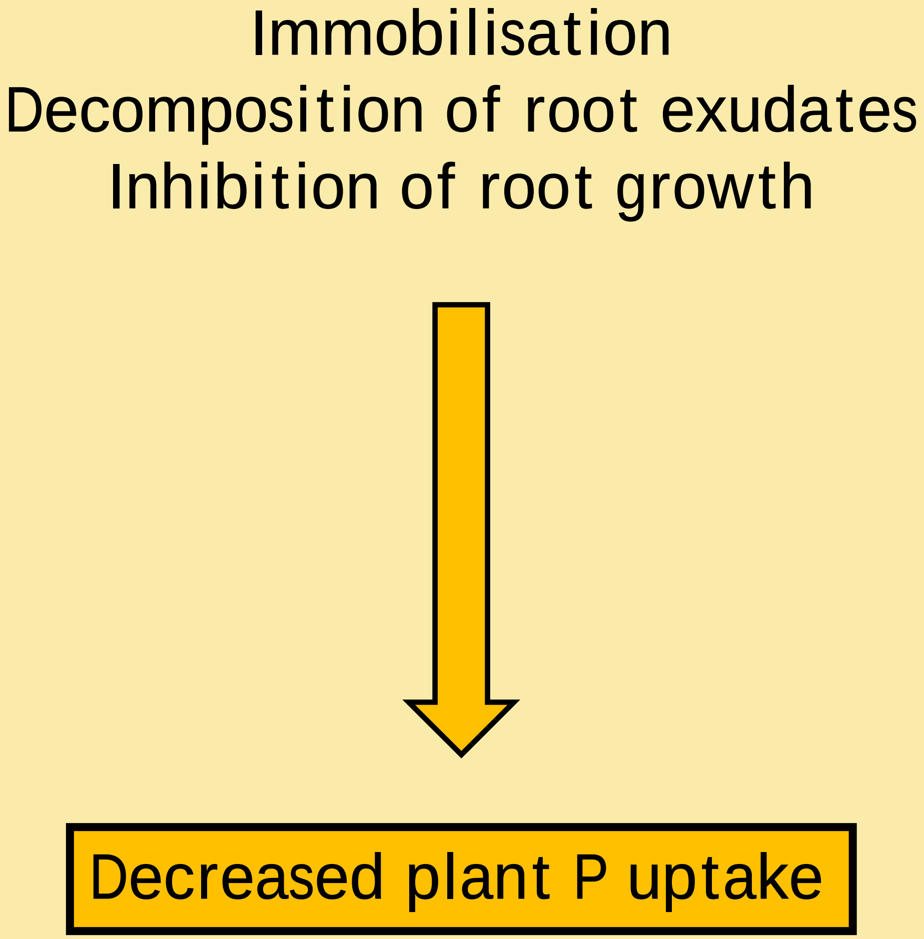
Subsoil 5-12 h

Jones et al. 1996
Jones 1998
Jones 1999

Root diseases and root growth



CSIRO Land and Water



Immobilisation
Decomposition of root exudates
Inhibition of root growth

Decreased plant P uptake

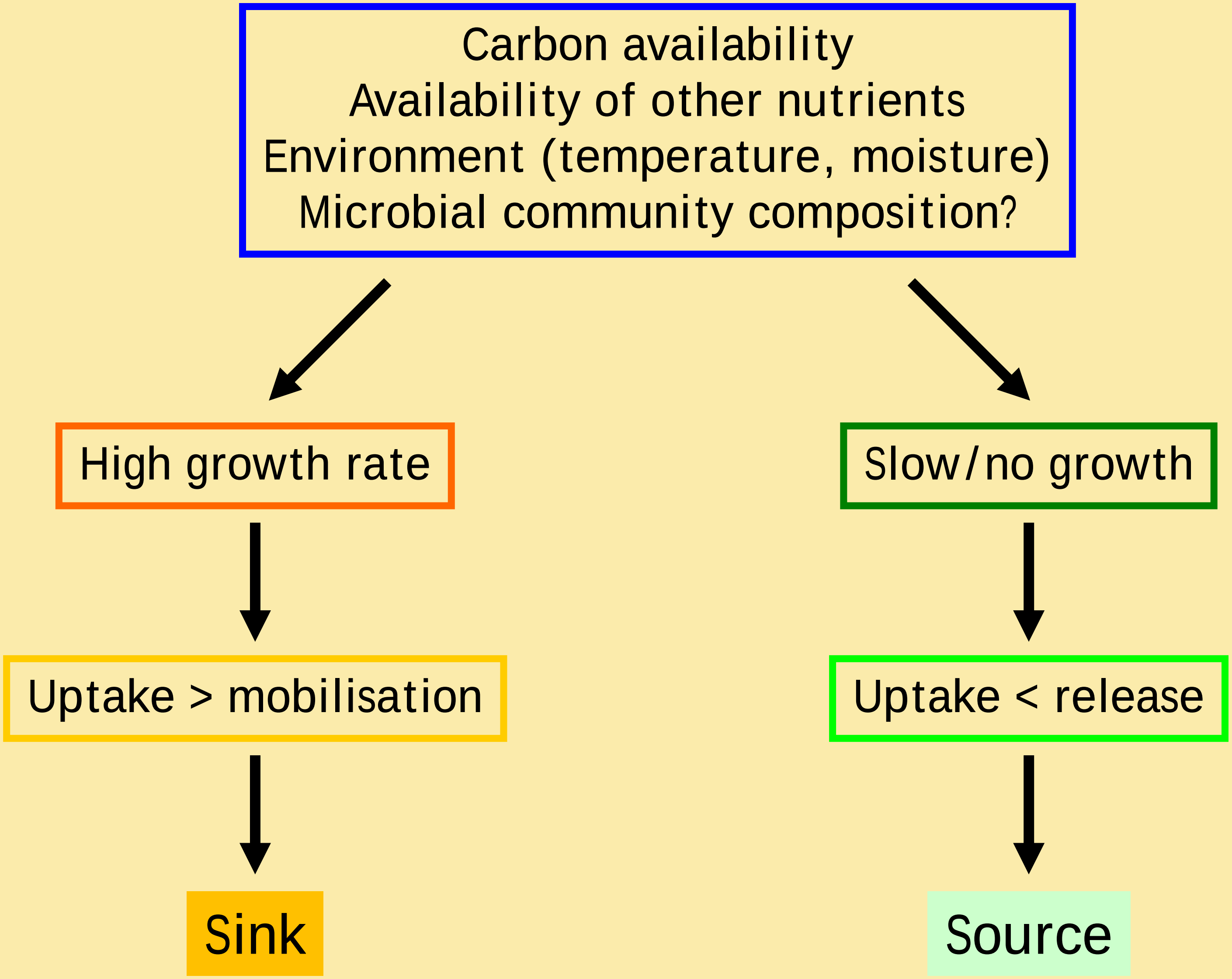
The role of microbial biomass P

Correlations with shoot P content

		TRL	Available P	MBP	Phosph
6 leaf	Poaceae	0.85	0.77	0.97	0.81
	Brassicas	0.79	0.88	0.45	0.46
Till/flow	Poaceae	0.67	0.96	0.78	0.73
	Brassicas	0.47	0.75	ns	0.48
Maturity	Poaceae	0.96	0.70	0.85	ns
	Brassicas	0.48	0.89	ns	ns

Marschner et al. 2006, 2007

How can the biomass be source and sink for P?



Carbon availability
Availability of other nutrients
Environment (temperature, moisture)
Microbial community composition?

High growth rate

Uptake > mobilisation

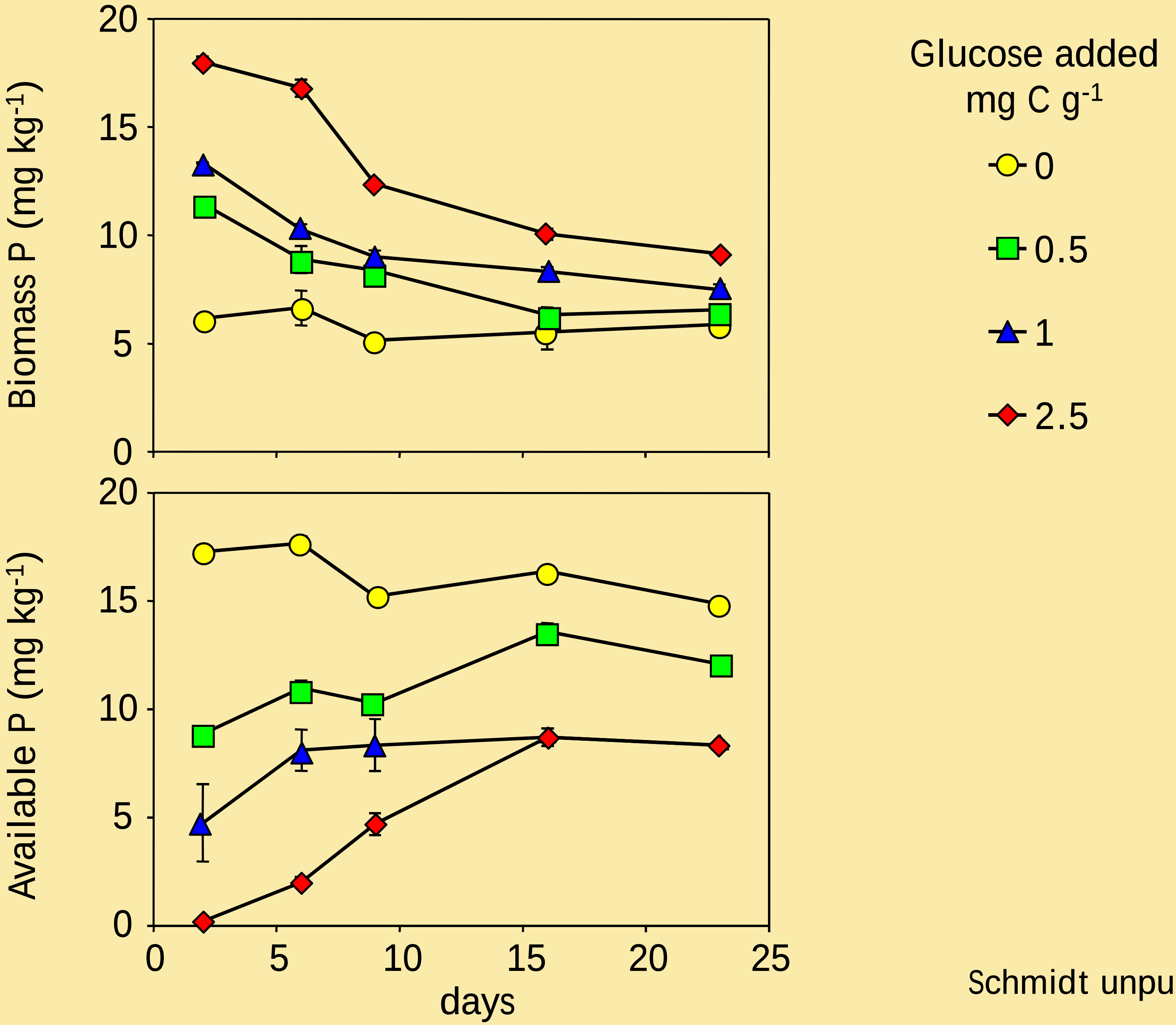
Sink

Slow/no growth

Uptake < release

Source

Temporal changes in microbial and available P



Schmidt unpublished

Hypothetical dynamics of biomass P in the rhizosphere

Low exudation rate

- Microbial growth < death rate

→ Net P mobilisation

Medium exudation rate

- Microbial growth = death rate

→ P immobilisation
= P mobilisation

High exudation rate

- Microbial growth > death rate

→ Net P immobilisation

Conclusions

- Rhizosphere microorganisms can increase or decrease Fe and P availability to plants.
- Their effect strongly depends on C (and N) availability and environmental factors affecting the growth rate (moisture, temperature) → likely to vary along the root axis.
- Their effect may also vary with plant genotype.
- Due to the wide-spread capacity among microorganisms to mobilise Fe and solubilise and/or mineralise poorly available P, the composition of the rhizosphere microbial community is probably less important than its activity.

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