Phosphorus bioavailability – Nothing but a rhizosphere story

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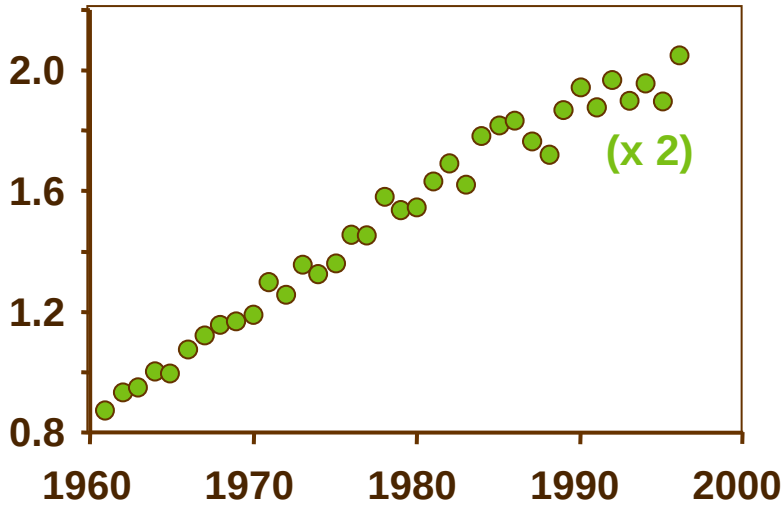
Many thanks to the organizers

for the kind invitation and support

Cereal production
per year
(10^{15} g World – USSR)



→ **Green revolution**

→ **Considerable increase in N and P use**

Global cereal production and fertiliser consumption over past 40 yrs

(Tilman, Cassman, Matson, Naylor & Polasky 2002 *– Nature 418)*

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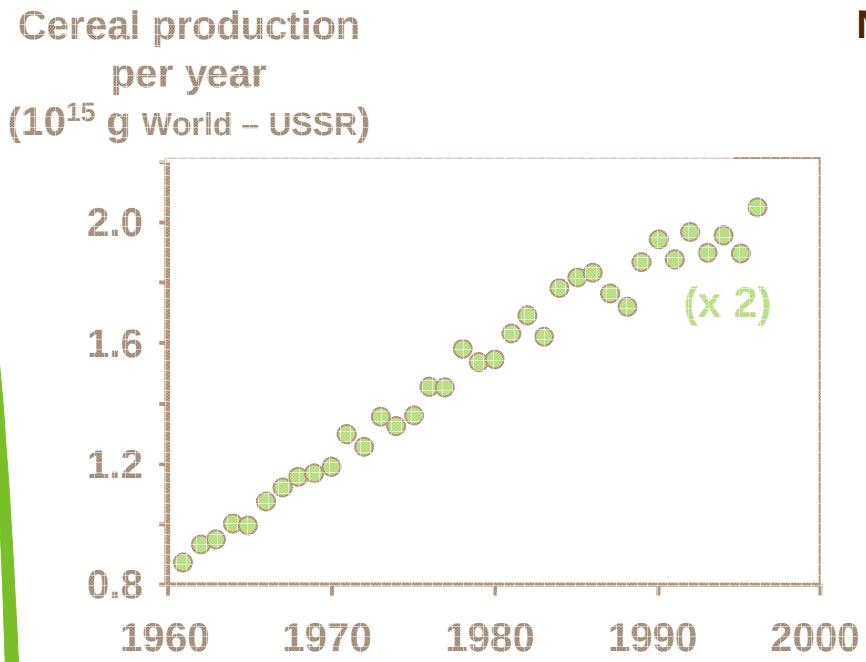
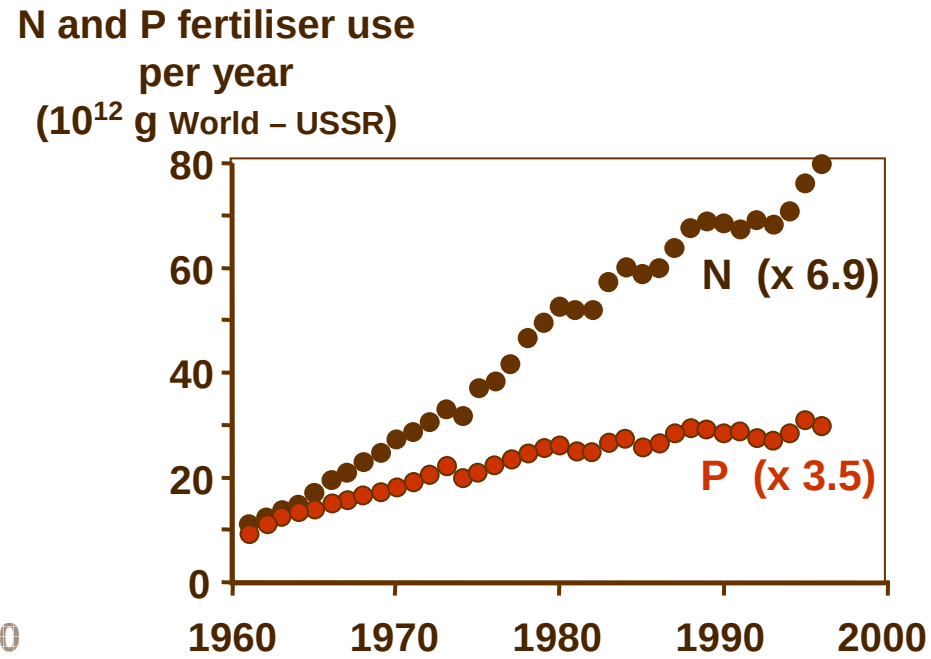




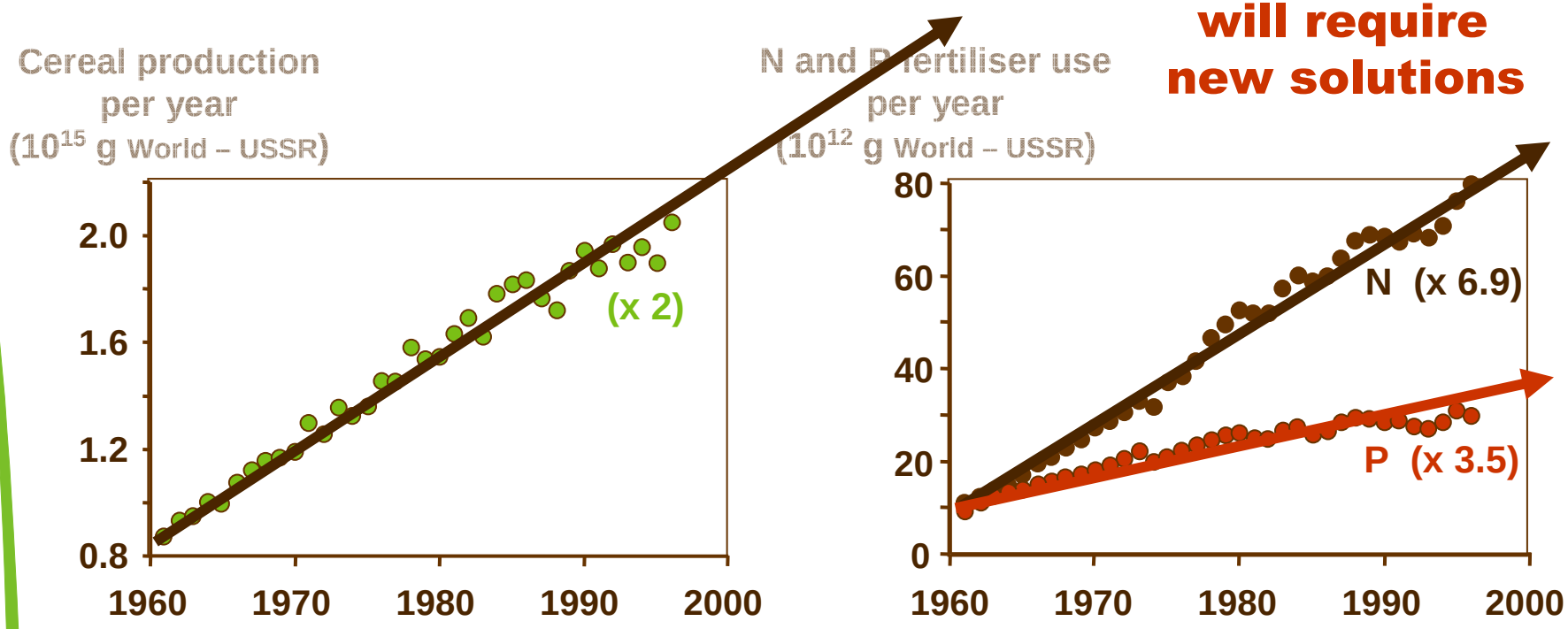
→ **Green revolution or massive eutrophication ???**

→ **Considerable decrease in N and P use efficiency**

Global cereal production and fertiliser consumption over past 40 yrs

(Tilman, Cassman, Matson, Naylor & Polasky 2002 *– Nature 418)*

→ **meeting future food demand will require new solutions**



→ **Green revolution or massive eutrophication ???**

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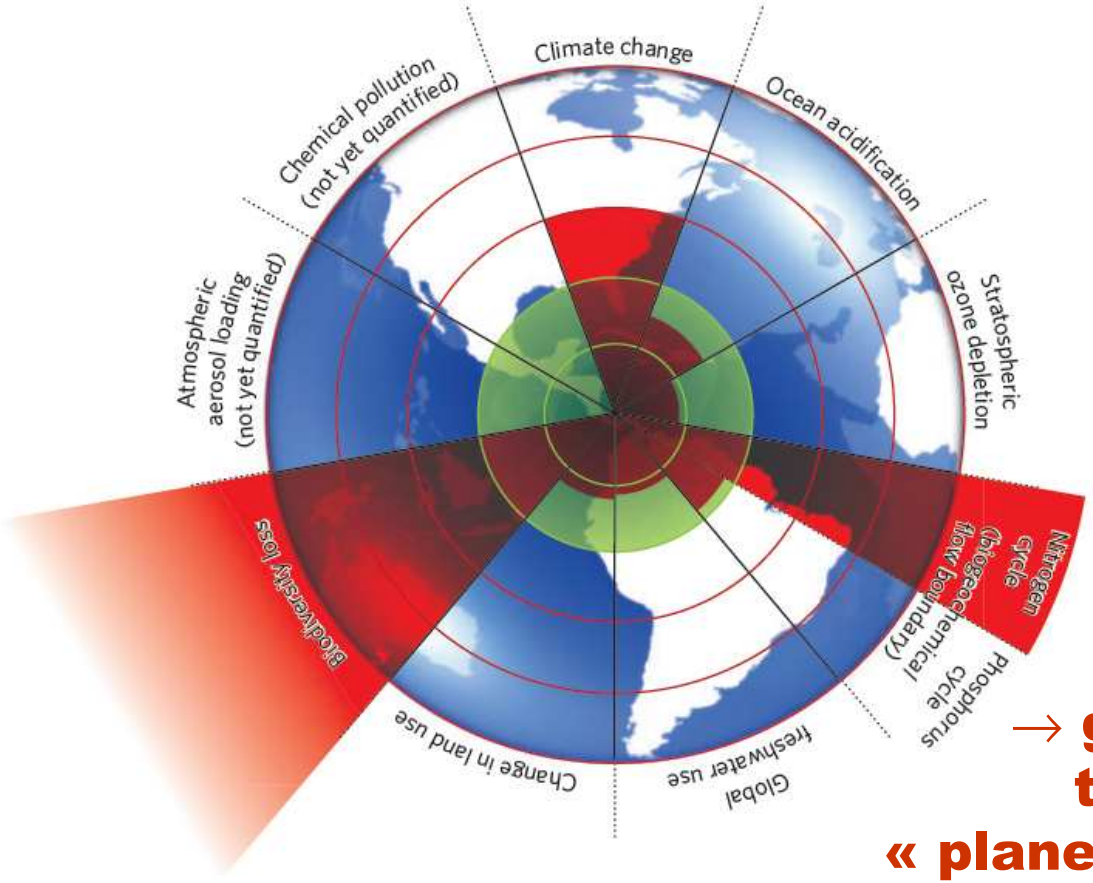
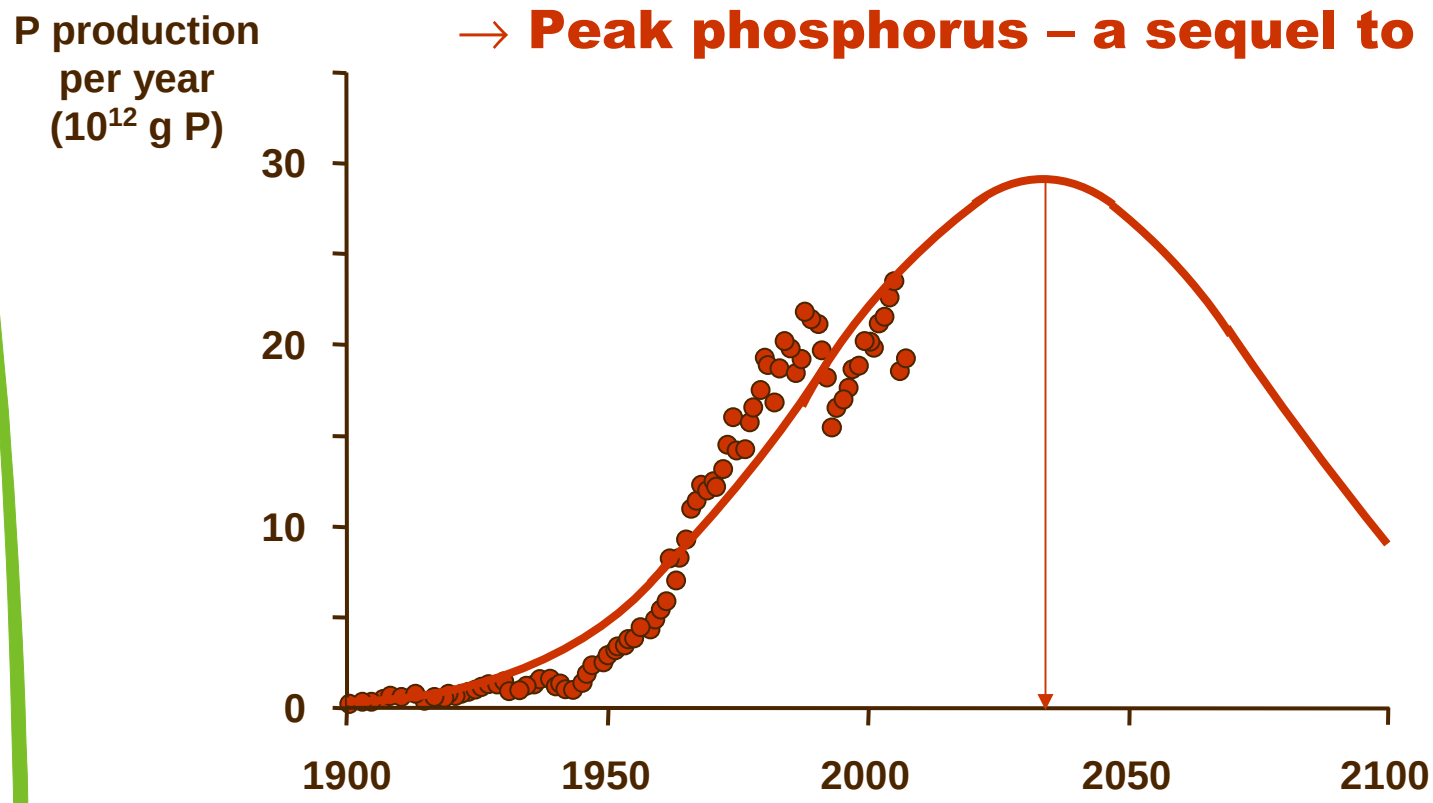


→ **getting close to exceeding « planetary boundaries »**

Human activities have resulted in major damages on biodiversity and ecosystem services, especially C, N and P biogeochemical cycles

***(Rockström et al. 2009** – Nature 461)*

→ Peak phosphorus – a sequel to peak oil ?



Indicative peak P curve, illustrating that, in a similar way to oil, global P reserves are also likely to peak after which production will be significantly reduced

***(Cordell, Drangert & White 2009** – Global Environ. Change 10)*

→ a urgent need to reduce P inputs

(Cordell, Drangert & White 2009 – Global Environ. Change 10)

(towards ecological intensification of agroecosystems)

(Tilman, Cassman, Matson, Naylor & Polasky 2002 – Nature 418)

→ is our knowledge and prediction of soil P bioavailability to plants good enough

under low input conditions

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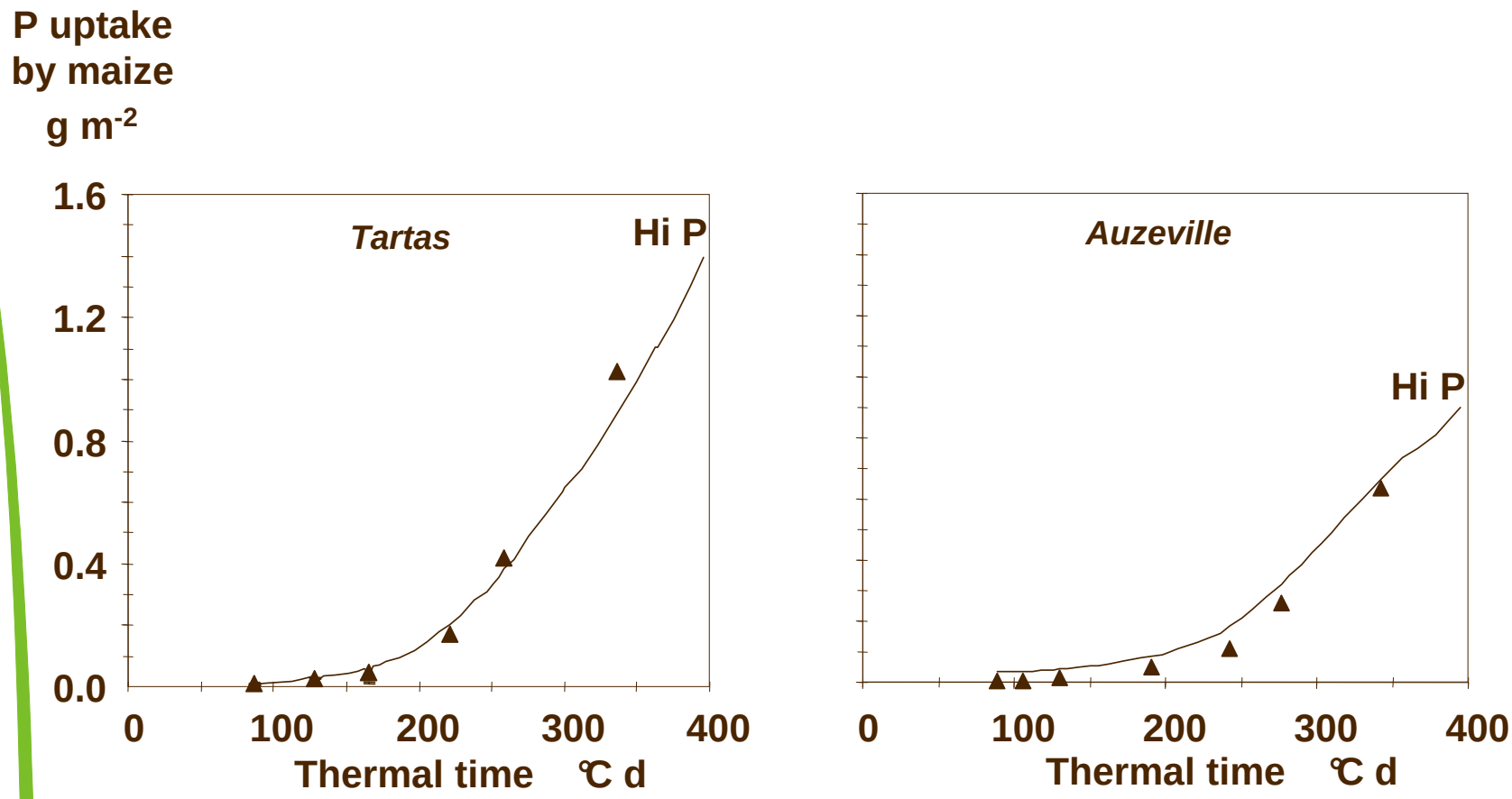

Barber-Cushman models and alike, incl. most recent P uptake models properly estimate P bioavailability in high P soils

(Mollier, De Willigen, Heinen, Morel, Schneider & Pellerin, 2008 *– Ecol. Model. 210)*

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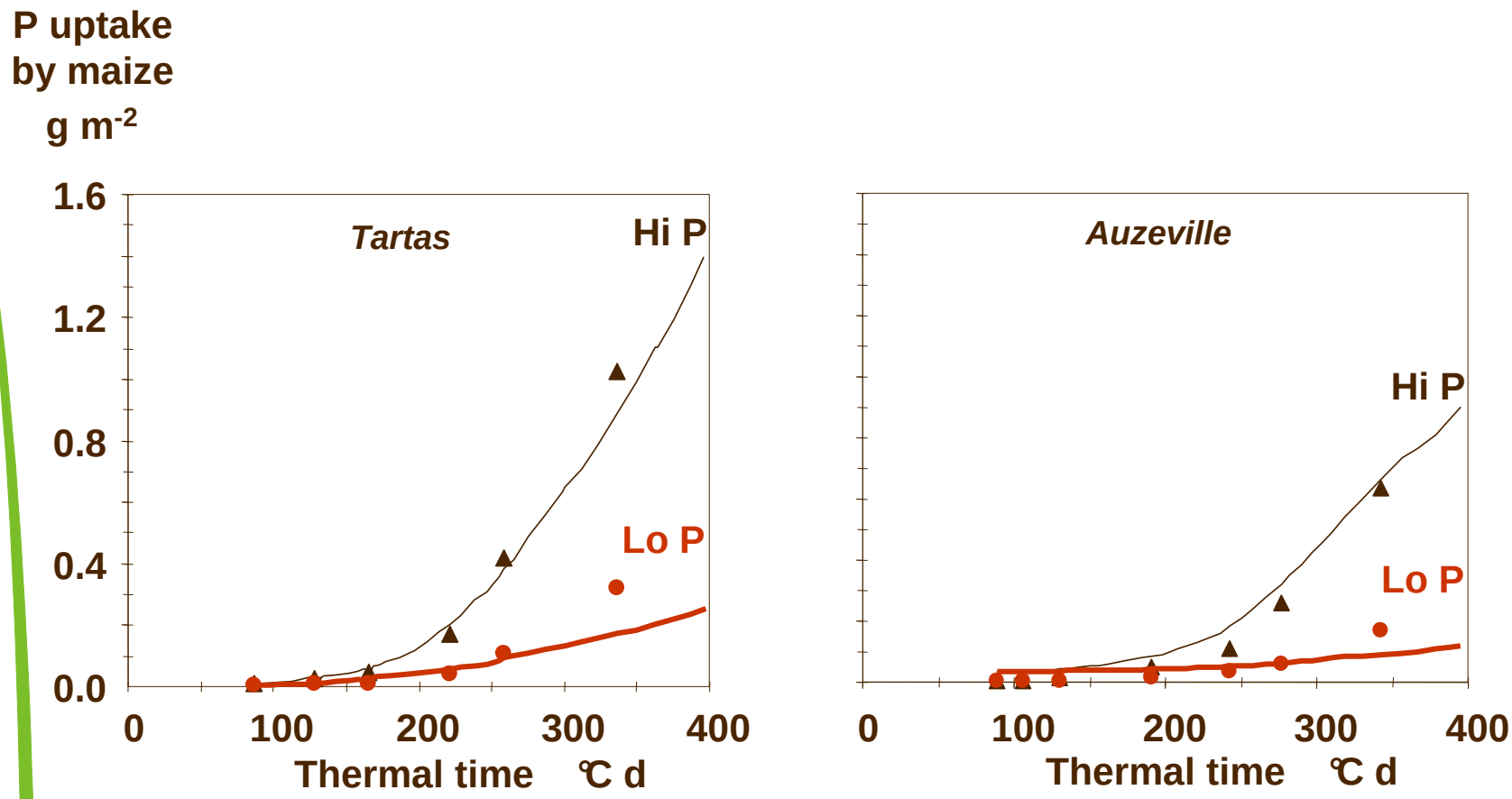

Barber-Cushman models and alike, incl. most recent P uptake models

largely underestimate P bioavailability in low P soils

(Mollier, De Willigen, Heinen, Morel, Schneider & Pellerin, 2008 – Ecol. Model. 210)

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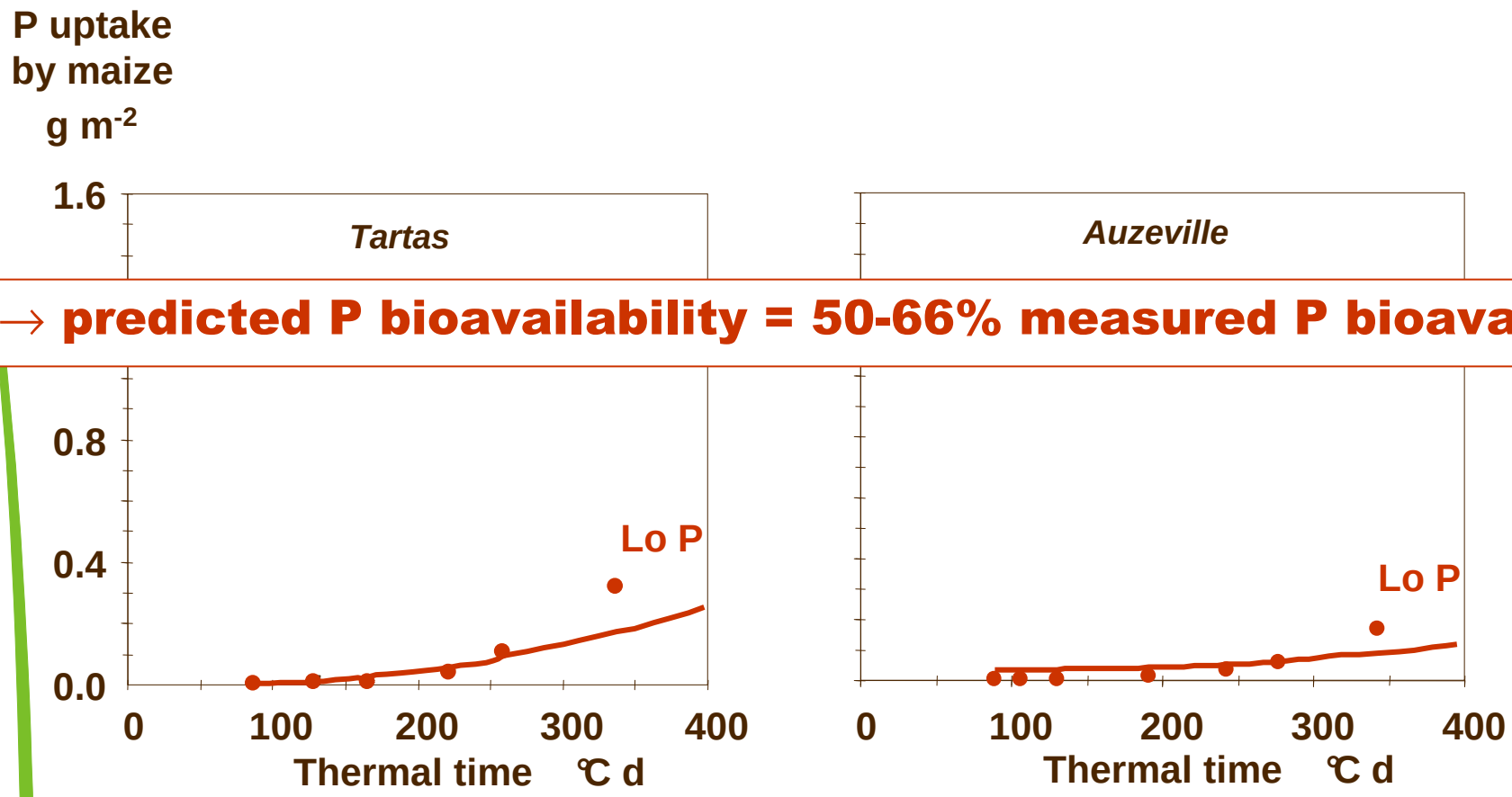

→ **predicted P bioavailability = 50-66% measured P bioavail.**

Barber-Cushman models and alike fail at predicting P bioavailability in low P soils

possibly because they do not account for rhizosphere processes and mycorrhizae

(Mollier, De Willigen, Heinen, Morel, Schneider & Pellerin, 2008 – Ecol. Model. 210)

definitions

… taking account of the time factor :

→ **bioavailability** is the **flux** of ~~contaminants~~ **phosphorus** to **biota** *(Gary et al., 1999)*

→ **bioavailability** is the **rate** at which ~~a chemical compound~~ **phosphorus** can be transported to the **specified biological population** *(Shor & Kosson, 2000)*

→ it thus varies with the considered plant species !!!

towards a unifying concept → ISO/DIS 17402 ***(ISO, 2006)***

(Harmsen et al., 2005 *– Land Contam. Reclam. 13* ***; Harmsen, 2007*** *– J. Environ. Qual. 36)*

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bioavailability is the **amount of** ~~a chemical~~ **phosphorus** in the soil that is present in forms and amounts **that plants** or other organisms **can take up during the time that they are growing** *(Harmsen et al., 2005)*

→ see Bioavailability Working Group (ISO/TC 190/SC 7/WG 8)

towards a unifying concept → ISO/DIS 17402 ***(ISO, 2006)***

(Harmsen et al., 2005 *– Land Contam. Reclam. 13* ***; Harmsen, 2007*** *– J. Environ. Qual. 36)*

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***environmental* availability**

total soil concentration

soil constituant – soil solution interactions

potentially available concentration
sorbed, dissolved complex/free species (speciation)

soil

towards a unifying concept → ISO/DIS 17402 ***(ISO, 2006)***

(Harmsen et al., 2005 *– Land Contam. Reclam. 13* ***; Harmsen, 2007*** *– J. Environ. Qual. 36)*

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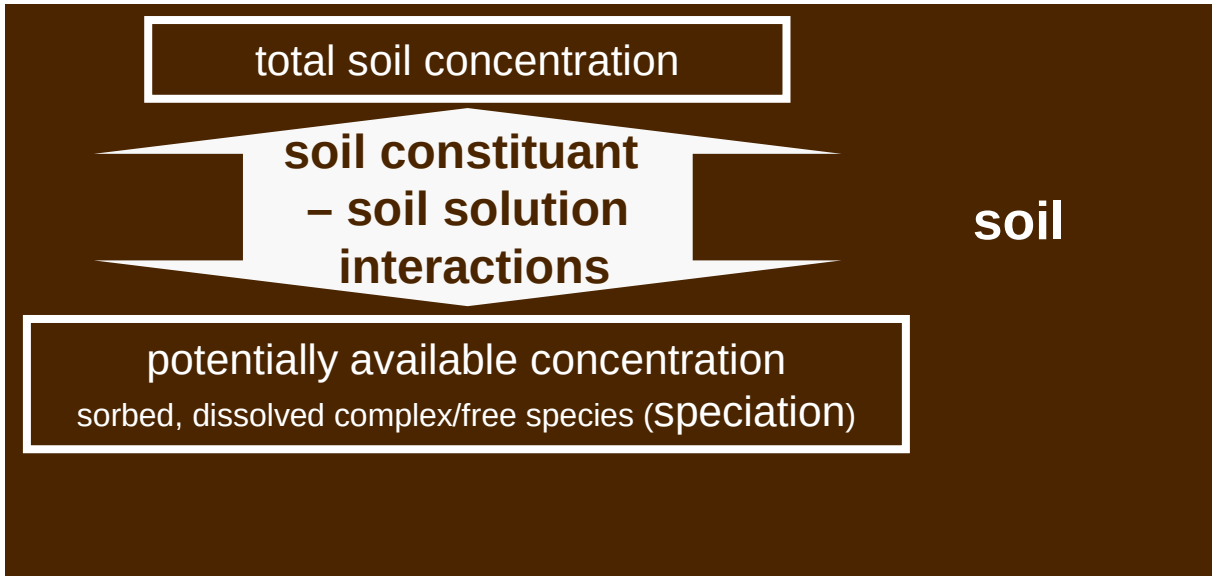

availability is nothing but **a surrogate of bioavailability**
that can be measured by soil testing procedures (chemical analyses)
and is thus independant of the biological receptor (e.g. plant species)

→ hence +17 methods are being used in Europe !!!

towards a unifying concept → ISO/DIS 17402 ***(ISO, 2006)***

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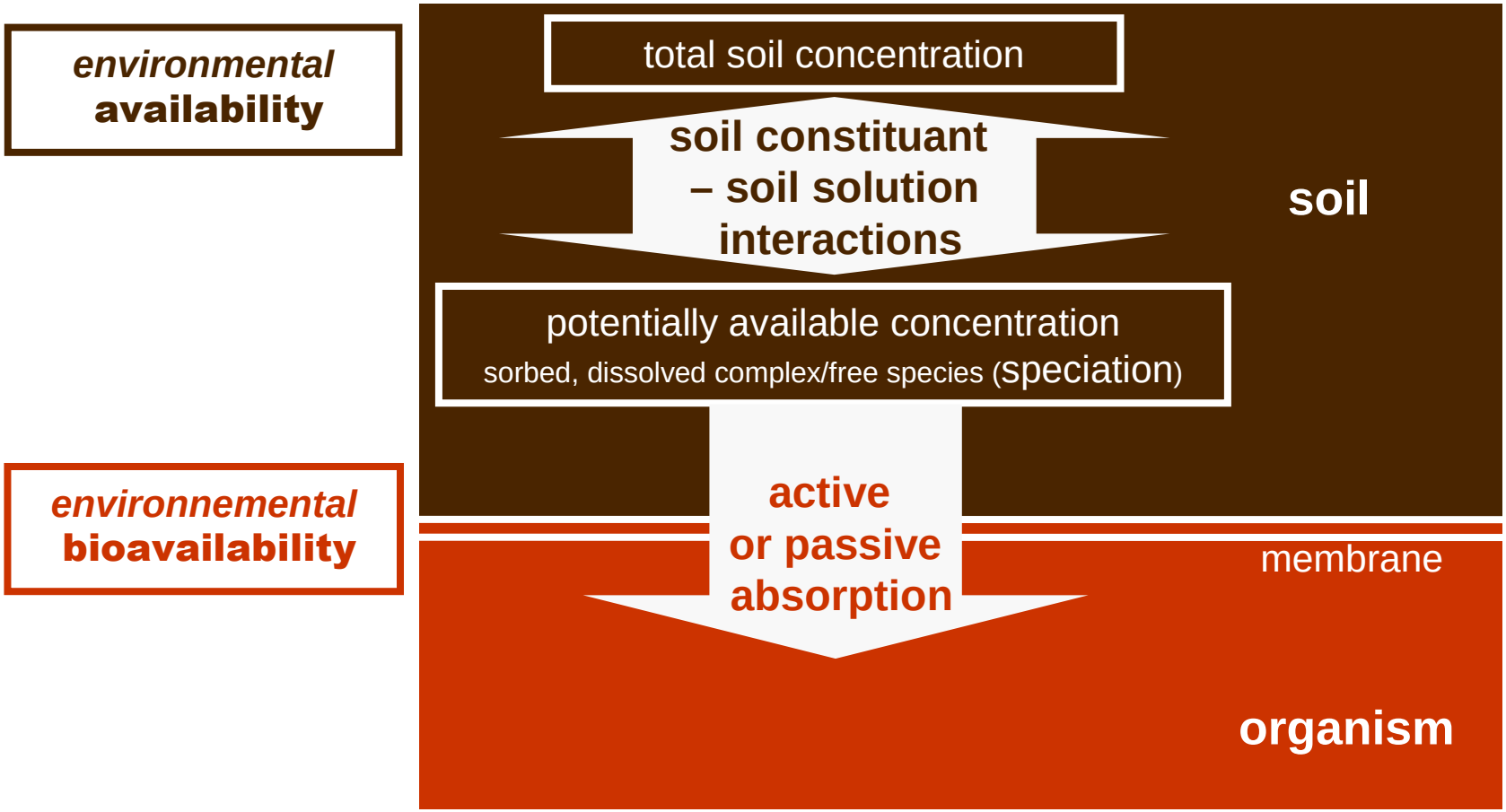

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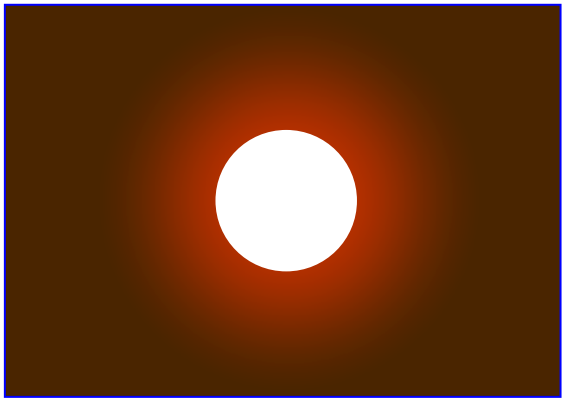
towards specific definitions …



… accounting for the target organism :

→ « **regarding the organisms, a 'bio-influenced' zone** can be defined, which is part of the surrounding soil and pore water with which an organism interacts.

Factors that influence this zone are the **potential of an organism to produce exo-enzymes** and other **exudates** or **to influence the pH** (uptake by organisms).

→ Consequently, the available concentration may have different values. »

towards a unifying concept → ISO/DIS 17402 ***(ISO, 2006)***

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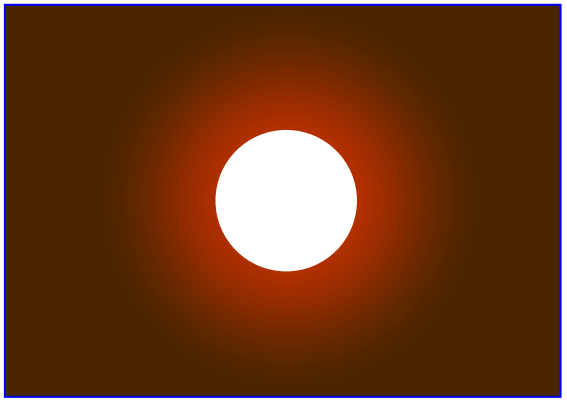

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« Thus, there could be different **bioavailabilities** depending on the type of target organisms and timescale, and, in turn, there could be numerous specific definitions. »
*(**Harmsen et al.**, 2005)*

towards a unifying concept → ISO/DIS 17402 ***(ISO, 2006)***
(Harmsen et al., 2005 *– Land Contam. Reclam. 13* ***; Harmsen, 2007*** *– J. Environ. Qual. 36)*

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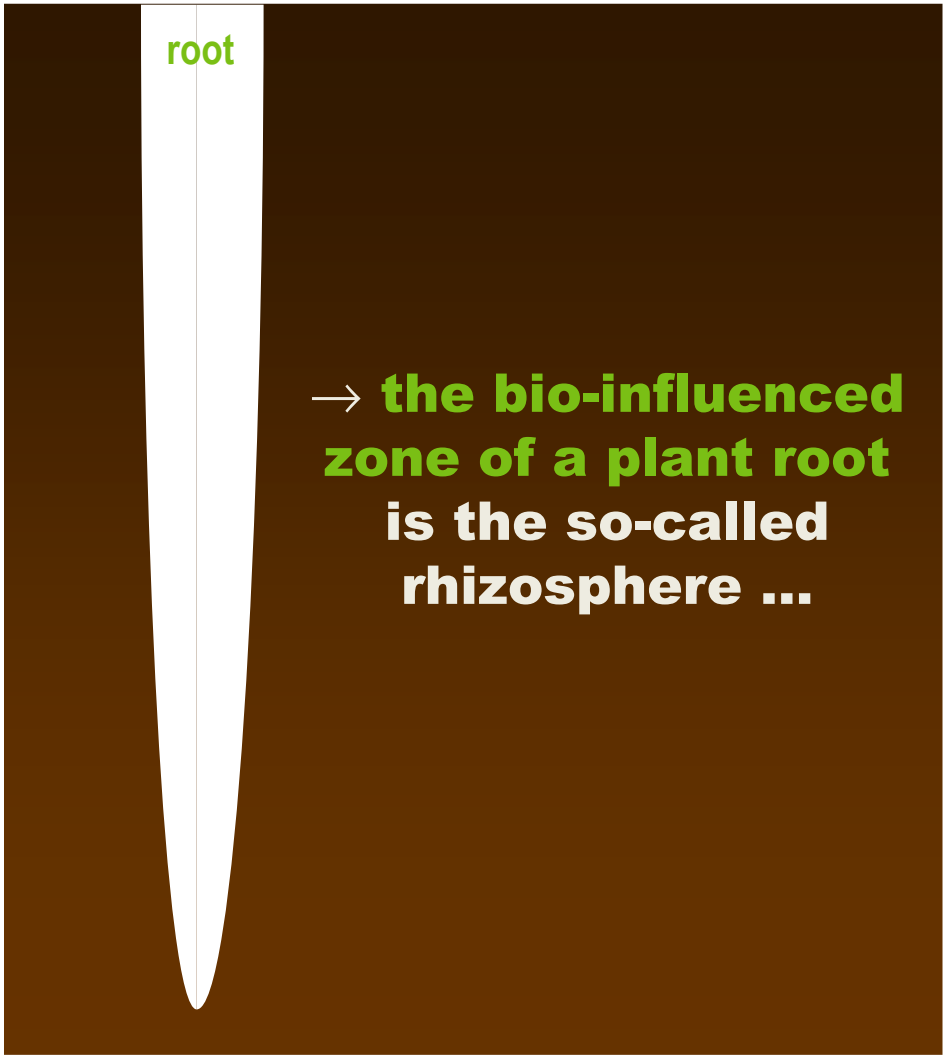

→ **the bio-influenced zone of a plant root is the so-called rhizosphere …**

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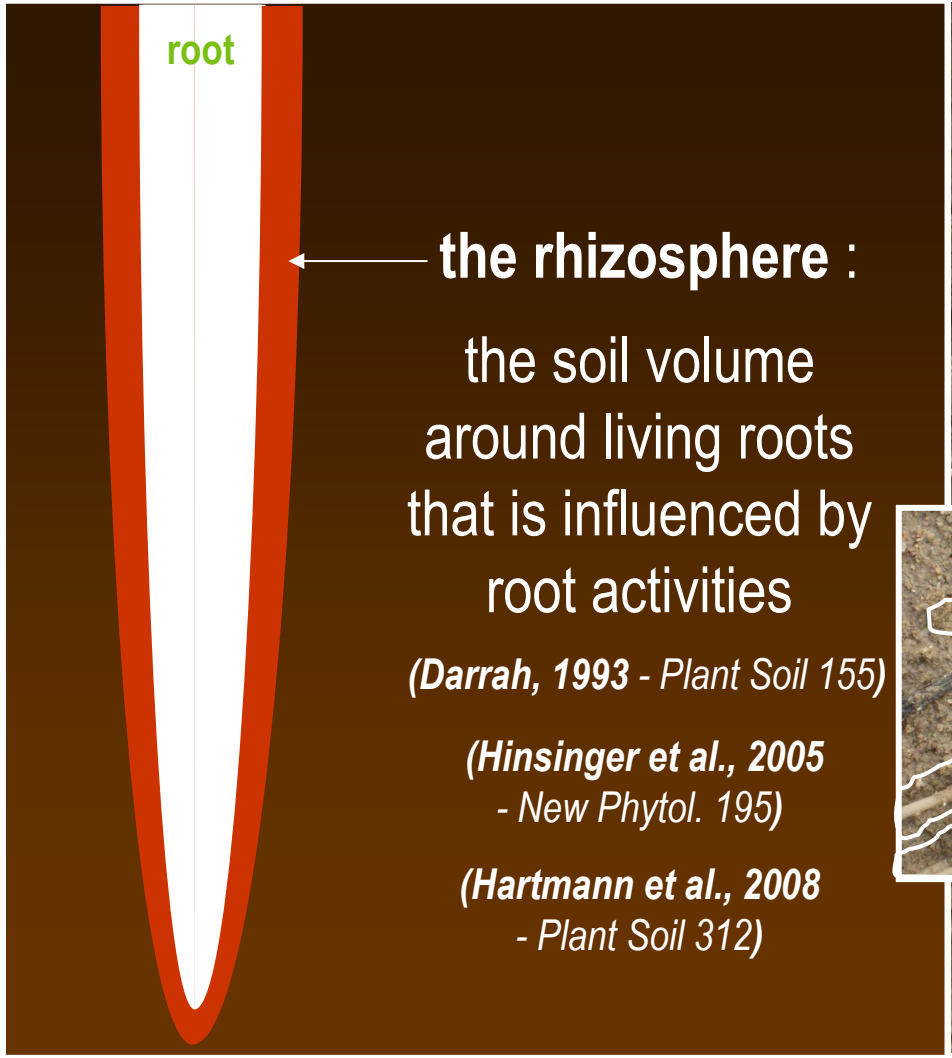

the rhizosphere :

the soil volume around living roots that is influenced by root activities

(Darrah, 1993 *- Plant Soil 155)*

(Hinsinger et al., 2005 *- New Phytol. 195)*

(Hartmann et al., 2008 *- Plant Soil 312)*

… a unique hotspot of soil biophysics and biogeochemistry

(Hinsinger, Bengough, Vetterlein & Young, 2009 *– Plant Soil 321)*

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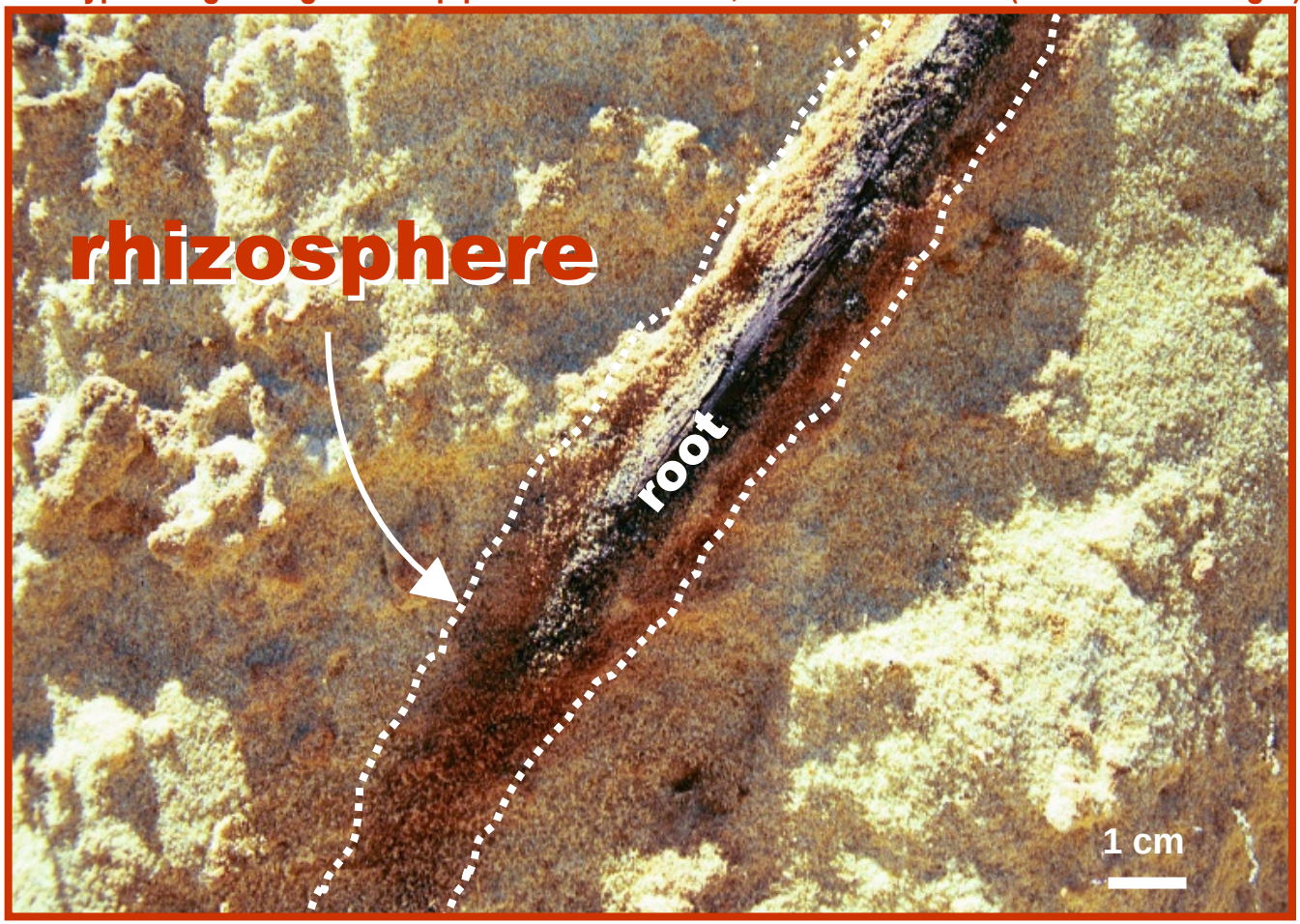
Eucalypt root growing in a deep podzol at Jandakot, Western Australia (Photo. P. Hinsinger)



the rhizosphere is a site of intense root–microbe-soil biogeochemical interactions

*(**Hinsinger, Plassard & Jaillard 2006** – J. Geochemical Explor. ; **Hinsinger, Bengough, Vetterlein & Young 2009** – Plant Soil 321)*

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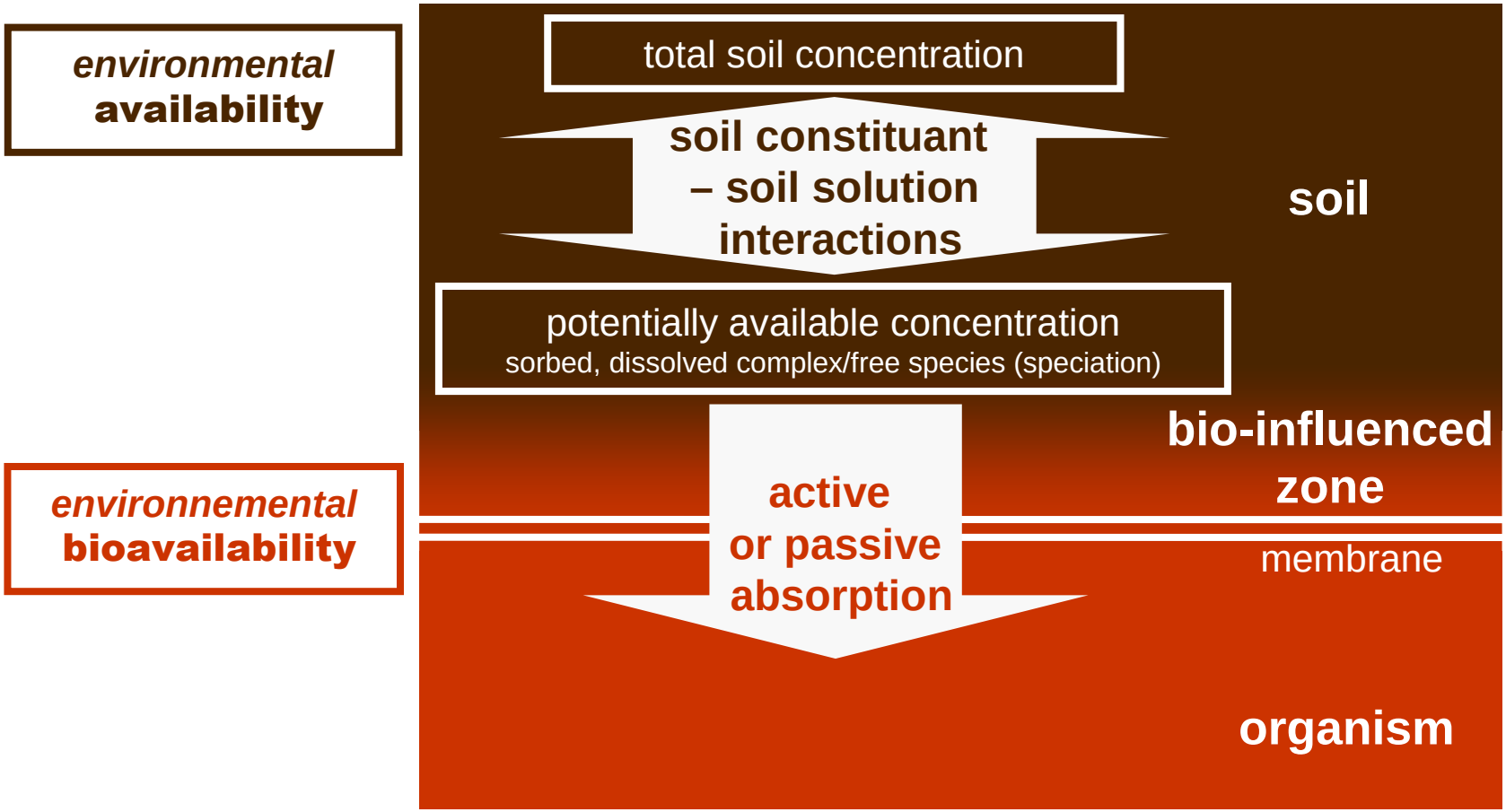

→ **availability is changing in the bio-influenced zone !!!**

towards a unifying concept → ISO/DIS 17402 ***(ISO, 2006)***

(adapted from Harmsen, 2007 *– J. Environ. Qual. 36)*

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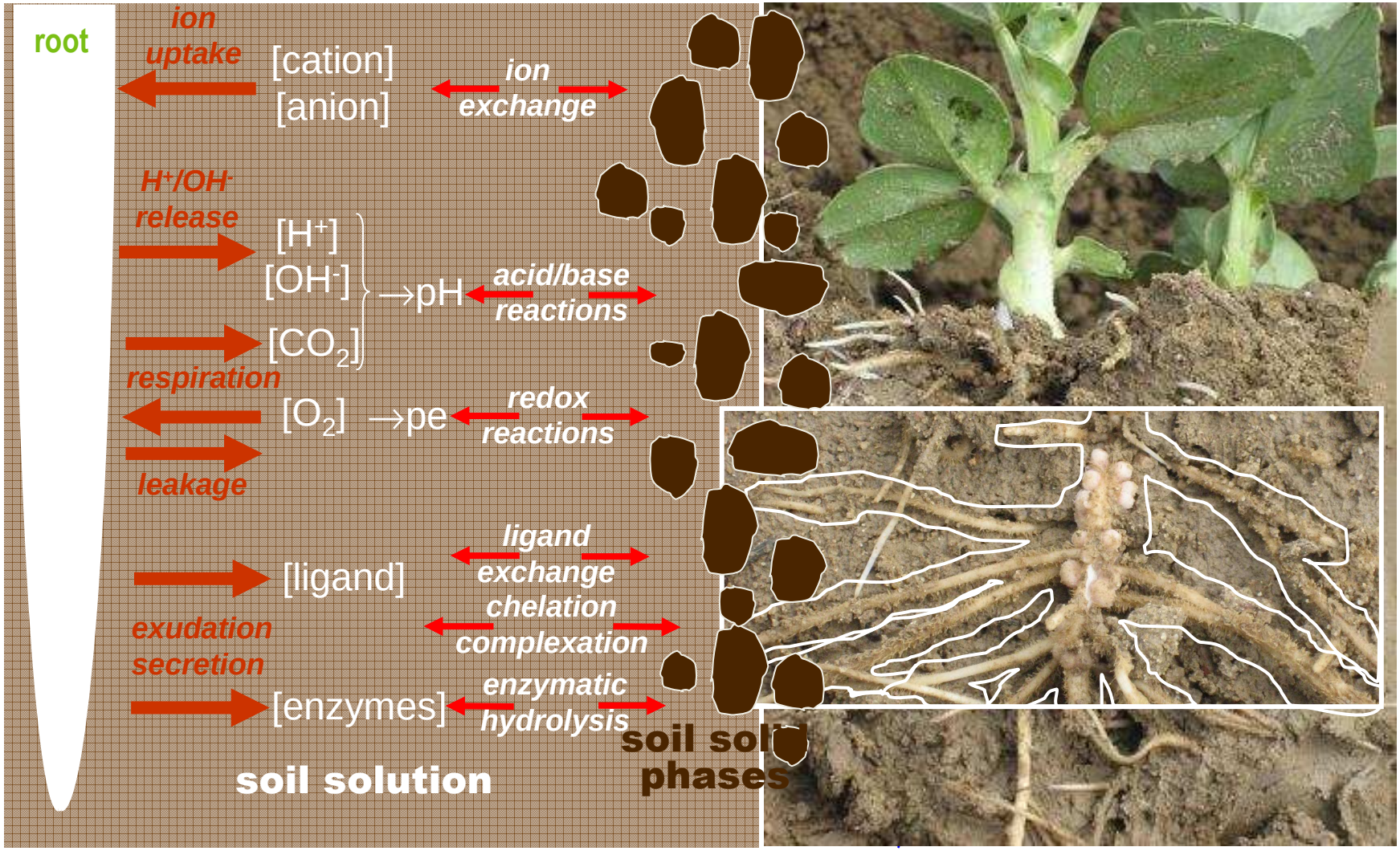

Major biogeochemical processes determining P bioavailability in the rhizosphere

(Hinsinger, Gobran, Gregory & Wenzel, 2005 – New Phytol. 195
Hinsinger, Jaillard, Le Cadre & Plassard, 2007 – Oceanis 33)

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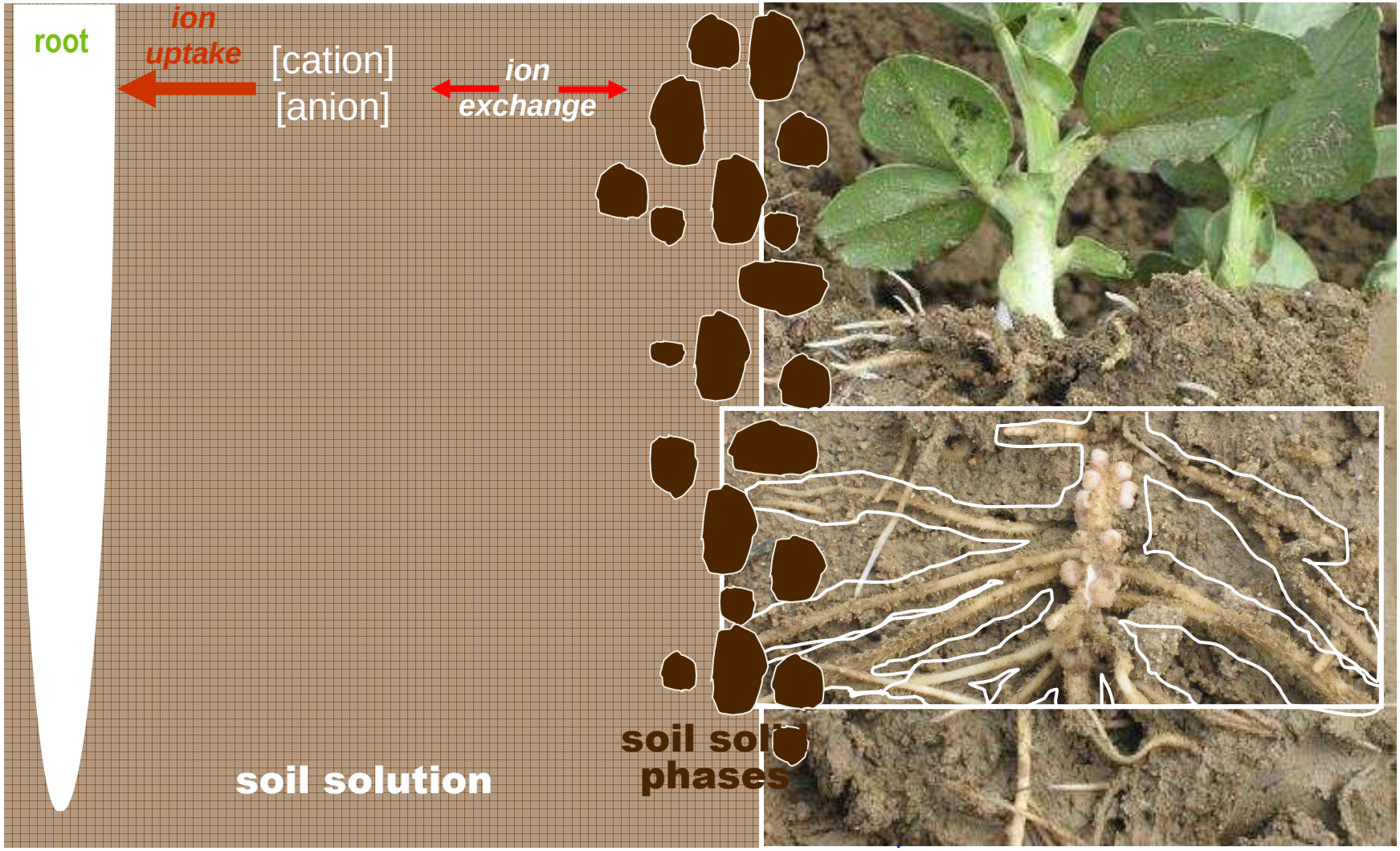

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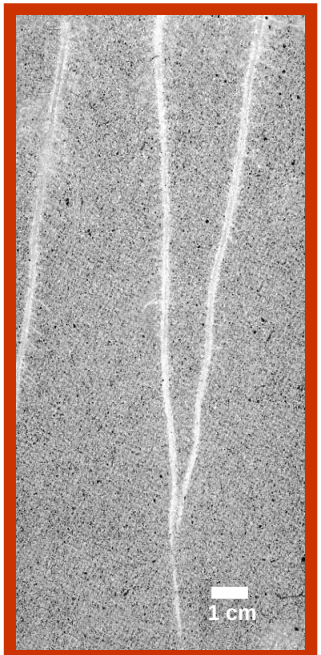

(Jungk, 2002)

→ nutrient depletion rules

= sole rhizosphere process accounted for in models of soil P bioavailability to plants (Barber-Cushman and alikes)

Rhizosphere P is depleted in the rhizosphere

(Jungk, 2002 – *In : Plant Roots The Hidden Half ;*
Hinsinger, Jaillard, Le Cadre & Plassard, 2007 *– Oceanis 33)*

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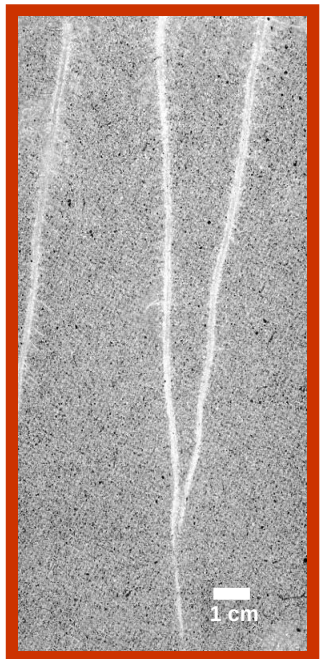

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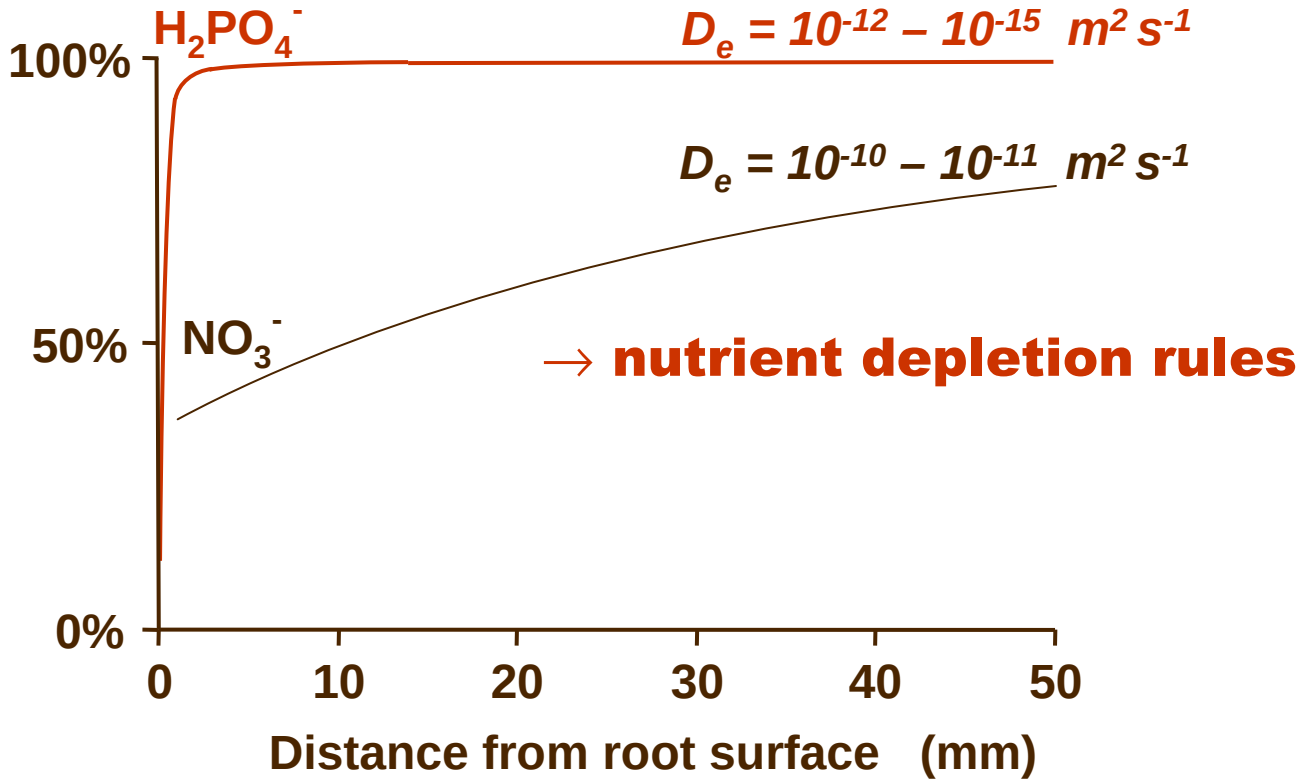

Rhizosphere P is depleted to a lesser extent than mobile nutrients such as N

(Hinsinger, 2004 – Encyclopedia Plant Crop Sci.)

because of its lower diffusion coefficients in soils - D_e

(Jungk, 2002 – In : Plant Roots The Hidden Half)

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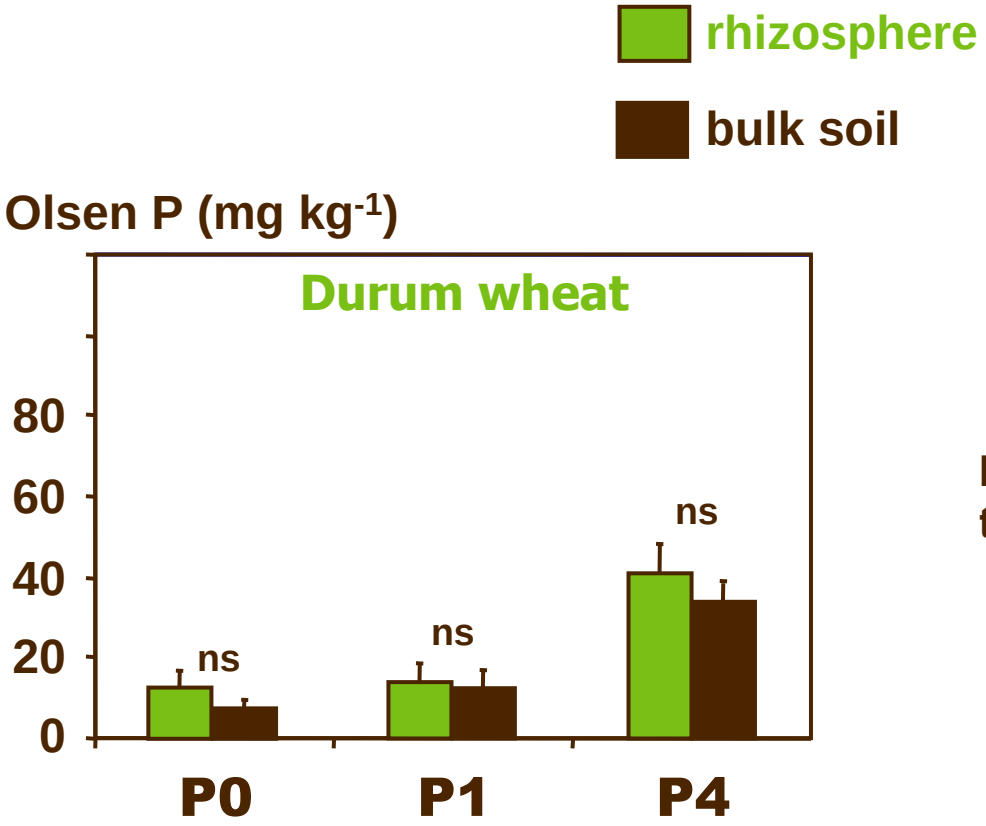

INRA long-term P fertiliser trial in Toulouse-Auzeville

Available P (Olsen P) was never depleted in the rhizosphere of durum wheat (field sampling) (no significant change)

(Betencourt, Colomb, Cordier, Justes, Souche & Hinsinger, 2010 – unpubl.)

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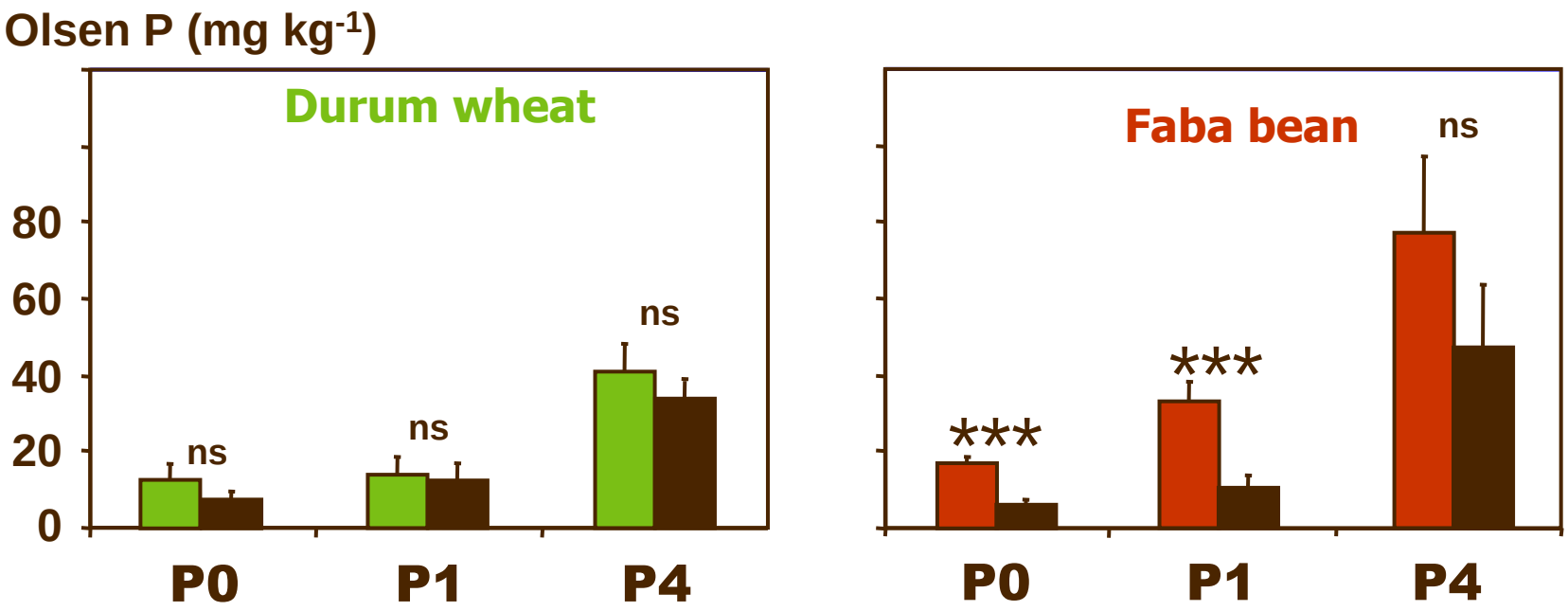
rhizosphere

bulk soil

INRA long-term P fertiliser trial in Toulouse-Auzeville



Olsen P increased instead of being depleted **in the rhizosphere** of durum wheat and even more so faba bean (field sampling) especially at low P input levels

(Betencourt, Colomb, Cordier, Justes, Souche & Hinsinger, 2010 – unpubl.)

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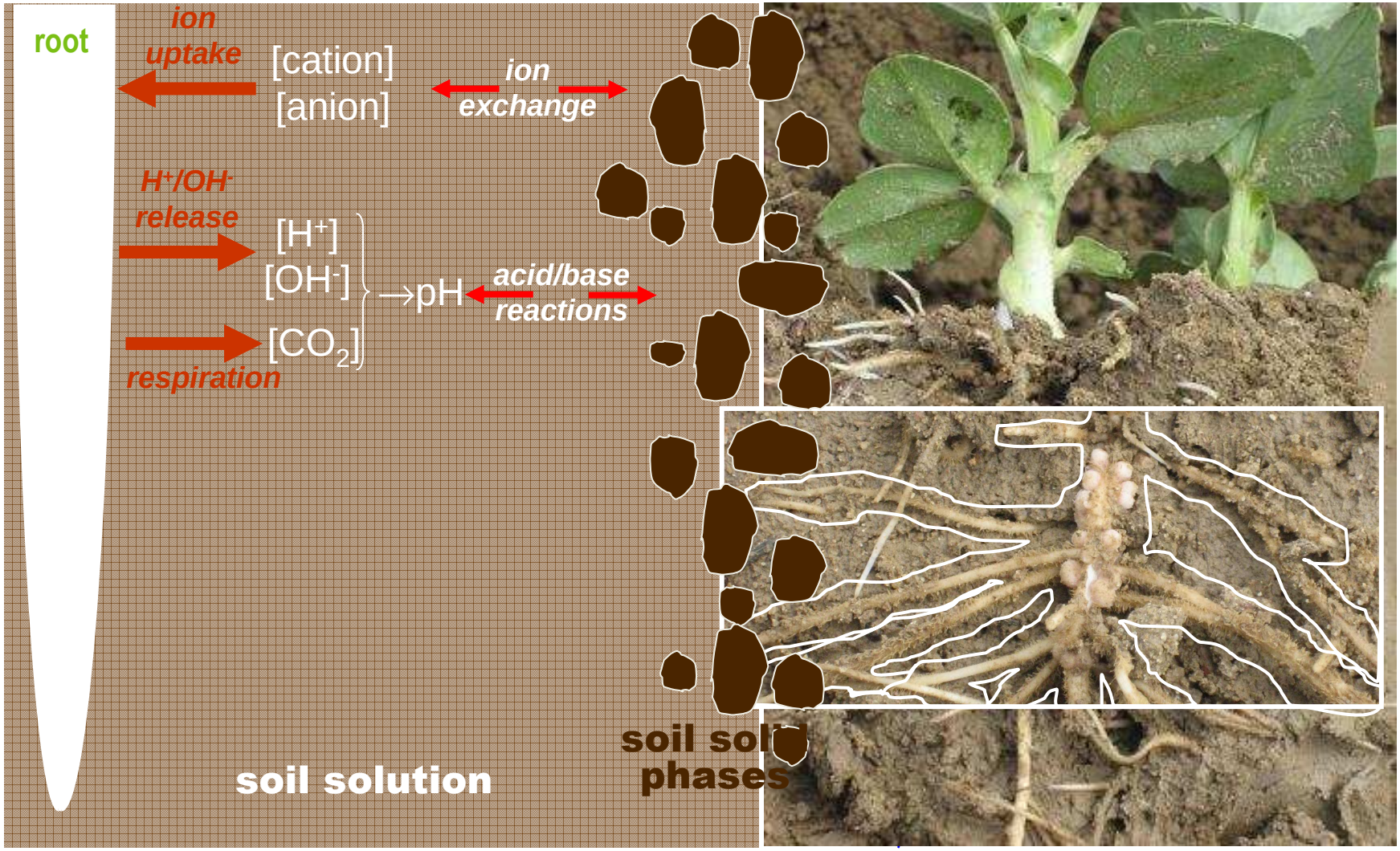

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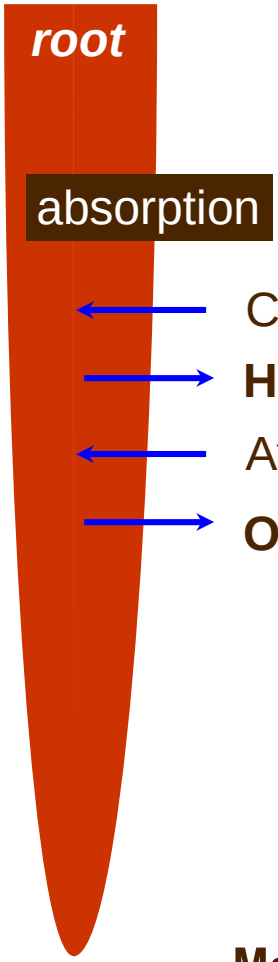


C^+ Cation (K^+, NH_4^+, Ca^{2+}, …)

H^+

A^- Anion (NO_3^-, $H_2PO_4^-$, …)

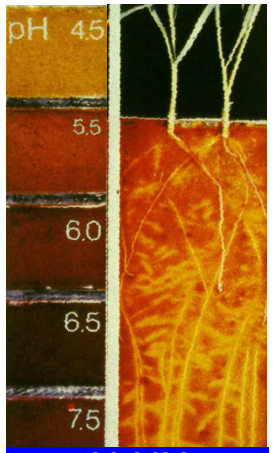
OH^-

if $\Sigma C^+ > \Sigma A^-$

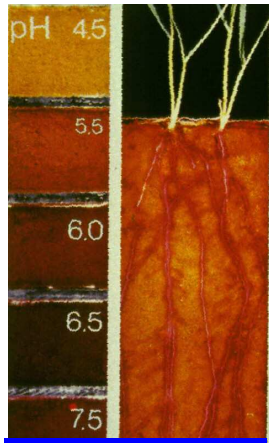
if $\Sigma C^+ < \Sigma A^-$

pH changes in the rhizosphere of wheat

(Römheld, 1986)



e.g. N-NH_4^+



e.g. N-NO_3^-

Major origin of pH changes in the rhizosphere – balancing the exchanged charges

***(Hinsinger, Plassard, Tang & Jaillard, 2003** - Plant Soil 248)*

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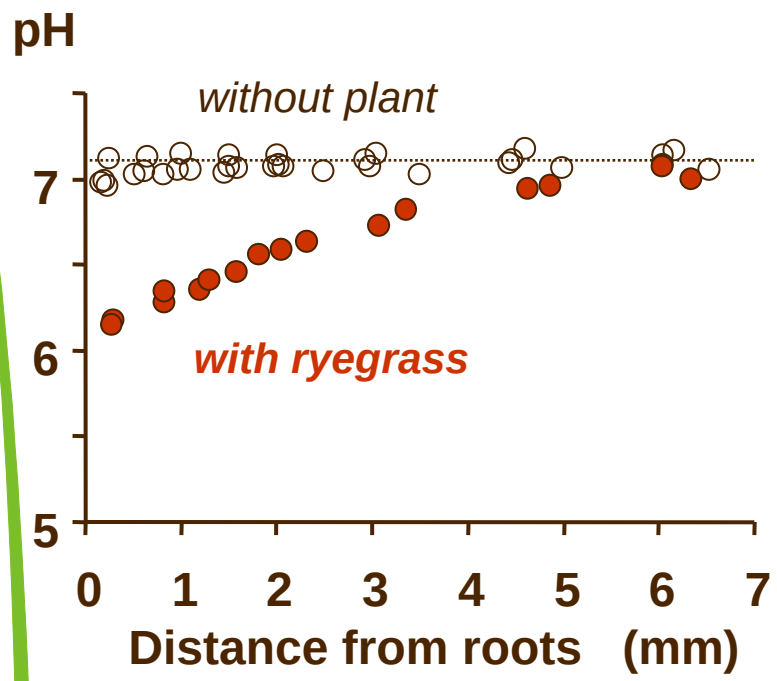

Root-induced acidification and dissolution of phosphate rock (PR) in the rhizosphere of ryegrass (*Lolium rigidum*) supplied with ammonium

(Hinsinger & Gilkes, 1996 – *Eur. J. Soil Sci. 47)*

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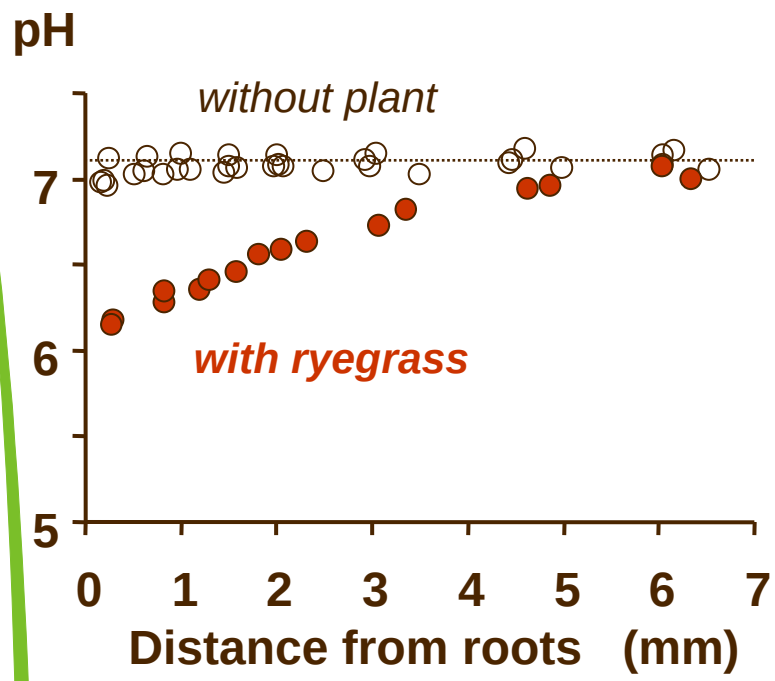

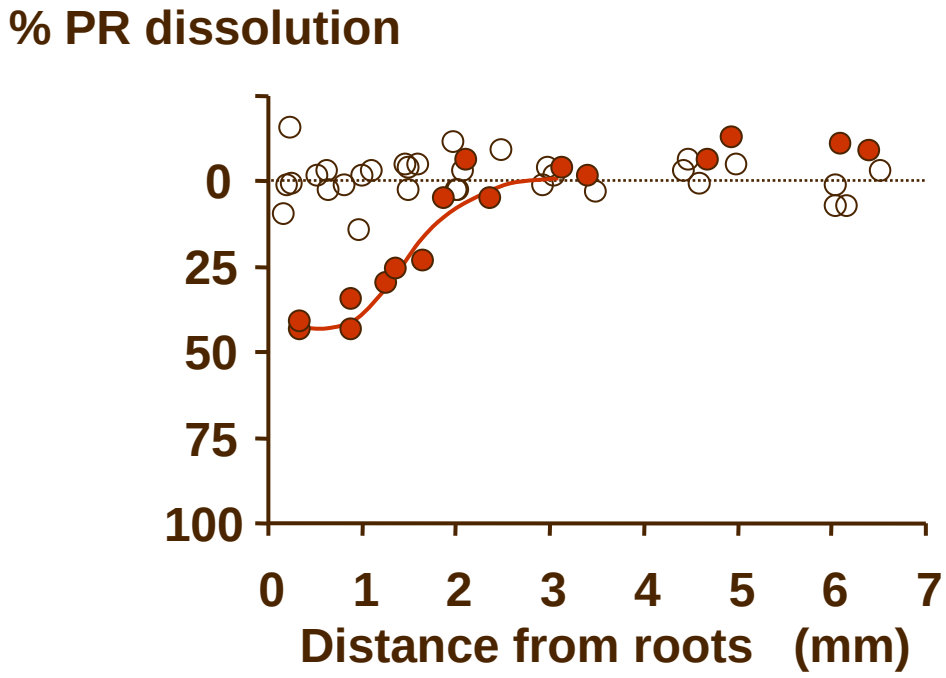

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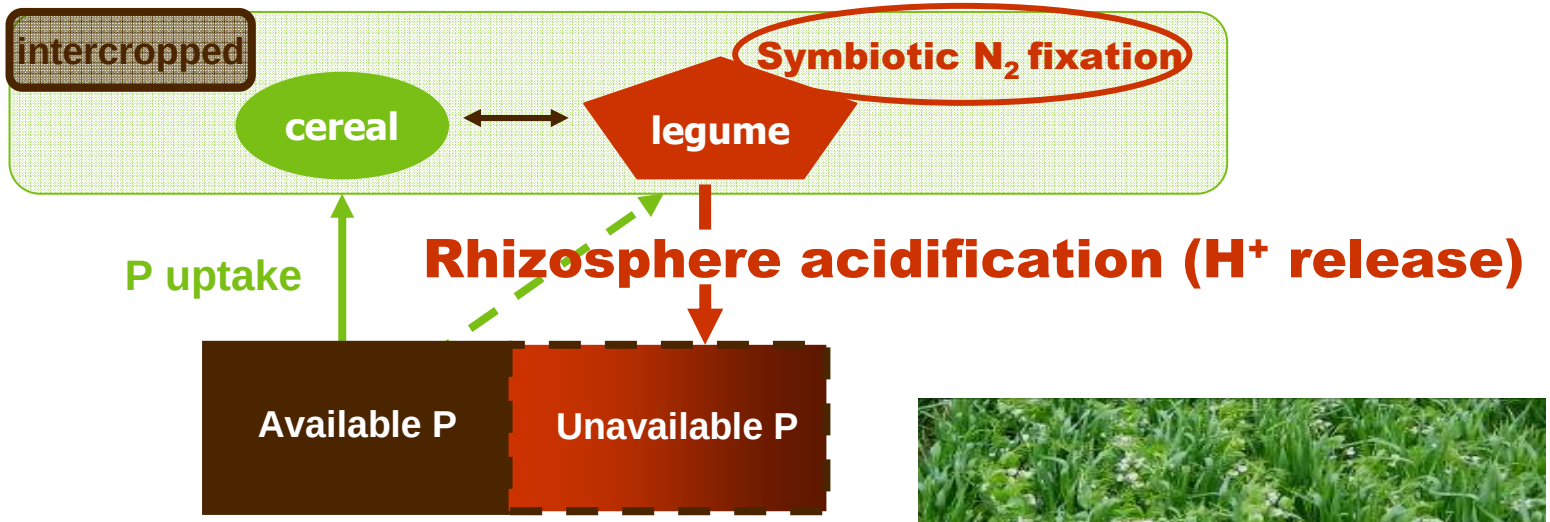

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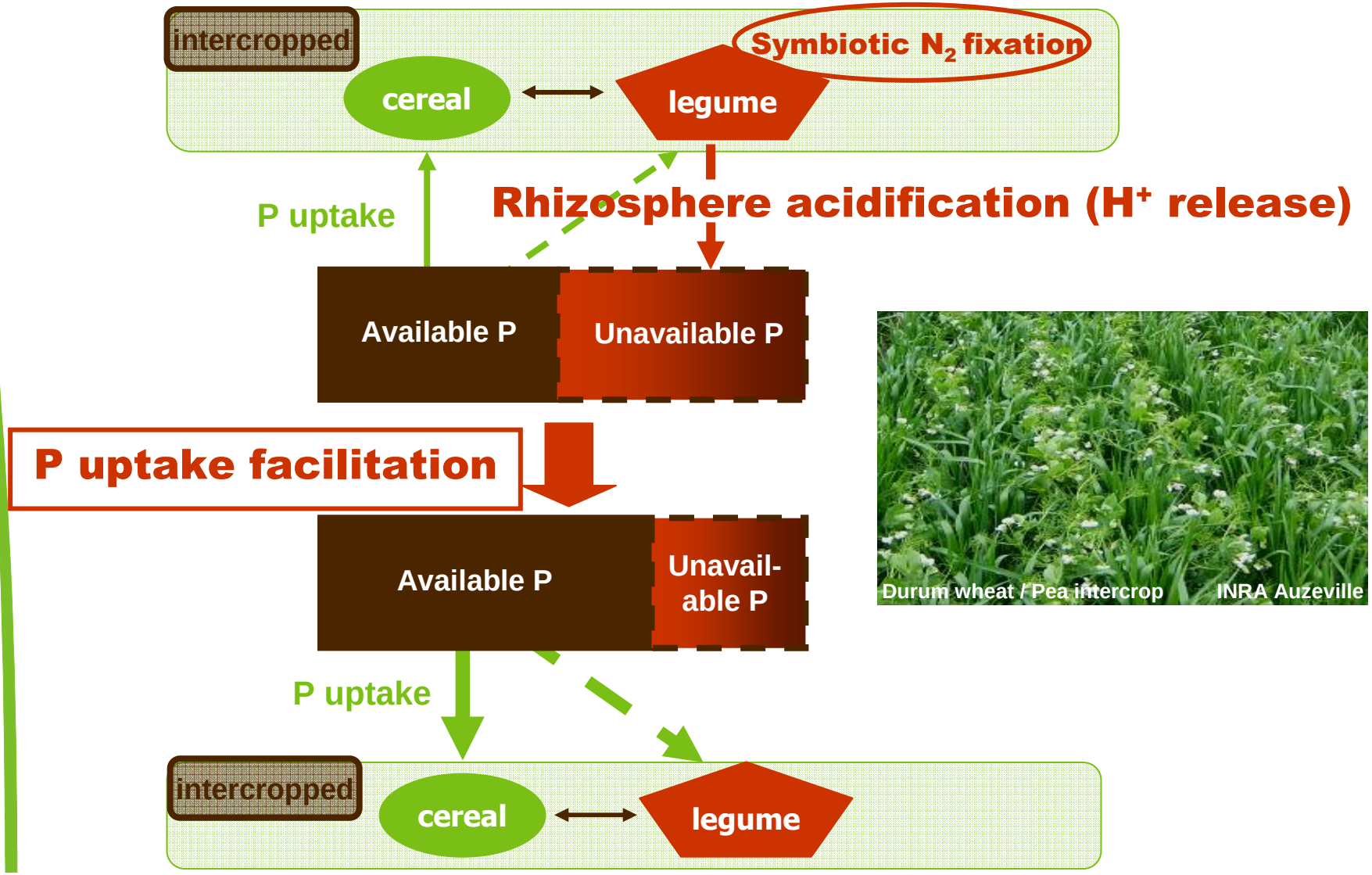

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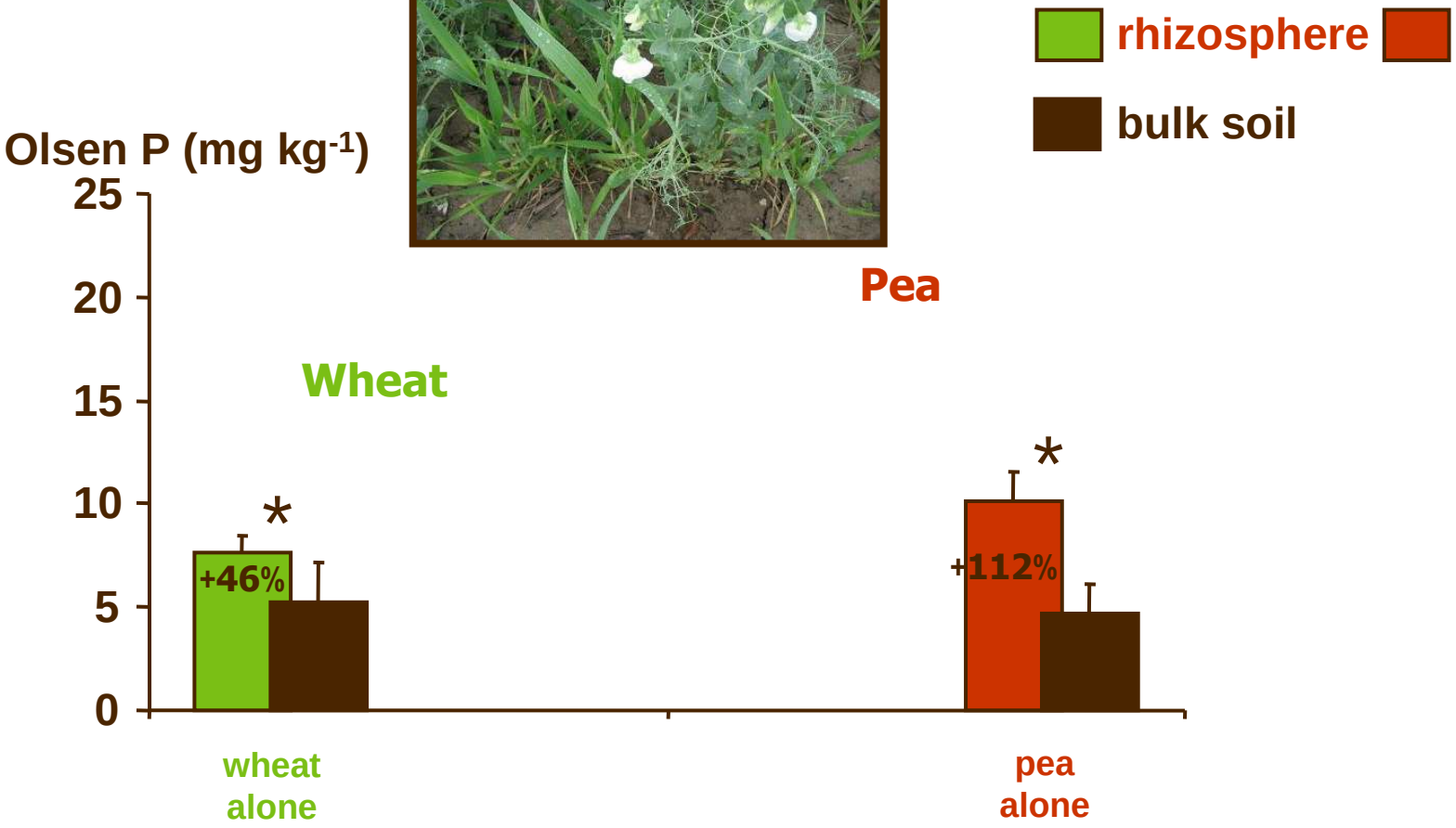

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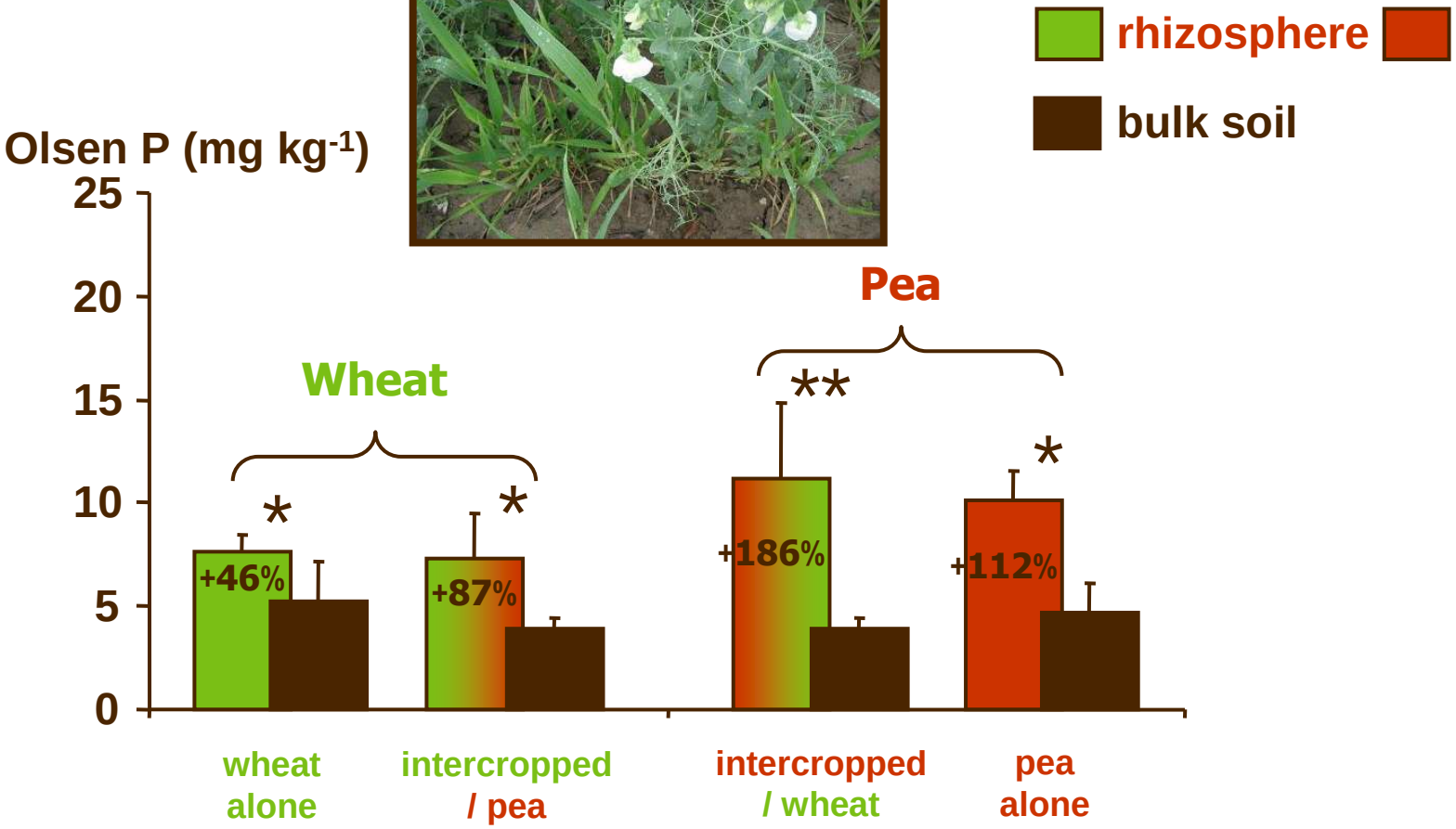

Greater increase in available P occurred in the rhizosphere of pea than durum wheat, especially when intercropped, at low P (field sampling)

(Betencourt, Colomb, Cordier, Justes, Souche & Hinsinger, 2010 – unpubl.)

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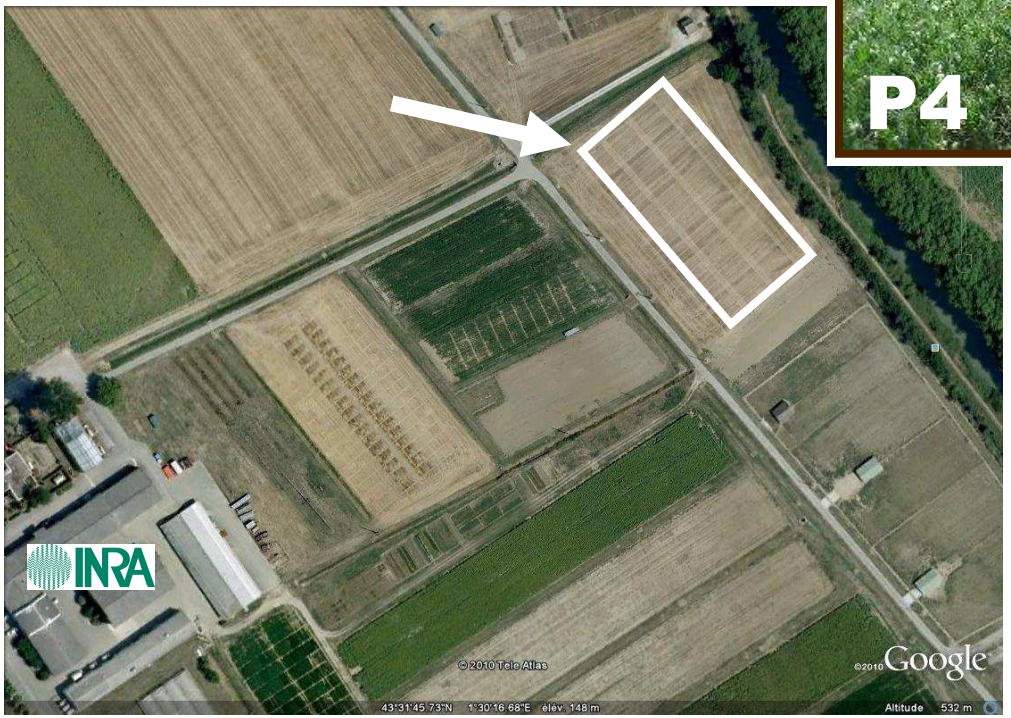
P0 nill

no P added for 40yrs

P Olsen = 5 mg kg^{-1}
P Tot. = 418 mg kg^{-1}



P4 overfertilised

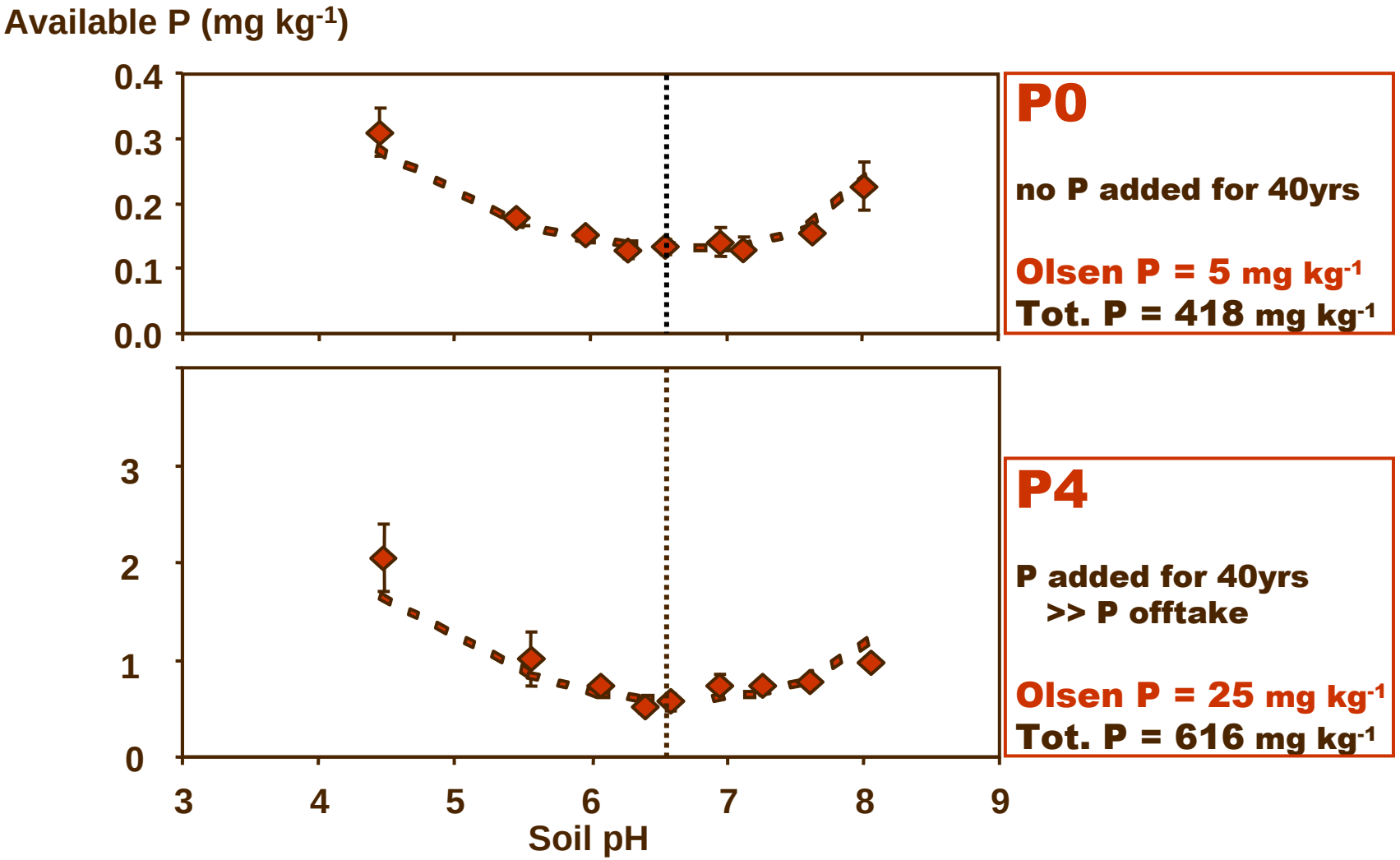
P added for 40yrs >> P offtake

Olsen P = 35 mg kg^{-1}
Tot. P = 616 mg kg^{-1}

Contrasted P availabilities at INRA long-term P fertiliser trial in Toulouse-Auzeville

*(see for more data: **Colomb, Debaecke, Jouany & Nolot, 2007** – Eur. J. Agron. 26)*

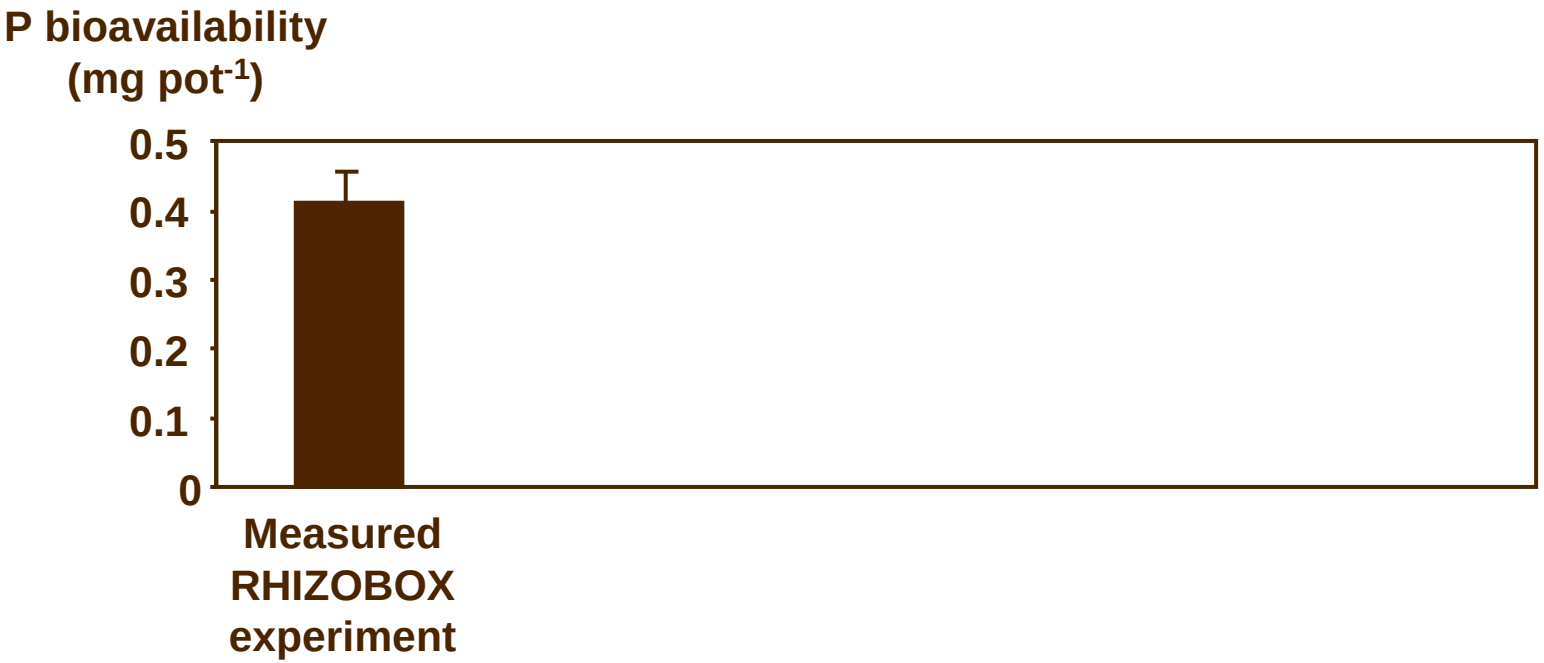
Phosphorus bioavailability – Nothing but a rhizosphere story



Measured and modelled pH-dependence of P availability (water-extractable P) in the studied luvisol – INRA long-term P fertiliser trial at Auzeville-Toulouse

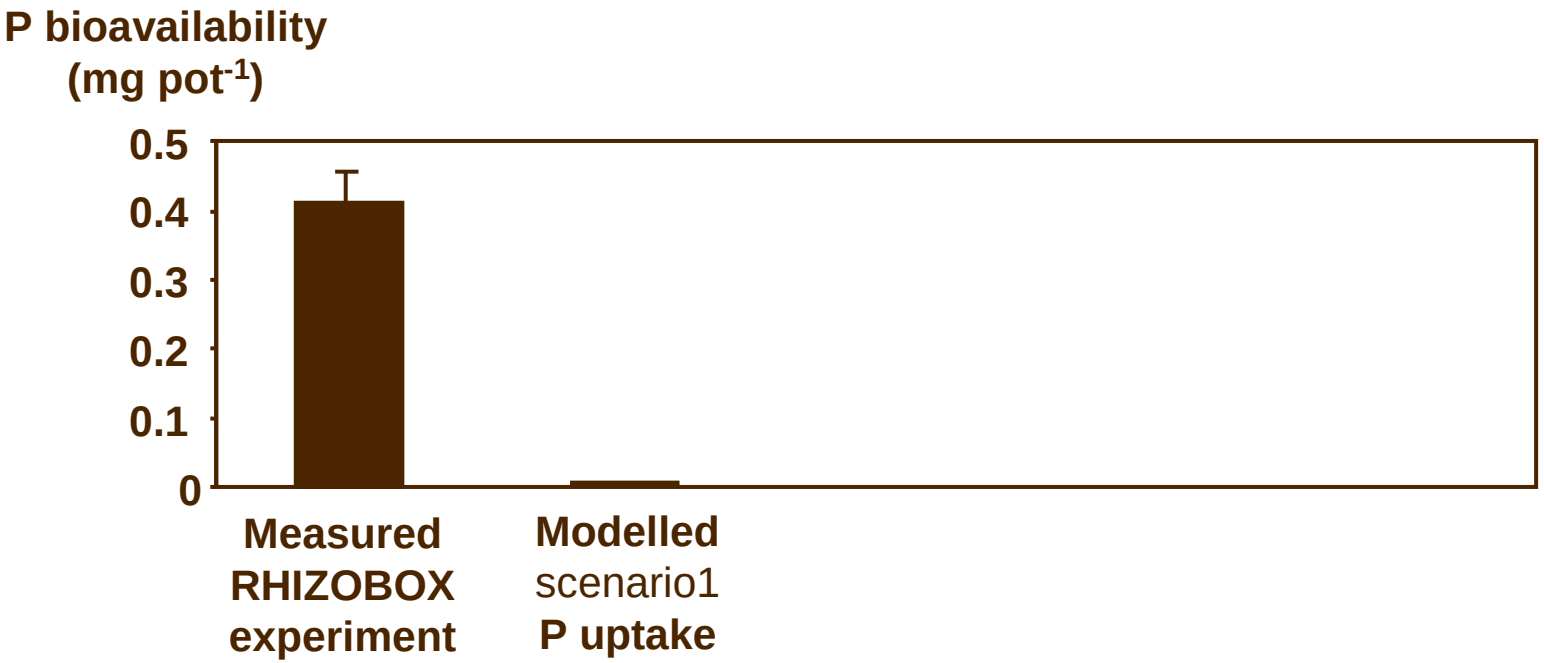
(Devau, Le Cadre, Hinsinger, Colomb & Gérard, 2010 – unpubl.)

Phosphorus bioavailability – Nothing but a rhizosphere story

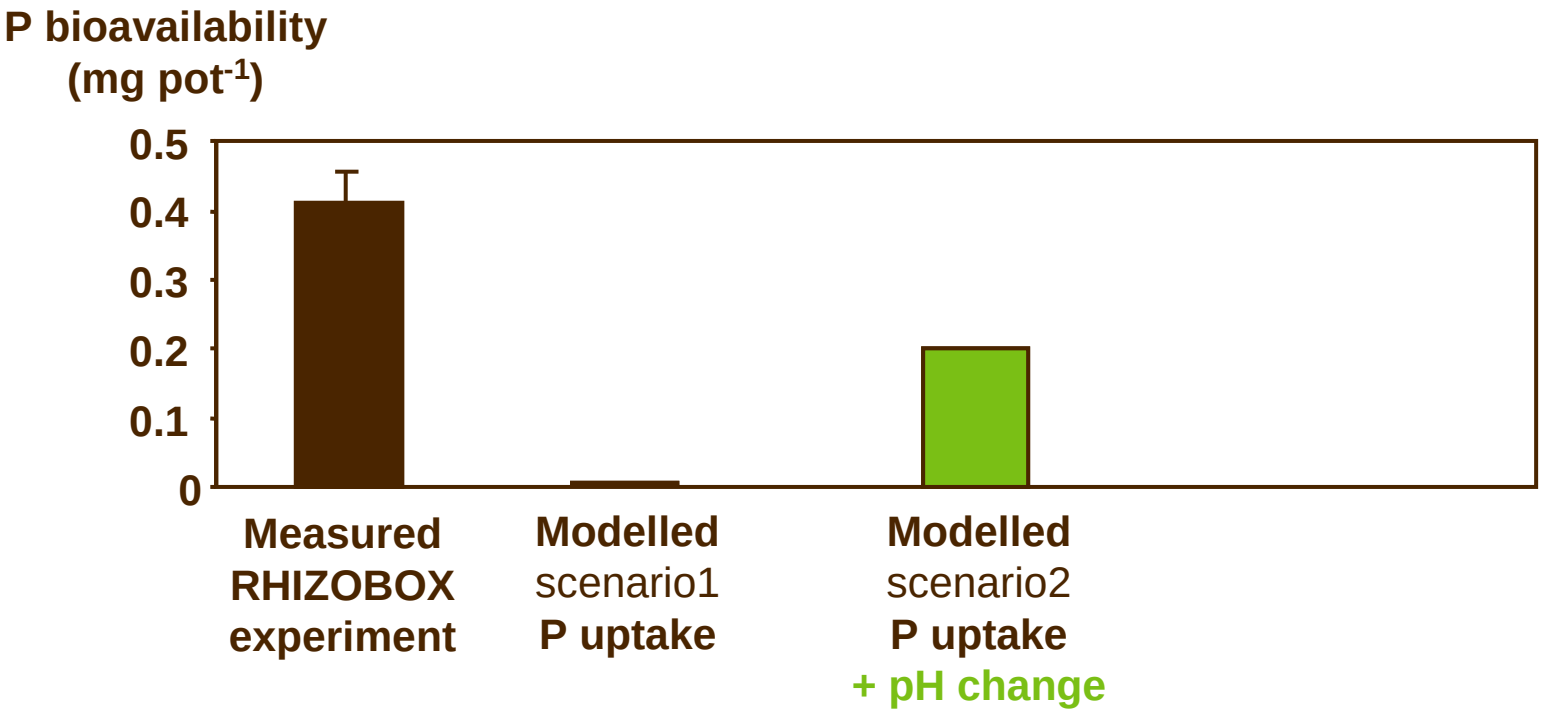


Phosphorus bioavailability – Nothing but a rhizosphere story

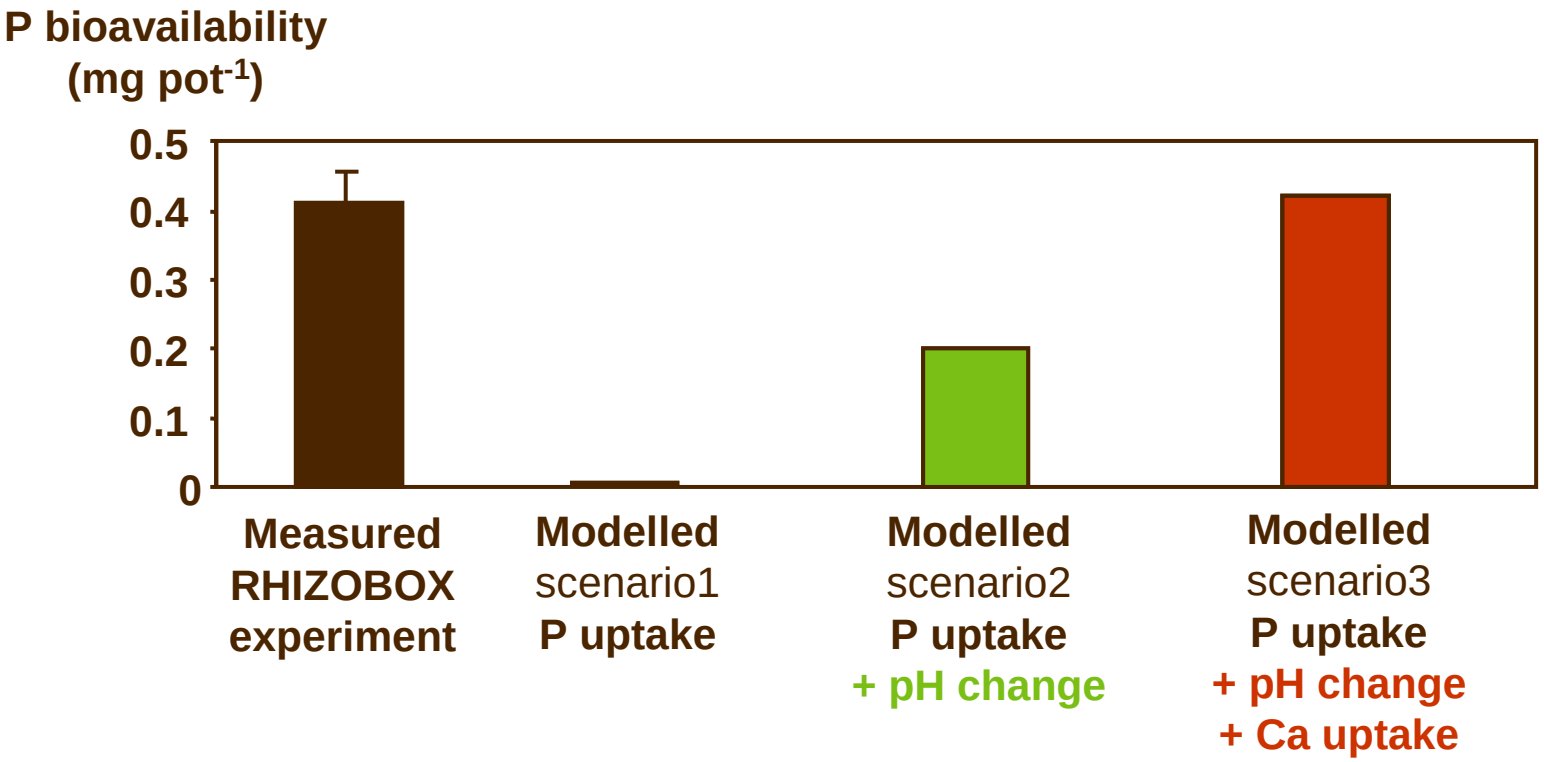
– C. Plassard –



Phosphorus bioavailability – Nothing but a rhizosphere story



Phosphorus bioavailability – Nothing but a rhizosphere story

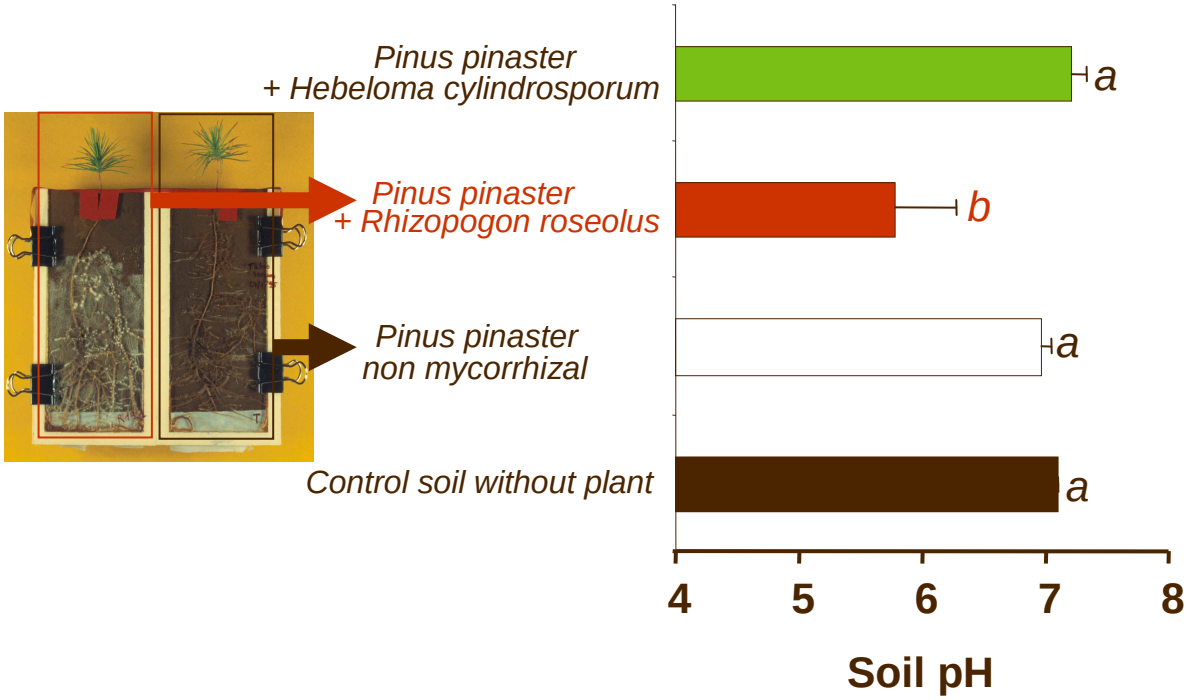


P bioavailability for durum wheat was adequately predicted by a mechanistic adsorption model* when accounting for pH change and Ca uptake on top of P uptake in the studied luvisol (P0 treatment)

(Devau, Le Cadre, Hinsinger & Gérard, 2009 – unpubl.)

* according to model published by *Devau, Le Cadre, Hinsinger & Gérard, 2009 – Annals Bot. 105*

Phosphorus bioavailability –
Nothing but a rhizosphere story



Changes of pH in the rhizosphere of young pine trees as a function of their mycorrhizal status

(Casarin, Plassard & Arvieu, 2003 *- Agronomie 23)*

bioavailability

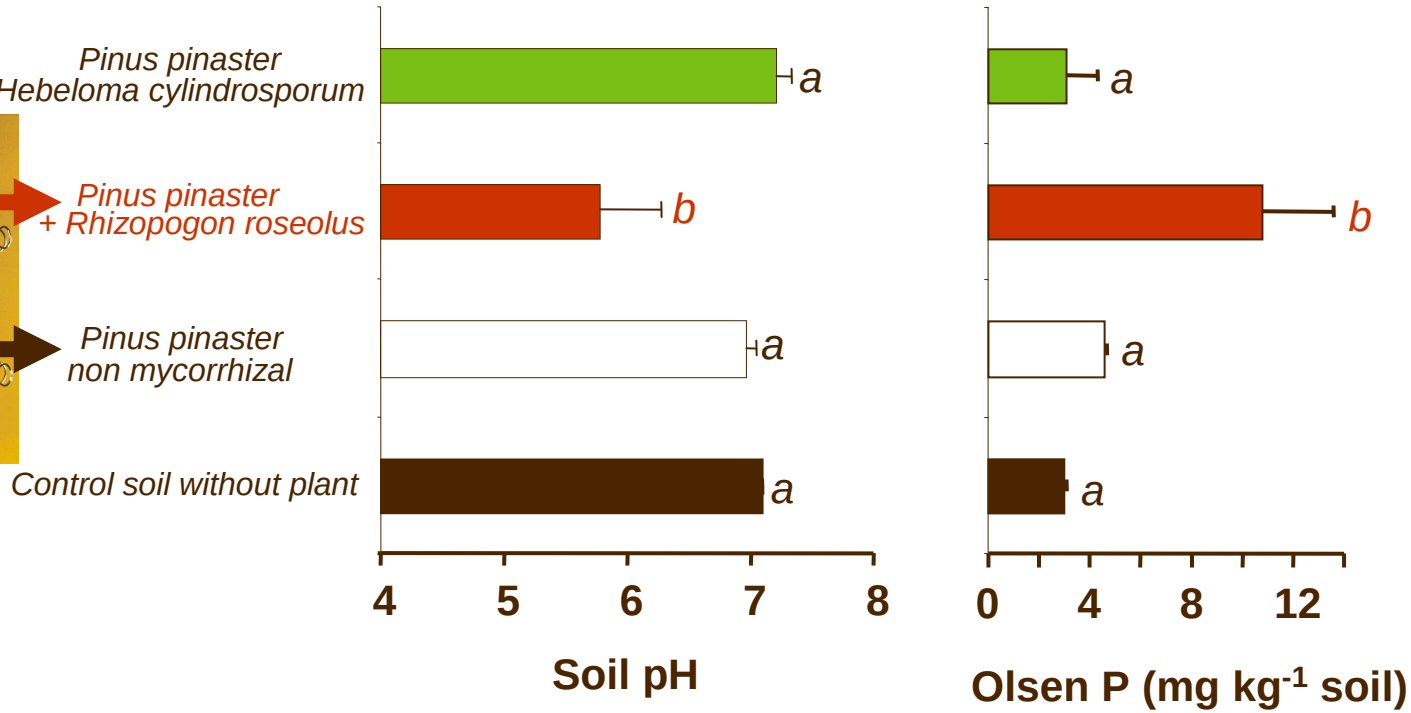
availability

Shoot P concentration (mg g^{-1} DM)

0.32 [a]

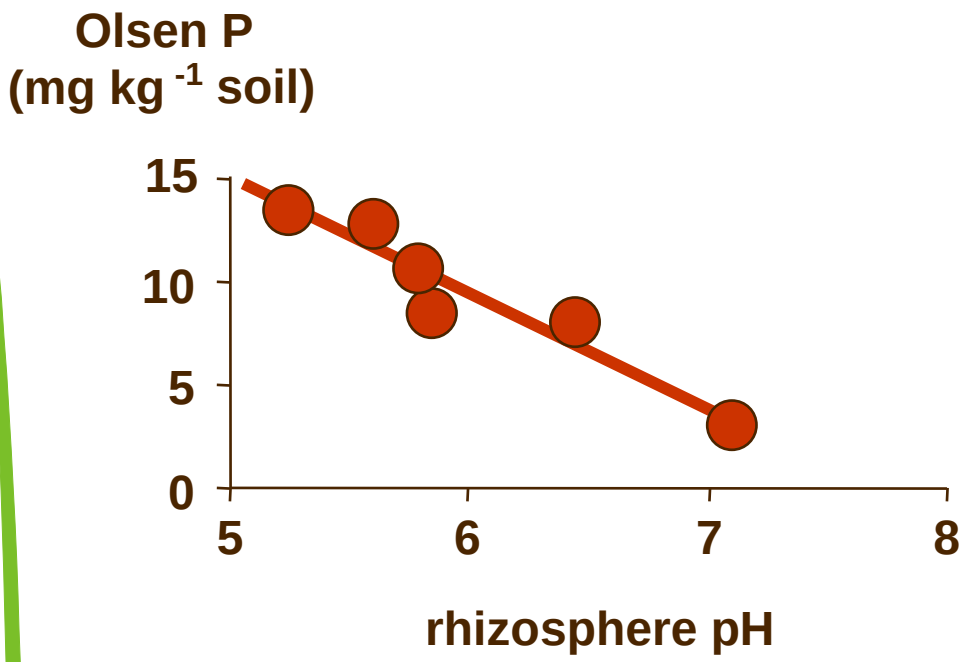
0.75 [b]

0.28 [a]



Changes of pH and P (bio)availability in the rhizosphere of young pine trees as a function of their mycorrhizal status

(Casarin, Plassard & Arvieu, 2003 - Agronomie 23)

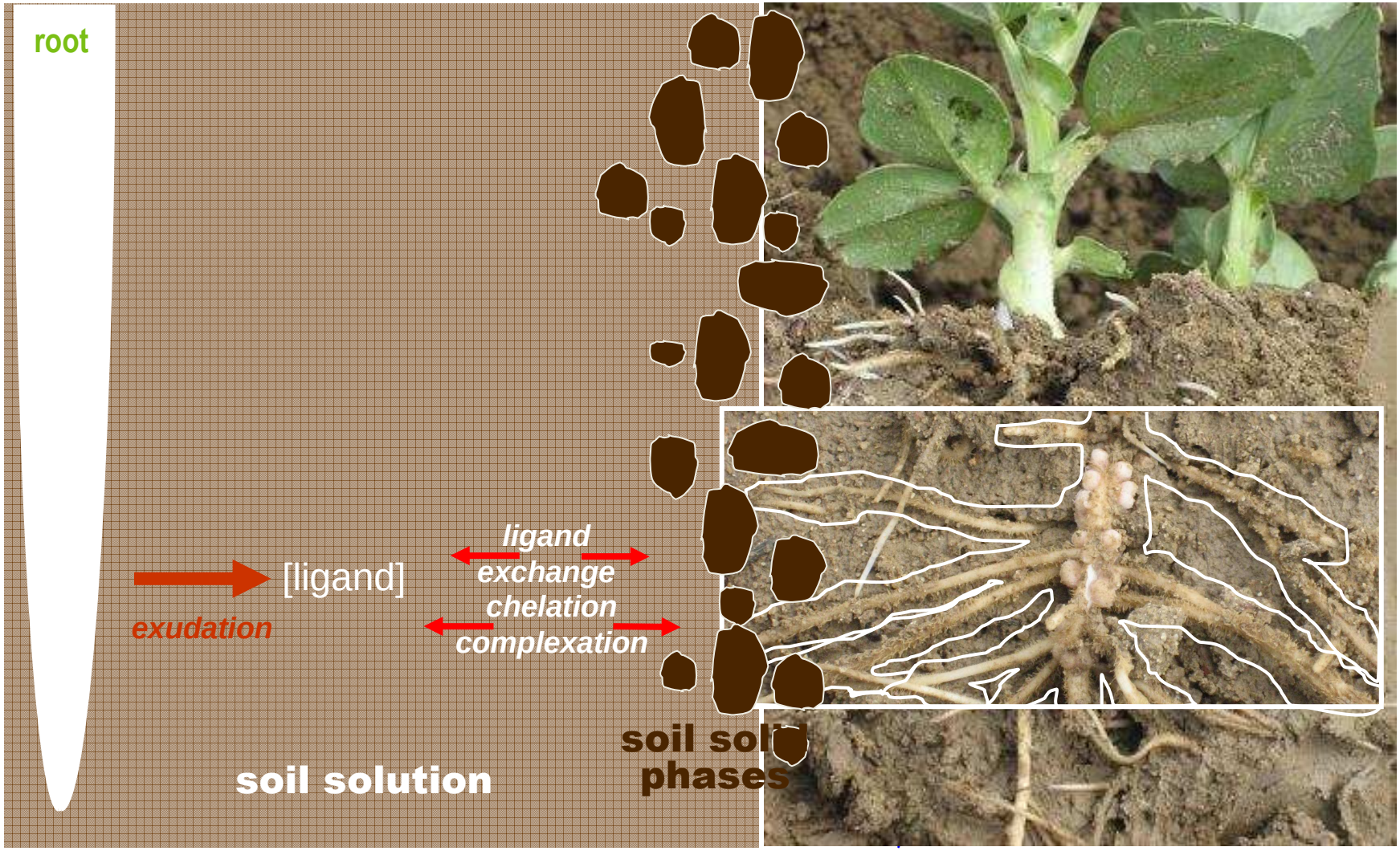


P availability (Olsen P) as a function of pH in the rhizosphere of pine mycorrhized by *Rhizopogon roseolus*

(Casarin, Plassard, Hinsinger & Arvieu, 2004 – New Phytol. 163)

Phosphorus bioavailability – Nothing but a rhizosphere story

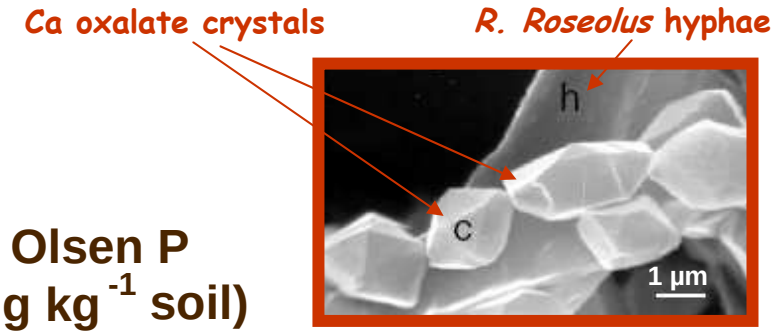
– C. Plassard –

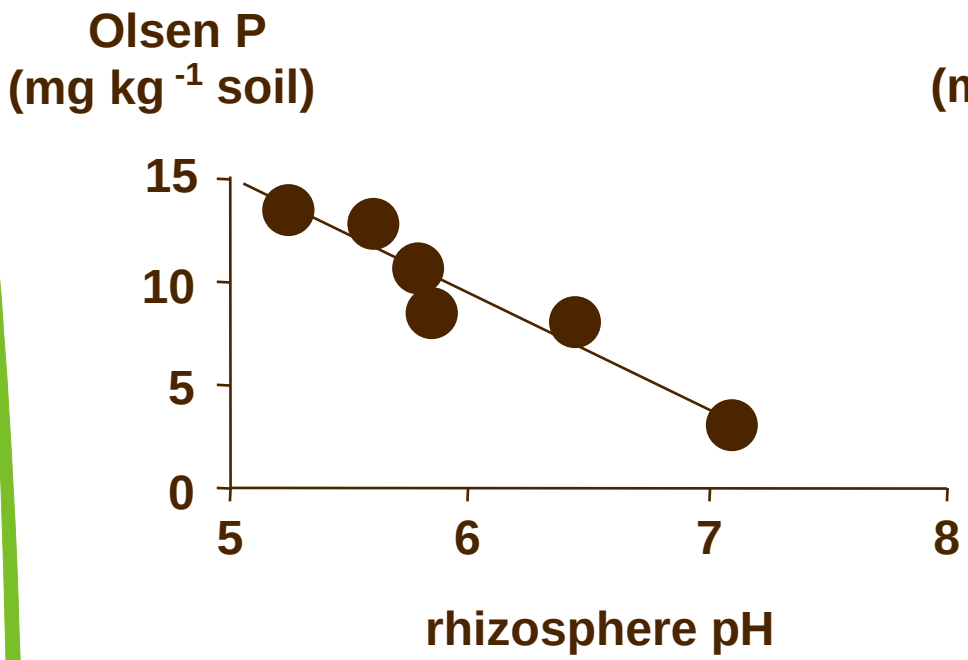


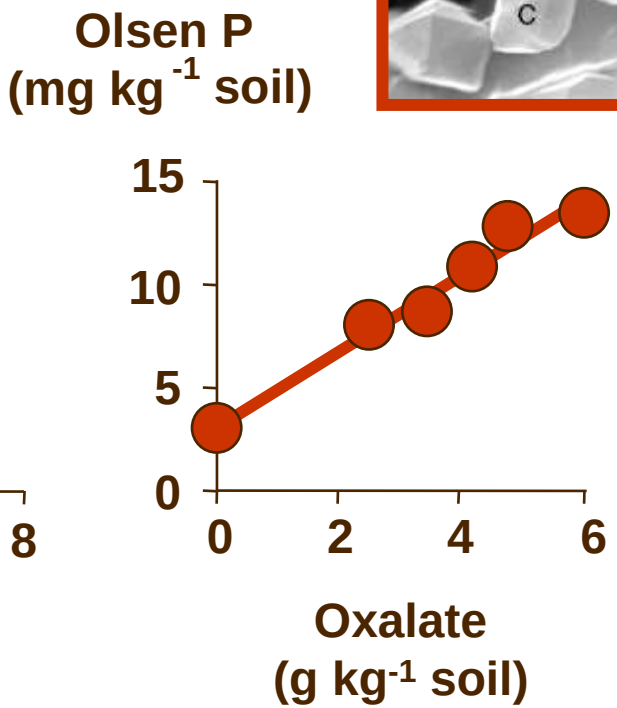
Major biogeochemical processes determining P bioavailability in the rhizosphere

(Hinsinger, Gobran, Gregory & Wenzel, 2005 – New Phytol. 195
Hinsinger, Jaillard, Le Cadre & Plassard, 2007 – Oceanis 33)

Phosphorus bioavailability – Nothing but a rhizosphere story



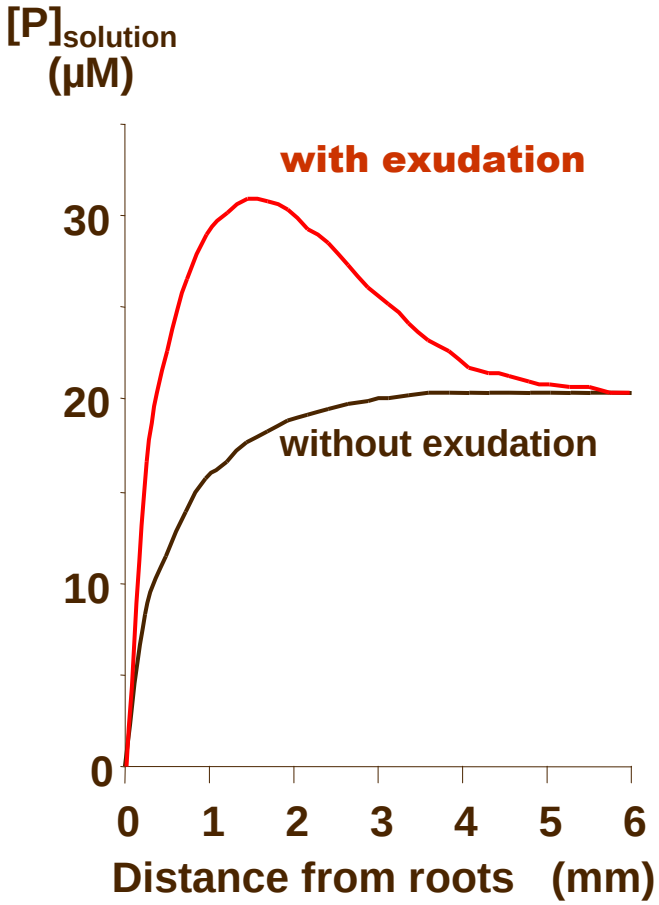


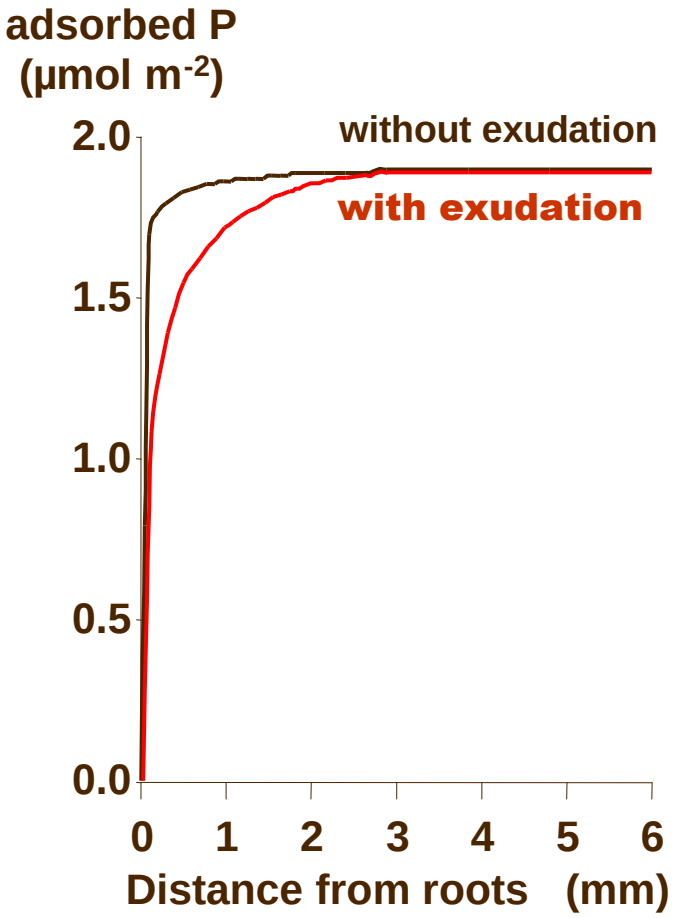


P availability (Olsen P) as a function of pH and oxalate concentration in the rhizosphere of pine mycorrhized by *Rhizopogon roseolus*

(Casarin, Plassard, Hinsinger & Arvieu, 2004 – New Phytol. 163)

Phosphorus bioavailability – Nothing but a rhizosphere story

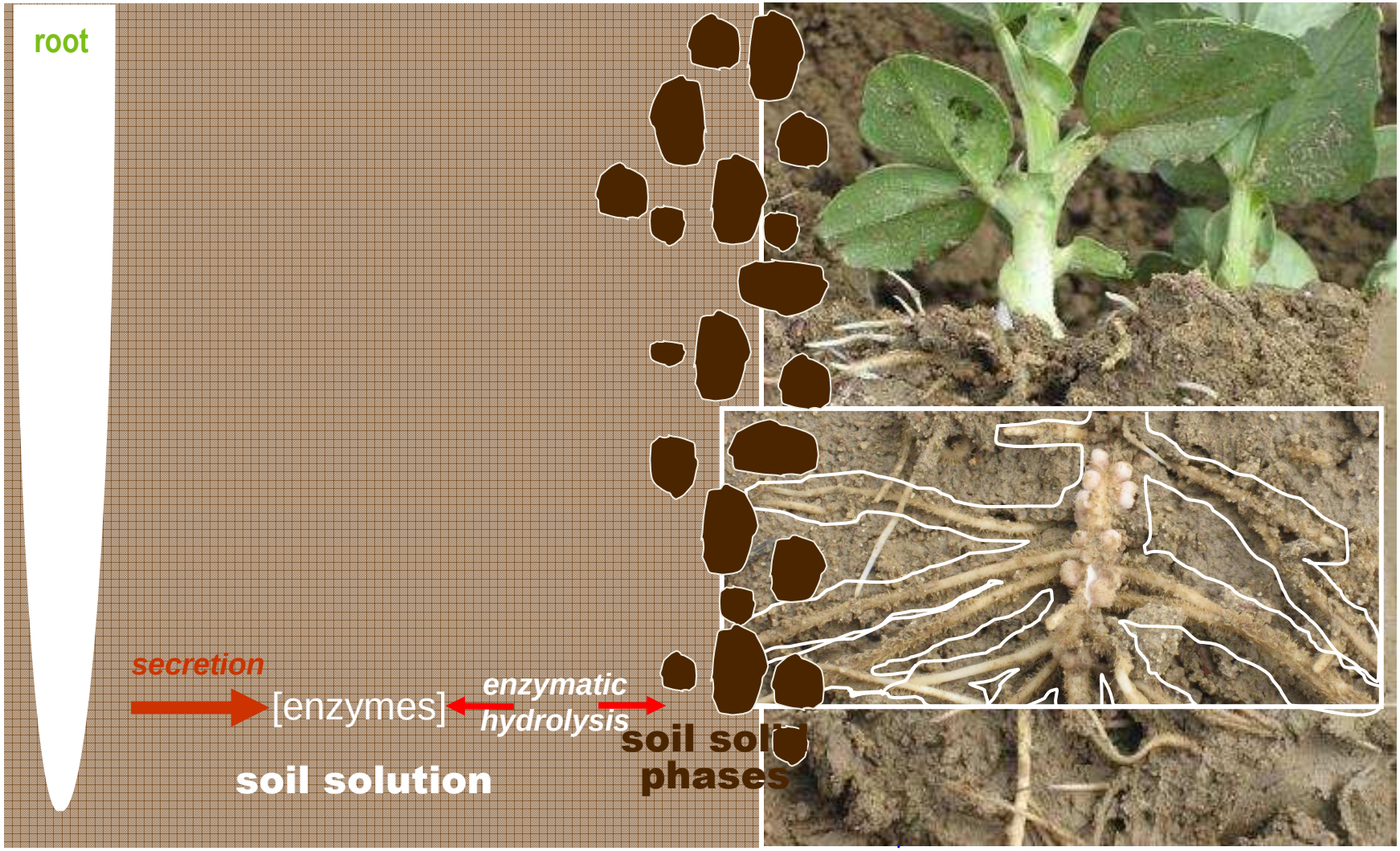




Solution P concentration and the desorption of goethite-P increase as a result of citrate exudation in the rhizosphere of maize according to model simulations *(Geelhoed, van Riemsdijk & Findenegg, 1999 – Eur. J. Soil Sci. 50)*

Phosphorus bioavailability – Nothing but a rhizosphere story

– C. Plassard –



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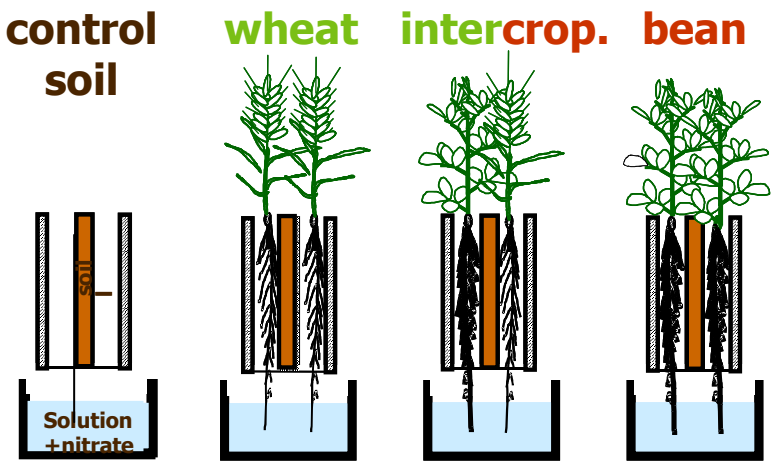
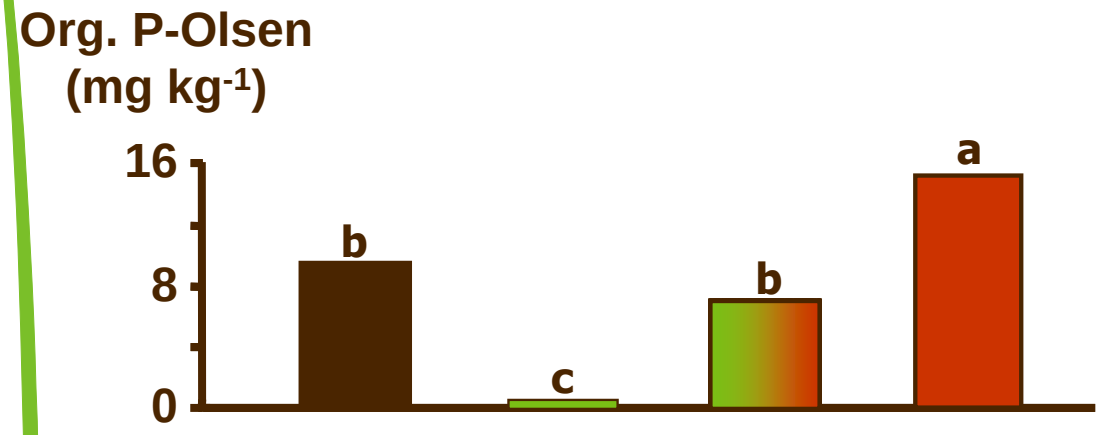
Phosphorus bioavailability – Nothing but a rhizosphere story





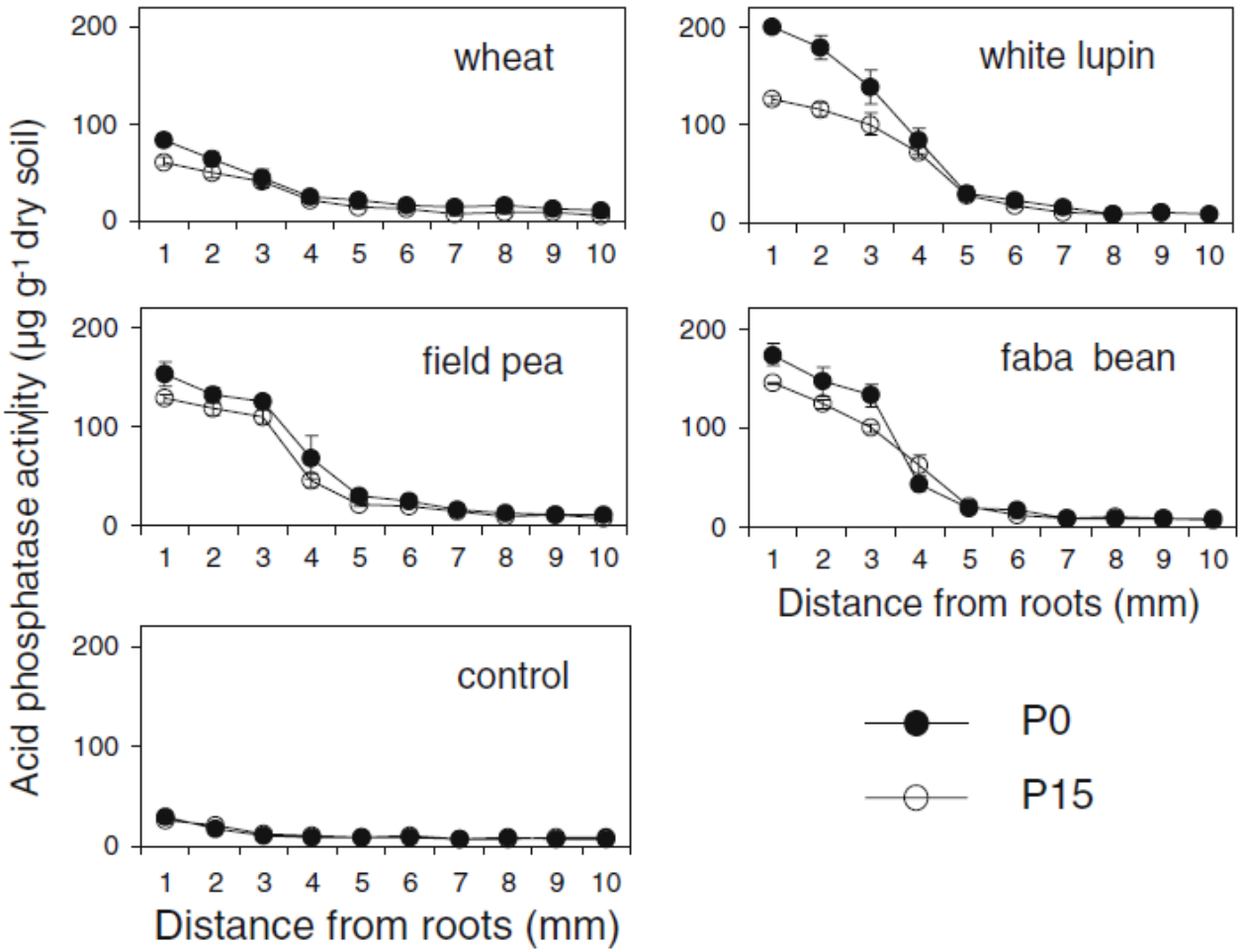
→ **wheat depletes org. P**

→ **while c. bean increases this pool**

Decreased/increased availability of organic P (Olsen extract) in the rhizosphere of wheat and N_2-fixing bean grown alone or intercropped

(Li, Shen, Zhang, Clairotte, Drevon, Le Cadre & Hinsinger, 2008 – Plant Soil 312)

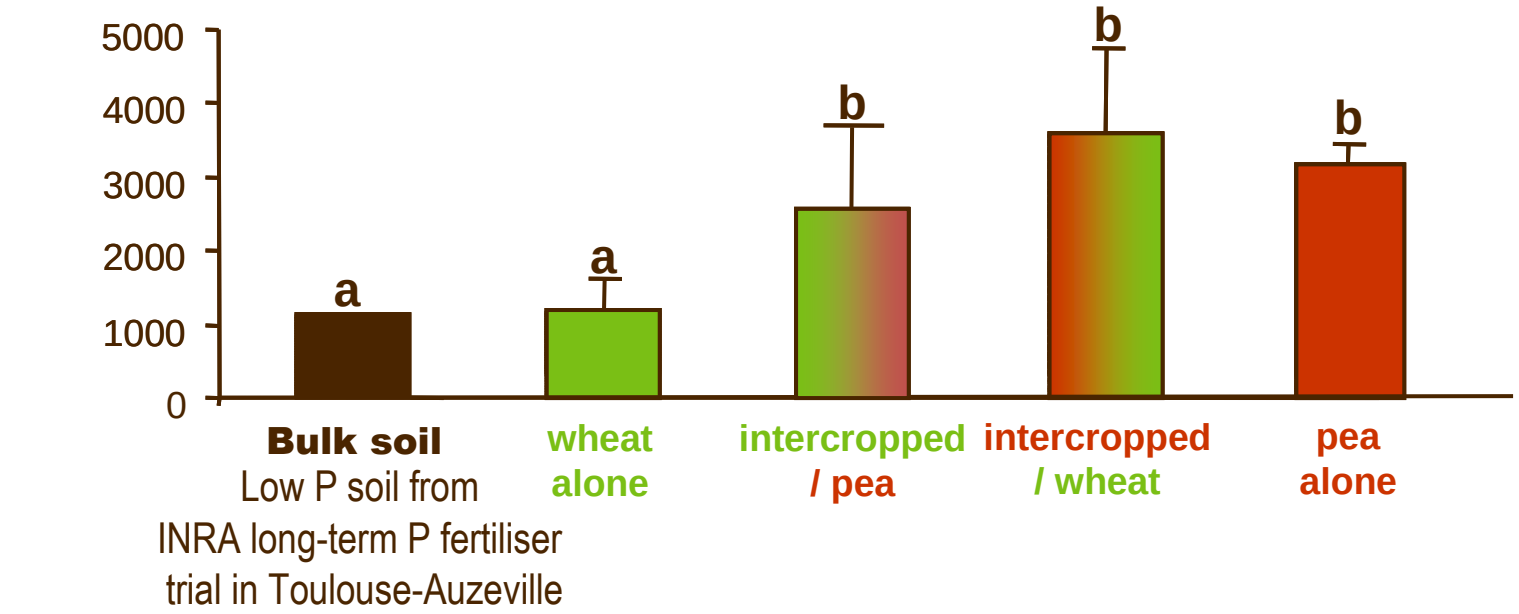
Phosphorus bioavailability – Nothing but a rhizosphere story



Acid phosphatase activity is consistently increased in the rhizosphere for a range of crop species, relative to unplanted control soil

***(Nuruzzaman, Lambers, Bolland & Veneklaas, 2006** – Plant Soil 281)*

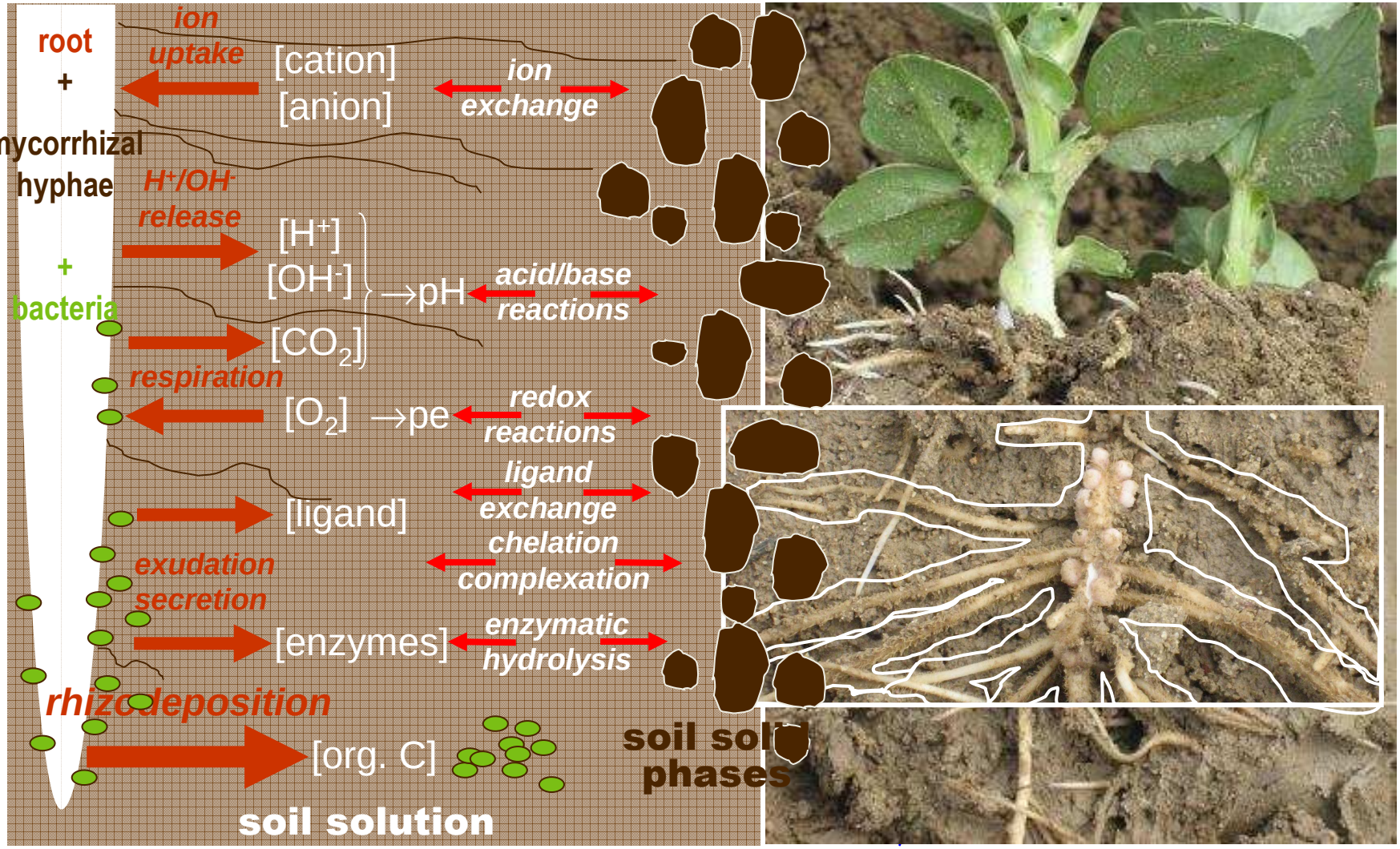
Phosphorus bioavailability – Nothing but a rhizosphere story



Phosphatase activity is enhanced in the rhizosphere of chickpea and durum wheat (only) when intercropped with chickpea (pot experiment)

(Duputel, Betencourt, Colomb & Hinsinger, 2010 – unpubl.)

Phosphorus bioavailability – Nothing but a rhizosphere story



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(Hinsinger, Gobran, Gregory & Wenzel, 2005 – New Phytol. 195
Hinsinger, Jaillard, Le Cadre & Plassard, 2007 – Oceanis 33)

→ conclusions

→ Phosphorus bioavailability is a rather complicated story

→ Nothing but a rhizosphere story

→ the necessary ecological intensification of agroecosystems

→to face Phosphorus scarcity

shall make better use of all those tricks evolved by roots and rhizosphere microorganisms to increase soil P resource acquisition efficiency

→ acknowledgements : funding body…

ANR-08-STRA-11

→ thanks for your attention

→ **see you there**

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