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
\(10^{15} \text{ g World – USSR}\)

- **Green revolution**
- **Considerable increase in N and P use**

Global cereal production and fertiliser consumption over past 40 yrs

\(\text{Tilman, Cassman, Matson, Naylor & Polasky 2002 – Nature 418}\)
Global cereal production and fertiliser consumption over past 40 yrs

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

→ 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 ???

→ Considerable decrease in N and P efficiency
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)
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

Barber-Cushman models and alike, incl. most recent P uptake models largely underestimate P bioavailability in low P soils

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

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

bioavailability is the rate at which a chemical compound 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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... taking account of the time factor:

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

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

**bioavailability** is the __amount of a chemical 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 constituent – soil solution interactions
- Potentially available concentration: sorbed, dissolved complex/free species (speciation)

→ ISO/DIS 17402 (ISO, 2006)
  (Harmsen et al., 2005 – Land Contam. Reclam. 13; Harmsen, 2007 – J. Environ. Qual. 36)
**Phosphorus bioavailability – Nothing but a rhizosphere story**

- **Environmental availability**
  - Total soil concentration
  - Soil constituent – soil solution interactions
  - Potentially available concentration: sorbed, dissolved complex/free species (speciation)

**Availability** is nothing but a surrogate of bioavailability that can be measured by soil testing procedures (chemical analyses) and is thus independent 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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Environmental bioavailability

→ → → →

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

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

« 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)
the bio-influenced zone of a plant root is the so-called rhizosphere ...
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)
the rhizosphere is a site of intense root–microbe-soil biogeochemical interactions

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Environmental availability

- Total soil concentration
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Bio-influenced zone

Active or passive absorption

Organism

→ 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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Rhizosphere P is depleted in the rhizosphere

Rhizosphere P is depleted to a lesser extent than mobile nutrients such as N because of its lower diffusion coefficients in soils - $D_e$.

$D_e = 10^{-12} - 10^{-15} \text{ m}^2 \text{s}^{-1}$

$D_e = 10^{-10} - 10^{-11} \text{ m}^2 \text{s}^{-1}$

→ nutrient depletion rules

(Hinsinger, 2004 – Encyclopedia Plant Crop Sci.)

(Jungk, 2002 – In: Plant Roots The Hidden Half)
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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**Olsen P increased** instead of being depleted **in the rhizosphere**
of durum wheat and even more so fava bean (field sampling)
especially at low P input levels

*(Betencourt, Colomb, Cordier, Justes, Souche & Hinsinger, 2010 – unpubl.)*
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(Hinsinger, Gobran, Gregory & Wenzel, 2005 – New Phytol. 195
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Major origin of pH changes in the rhizosphere – balancing the exchanged charges

(Hinsinger, Plassard, Tang & Jaillard, 2003 - Plant Soil 248)
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- Intercropped cereal
- Symbiotic N₂ fixation
- Legume
- Rhizosphere acidification (H⁺ release)

Available P  Unavailable P

P uptake

Durum wheat / Pea intercrop INRA Auzeville
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- Available P
- Unavailable P
- Rhizosphere acidification (H⁺ release)
- Symbiotic N₂ fixation
- P uptake facilitation
- Durum wheat / Pea intercrop INRA Auzeville
INRA long-term P fertiliser trial in Toulouse-Auzeville

Olsen P (mg kg\(^{-1}\))

- Wheat
  - Bulk soil
  - Rhizosphere
  - Pea alone: +112%
  - Wheat alone: +46%

* Significant differences
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.)
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)

**P0 null**
- 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
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Available P (mg kg\(^{-1}\))

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

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

P bioavailability (mg pot$^{-1}$)

$0 \quad 0.1 \quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5$
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Measured RHIZOBOX experiment

Modelled scenario1 P uptake

P bioavailability (mg pot⁻¹)

- C. Plassard -
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P bioavailability
(mg pot\(^{-1}\))

- Measured RHIZOBOX experiment
- Modelled scenario 1 P uptake
- Modelled scenario 2 P uptake + pH change
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
Changes of pH in the rhizosphere of young pine trees as a function of their mycorrhizal status (Casarin, Plassard & Arvieu, 2003 - Agronomie 23)
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* 
(Casarín, Plassard, Hinsinger & Arvieu, 2004 – New Phytol. 163)
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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)
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)
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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)*

![Graph showing solution P concentration and adsorbed P with and without exudation](image)
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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)
Decreased/increased availability of organic P (Olsen extract) in the rhizosphere of wheat and N\textsubscript{2}-fixing bean grown alone or intercropped

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

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Systerra

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→ thanks for your attention

IPW6 – 6th International Phosphorus Workshop
Phosphorus bioavailability –
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Burswood Convention Centre
Perth, Western Australia
Sunday 25th – Friday 30th September 2011

http://rhizosphere3.com

→ see you there