

Root traits and rhizosphere characteristics determining potassium acquisition from soils

Philippe Hinsinger, Michael Bell, Philip J. White

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Root and rhizosphere-related traits determining K acquisition efficiency and placement decisions

Philippe Hinsinger



science & impact Iontpellier France



\rightarrow acknowledgements – co-authors / sponsor



Michael Bell
 Brisbane – Australia



• Philip White Dundee – Scotland / UK











→ introduction – why/how improving soil K acquisition efficiency ?

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... a unique hotspot of soil biogeochemistry determining nutrient bioavailability (Hinsinger, Bengough, Vetterlein & Young, 2009 – Plant Soil 321)





\rightarrow K mobility : mass-flow vs diffusion



Nutrient	Concentration range		
Ρ	110 μM		
K	100…1000 μM		
N	1000…10000 μM		

\rightarrow due to strong interactions with soil solid phases (adsorption/desorption)

→ range of typical K⁺ ions concentrations in soil solutions is 10-fold greater than phosphate and 10-fold smaller than nitrate

= a major constraint for K acquisition

(Hinsinger et al. 2011 – Plant Soil / Marschner Review)





\rightarrow K mobility : mass-flow vs diffusion



	Nutrient	Mass-flow	Diffusion
Least mobile	Р	7%	93%
	K	18%	82%
	Ν	79%	21%
	Ca or Mg	>100%	-
Most mobile	S	>100%	-

Respective contributions of mass-flow and diffusion to nutrient acquisition by maize

(Barber 1995)

 \rightarrow K^+ ions are poorly mobile in soils

more than phosphate and much less than nitrate

= a major constraint for K acquisition

(Hinsinger et al. 2011 – Plant Soil / Marschner Review)





ightarrow K mobility : mass-flow vs diffusion





 \rightarrow steep K⁺ concentration gradient promoting K⁺ diffusion

Depletion of K⁺ ions in the rhizosphere extends several mm

(Hinsinger 2004 – Encyclopedia of Plant and Crop Science)





\rightarrow K mobility : mass-flow vs diffusion





(Walker and Barber, 1962)

 \rightarrow Rb or K uptake by roots and rhizosphere depletion occur over a small volume of soil due to poor mobility of Rb⁺ or K⁺ ions in soils

= a major constraint for K acquisition

(Hinsinger et al. 2011 – Plant Soil / Marschner Review)



Rhizosphere depletion of ⁸⁶Rb due to ion uptake by 13-day old maize roots (Walker and Barber 1962 – Plant Soil 17)



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



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



\rightarrow K availability vs K bioavailability





Pools of K and processes determining K availability in soils

(Hinsinger, 2006 – Encycl. Soil Science 2nd Ed.)





\rightarrow K availability vs K bioavailability





Pools of K and processes determining K availability in soils

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ightarrow K availability vs K bioavailability







Large depletion of exchangeable K in the rhizosphere within 4 days of plant growth

- Iong-term K fertilizer trial of Gembloux, Belgium -(Hinsinger 2004 – Encyclop. Plant Crop Science)





ightarrow K availability vs K bioavailability





Large depletion of exchangeable K in the rhizosphere within 4 days of plant growth contributing 40-80% of K acquisition by oilseed rape - long-term K fertilizer trial of Gembloux, Belgium -(Hinsinger 2004 – Encyclop. Plant Crop Science)

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\rightarrow K availability vs K bioavailability







\rightarrow K availability vs K bioavailability







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\rightarrow K distribution : topsoil *vs* subsoil K availability





 \rightarrow some soils can exhibit strong vertical gradients while others show more even distribution of K with depth while while others show more even distribution of K with depth



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→ large contribution of subsoil K, depending on its K content % uptake from subsoil K



(Kuhlmann 1990 – Plant Soil 127)



 \rightarrow root morphological traits determining the K foraging capacity of plants



\rightarrow root system architecture and plasticity

 \rightarrow root length and growth

 \rightarrow root hairs and mycorrhiza





\rightarrow root system architecture and plasticity



K uptake from the subsoil in a loess soil with topsoil exch. K = 90 mg K kg⁻¹ soil as related to rooting depth of different crop species

(Kuhlmann 1990 – Plant Soil 127)

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\rightarrow no plasticity for K acquisition, as for P or N



Root proliferation (foraging) in the central compartment (100-fold enriched) in hydroponically-grown barley : does not occur for K (Drew, 1975 – New Phytol. 75)





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Simulation of the volume of depletion zones for poorly-mobile nutrients exhibiting different diffusion coefficients (De) in 13-day old common bean (Ge, Rubio & Lynch, 2000 – Plant Soil 218)



Relation between efficiency* and total length of the root system (4096 simulations) (Pagès, 2011 – Plant Cell Environ. 34)

 * the ratio of the colonized volume to the volume of a virtual cylinder with the same length as the whole root system

 $e = EV/(\pi * TL * d_i^2)$

→ increasing root length is less necessary for K than for phosphate, but more so than for nitrate







\rightarrow substantial variation within a given crop species



(Gahoonia & Nielsen, 1995 – Plant Soil 262)

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\rightarrow root hairs and mycorrhiza





\rightarrow while mycorrhizal hyphae can considerably increase the actual volume of the rhizosphere / depletion zone (extending up to several centimeters from root surface),

(Jakobsen, Abbott & Robson, 1992 – New Phytol. 120; Thonar, Schnepf, Frossard, Roose & Jansa, 2011 – Plant Soil 339)

their quantitative contribution to K acquisition is little documented, compared with P acquisition





 \rightarrow root physiological traits determining the K mining capacity of plants



\rightarrow K uptake and depletion in the rhizosphere

\rightarrow pH modification in the rhizosphere

\rightarrow exudation in the rhizosphere





ightarrow K uptake and depletion in the rhizosphere





Distance from root surface (mm)

 \rightarrow steep depletion: rhizosphere K concentration \approx 2-3 μM

 \rightarrow driving force for root-induced release of interlayer K

Depletion of K in the rhizosphere of maize in two different soils (Claassen & Jungk 1982 - Z. Pflanzenernaehr. Bodenkd. 145)











Low K concentration in the soil solution (below a threshold value of 3-4 µM) is promoting the release of nonexchangeable K in soils (Springob & Richter, 1998 – J. Plant Nutr. Soil Sci. 161)





ightarrow K uptake and depletion in the rhizosphere



→ wheat and sugar beet can take up more K than potato at low concentrations

K uptake kinetics of three crop species, showing that poor K acquisition efficiency of potato is related to its lesser uptake capacity (higher K_m) (Steingrobe & Claassen, 2000 – J. Plant Nutr. Soil Sci. 163)







Rhizosphere processes possibly contributing to the mining strategy of plant roots (Hinsinger et al. 2011 – Plant Soil / Marschner Review)





\rightarrow root mining strategy resulting in increased rhizosphere K availability



Rhizosphere processes possibly contributing to the mining strategy of plant roots

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\rightarrow root mining strategy resulting in increased rhizosphere K availability



→ pH modification in the rhizosphere (Blossfeld, S considerable: up to +/- 2-3 pH units & ^(Blossfeld, S)

(Blossfeld, Schreiber, Liebsch, Kuhn & Hinsinger 2013 – Ann. Bot. 112)

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

resulting in K release from mica (Hinsinger, Elsass, Jaillard & Robert, 1993 – J. Soil Sci. 44)





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resulting in K release from mica (Hinsinger, Elsass, Jaillard & Robert, 1993 – J. Soil Sci. 44)

\rightarrow exudation in the rhizosphere: role of complexing carboxylates such as citrate, oxalate ?

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> ...little direct evidence except for ectomycorrhizal roots of trees resulting in K release from mica / feldspar (Wallander & Wickman, 1999 – Mycorrhiza 9)

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Root-induced acidification and increase of available K at depth in the rhizosphere of eucalypts in a deep, poor oxisol in Brazil (Pradier, Hinsinger, Laclau, Bouillet, Guerrini, Gonçalves, Asensio, Abreu-Junior & Jourdan 2017 – Plant Soil in press)







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Relationship between pH and available K across soil depths in the bulk soil in a deep, poor oxisol in Brazil (Pradier, Hinsinger, Laclau, Bouillet, Guerrini, Gonçalves, Asensio, Abreu-Junior & Jourdan 2017 – Plant Soil in press)



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Relationship between pH and available K across soil depths in the bulk soil / rhizosphere of eucalypts in a deep, poor oxisol in Brazil (Pradier, Hinsinger, Laclau, Bouillet, Guerrini, Gonçalves, Asensio, Abreu-Junior & Jourdan 2017 – Plant Soil in press)



\rightarrow conclusions : promising subterranean strategies

Manipulating either root traits or microbial communities

→ root and rhizosphere strategies

for an ecological intensification of agroecosystems (Bakker, Manter, Sheflin, Weir & Vivanco, 2012 – Plant Soil)

- **Root foraging strategies**
 - Root architecture
 - Root length and growth
 - Root hairs
 - Mycorrhizal symbiosis
 + PGPR-induced promotion
- **Root mining strategies**
 - Rhizosphere K depletion
 - Rhizosphere acidification
 - Organic C exudation
 - Microbial activity stimulation

\rightarrow conclusions : root traits for nutrient acquisition



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Topsoil foraging for P Early root vigour Large root biomass or root/shoot ratio

More cortical aerenchyma

Large root surface area (lateral rooting, root hairs) in topsoil

High root length density

Proliferation in patches of high P phytoavailability

Mycorrhizal associations

Greater exudation of H⁺ and organic compounds

Greater exudation of phosphatases

Greater phosphate uptake capacity of root cells



Early root vigour Large root biomass or root/shoot ratio

Large root surface area (lateral rooting, root hairs)

High root length density

Proliferation in patches of high K phytoavailability

Greater exudation of H⁺ and organic compounds

Greater K⁺ uptake capacity of root cells

Greater water uptake through transpiration



Steep, cheap and deep for N Early root vigour Large root biomass or root/shoot ratio

More cortical aerenchyma

Initial roots with shallow growth angles

Later roots with steep root growth angles

Large root surface area (lateral rooting, root hairs)

High root length density

Greater N-uptake capacity of root cells

Greater water uptake through transpiration

Greater exudation of Biological Nitrification Inhibitors

Greater association with organisms fixing N₂



(White, George, Gregory, Bengough, Hallett & McKenzie 2013 – Ann. Bot. 112)

Intermediate response for K

More cortical aerenchyma



\rightarrow conclusions : root traits for nutrient acquisition









topsoil foraging

intermediate response

steep, cheap and deep

→ a matter of trade-offs when aiming for improving simultaneously P, K and N (or water) acquisition efficiency

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(White, George, Gregory, Bengough, Hallett & McKenzie 2013 – Ann. Bot. 112)











\rightarrow any questions ?





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\rightarrow Pyramiding the foraging and mining strategies of P acquisition – numerical modelling to find novel ideotypes



Coupling the ArchiSimple and MIN3P models in a cereal (e.g. maize) – Rhizosphere acidification is solubilising more P where root density is greatest (Gérard, Blitz, Hinsinger & Pagès 2016 – Plant Soil)









Simulated P acquisition as a function of root architecture in common bean grown in a soil exhibiting a strong P availability gradient in the topsoil (Ge, Rubio & Lynch, 2000 – Plant Soil 218)

