New insights on the role of radial root conductivity on the overall water uptake dynamics

Guillaume Lobet, Valentin Couvreur, Mathieu Javaux and Xavier Draye
Water fluxes in the plant

Root image from Kutschera et al., 1997
Water fluxes in the plant

\[ J = K \cdot \Delta \psi \]

Root image from Kutschera et al., 1997
Relative ranges of conductivities

Draye et al. 2010, J Exp Bot 61 (8)
Relative ranges of conductivities

Draye et al. 2010, J Exp Bot 61 (8)
Hydraulics and architecture
Influence of the soil conductivity

Simulation with R-SWMS

Clay
Clay-loam
Loam

Javaux et al. 2008, Vadoze Zone J 7
Can we extend these concepts to study the plant behaviour?
Can we extend these concepts to study the plant behaviour?

Conceptual framework → Proof of concept → Real situation
Can we extend these concepts to study the plant behaviour?

Conceptual framework → Proof of concept → Real situation

Experimental platform
**Experimental platform**

- **Zea mays**
- **Rhizotrons**
- **Visible light**
- **Rhizotron**
- **CCD camera**
- **Soil θ**

**Experimental platform**

- Visible light
- Rhizotron
- CCD camera
- Soil θ
Visible light

Rhizotron

CCD camera

Soil $\theta$
Experimental platform

Zea mays

Light Transmission

Visible light

Rhizotron

CCD camera

Soil $\theta$

Rhizotrons
Water uptake follows a downward dynamics during a water deficit episode.
Local uptake analysis

Root data

Water potential data

Local analysis
Kr influences local uptake rates

- **Local uptake rates**

- **Uptake rates (% Cont)**
  - Control
  - Kr+

- Graph shows higher uptake rates for Kr+ compared to Control.
Uptake rate influences water depletion

Water depletion around the roots

Cont

Kr+

Water depletion (% Cont)

Control

Kr+

a

b
Water depletion influences dynamics

Relative uptake depth

Uptake depth (% of total root depth)

Hours of water shortage

R² = 0.9695

R² = 0.9633
Integration of root and soil parameters

- High uptake rate
- Soil water depletion
- Local conductivity drop
- Uptake moves downward
- “Drought” in a wet soil
Integration of root and soil parameters

- Cont
- Kr+

↑ Kr
↓
↑ Flux
↓
↑ RLD
↓

High uptake rate
↓
Soil water depletion
↓
Local conductivity drop
↓
Uptake moves downward
↓
“Drought” in a wet soil
Integration of root and soil parameters

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- Soil water depletion
- Local conductivity drop
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↓  ↓  ↓

High uptake rate

Soil water depletion

Local conductivity drop

Uptake moves downward

“Drought” in a wet soil

Introduction
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Integration of root and soil parameters

- High uptake rate
- Soil water depletion
- Local conductivity drop
- Uptake moves downward
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- “Drought” in a wet soil
New insights

Kr → RLD → Flux → Soil → Local conductivity drop

- Decrease water availability
- Partial Root Zone Drying
- Decrease yield
- Increase WUE
New insights

Local conductivity drop

Kr → RLD → Flux → Soil

Decrease water availability

Decrease yield

Partial Root Zone Drying

Increase WUE
**New insights**

- **Kr**
- **RLD**
- **Flux**
- **Soil**

**Local conductivity drop**

- **Decrease water availability**
  - **Decrease yield**
- **Partial Root Zone Drying**
- **Increase WUE**
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- RLD
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Decrease yield

Increase WUE
Practical implications at the plant scale

- Influence uptake dynamics
  - Change soil properties
  - Change root characteristics

- Change root architecture
  - King et al. 2003, Ann Bot 91 (3)

- Change Kr and Kx
  - Richards et al., 1989, Aust J Agr Res 40
Practical implications at the plant scale

Influence uptake dynamics

→

Change soil properties

Change root characteristics

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  King et al. 2003, Ann Bot 91 (3)

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- Change soil properties
  - Computer modeling can be used to design water extraction strategies and ideotypes
Modelling as an ideotype design tool

R-SWMS

Kx

Kr
Modelling as an ideotype design tool

SSD

Standard Sink Distribution

Depth (cm)

RLD vs SSD
Modelling as an ideotype design tool

PlaNet - Maize
Importance of multi-scale and space-time dynamics

Need to integrate root system architecture and hydraulic properties (root and soil)

Uptake pattern matters

Experimental and modeling tools are available
Collaborations

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Ian Dodd

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Université catholique de Louvain
Walloon region
P.A.I.
Influence of the soil conductivity

Simulation with R-SWMS

SAME:
Root architecture
Root hydraulic properties
Transpiration

DIFFERENT:
Soil type

Uptake distribution

Javaux et al. 2008, Vadoze Zone J 7
Water uptake follows a downward dynamics

% of roots in depleted areas increases with time
Water uptake follows a downward dynamics

% of roots in depleted areas increases with time
Why does “radialness” matters?

Water flow \( (m^3s^{-1}) \)

Flux \( (m^3.m^{-2}.s^{-1}) \)

\[ \theta \quad (m^3.m^{-3}) \]

\[ K_s \quad (m^3.m^{-3}) \]

High influence of the uptake rate
Conductivities along a root

- **Root axial conductivity** (Kx)
  - Root type
  - Root segment age
  - Environment

- **Root radial conductivity** (Kr)
  - Root type
  - Root segment age
  - Environment

- **Soil conductivity** (Ks)
  - Soil type
  - Water content (θ)
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Conductivities along a root

Soil conductivity ($K_s$)

- Soil type
- Water content ($\theta$)

Root radial conductivity ($K_r$)

- Root type
- Root segment age
- Environment

Root axial conductivity ($K_x$)

- Root type
- Root segment age
- Environment
Conductivities along a root

- **Soil conductivity (Ks)**
  - Soil type
  - Water content ($\theta$)

- **Root radial conductivity (Kr)**
  - Root type
  - Root segment age
  - Environment

- **Root axial conductivity (Kx)**
  - Root type
  - Root segment age
  - Environment

**Equations:**

- $\mathbf{K_r}$
- $\mathbf{F}$
Conductivities along a root

- Root axial conductivity ($K_x$)
- Root radial conductivity ($K_r$)
- Soil conductivity ($K_s$)

Factors:
- Root type
- Root segment age
- Environment
- Soil type
- Water content ($\theta$)
Integration at the root system level

$$\sum K = \sum \frac{1}{K_x} + \sum \frac{1}{K_r} + \sum \frac{1}{K_s}$$

Water preferably takes the path of maximum conductance (for a given $\Delta \psi$)

The **lowest** conductance will be the limiting factor
Integration at the root system level

\[ \sum K = \sum \frac{1}{K_x} + \sum \frac{1}{K_r} + \sum \frac{1}{K_s} \]

Water preferably takes the path of maximum conductance (for a given \( \Delta \psi \))

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New insights

Kr  RLD  Flux  Soil

Local conductivity drop
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New insights

Kr → RLD → Flux → Soil → Local conductivity drop → Decrease water availability
Local conductivity drop

Decrease water availability

Decrease yield
Local conductivity drop

- Kr
- RLD
- Flux
- Soil

Decrease water availability
Partial Root Zone Drying
Decrease yield
New insights

- **Kr**
- **RLD**
- **Flux**
- **Soil**

Local conductivity drop

**Decrease water availability**

**Partial Root Zone Drying**

**Decrease yield**

**Increase yield**
New insights

Kr → RLD → Flux → Soil → Local conductivity drop

Decrease water availability
Partial Root Zone Drying

Decrease yield
Increase yield
Influence uptake dynamics
Practical implications

Influence uptake dynamics ➔ Change soil properties
Practical implications

Influence uptake dynamics \rightarrow \text{\color{red}Change soil properties}
Practical implications

Influence uptake dynamics → Change soil properties

Change root characteristics
Practical implications

Influence uptake dynamics

Change soil properties

Change root characteristics

Change the root diameter

de Jong v. L. et al. 2006, Vadoze Zone J 5 (4)

Flux
\( (m^3 \cdot m^{-2} \cdot s^{-1}) \)

Ks
\( (m^3m^{-3}) \)
Influence uptake dynamics  \arrow{\Rightarrow}  Change soil properties

Change root characteristics

Change the root diameter
de Jong v. L et al. 2006, Vadoze Zone J 5 (4)

Change root architecture
King et al. 2003, Ann Bot 91 (3)
Practical implications

- Influence uptake dynamics
- Change soil properties
- Change root characteristics

- Change the root diameter
  - de Jong v. L. et al. 2006, Vadoze Zone J 5 (4)

- Change root architecture
  - King et al. 2003, Ann Bot 91 (3)

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Computer modeling can be used to define an ideotype
New insights

Kr → RLD → Flux → Soil

Local conductivity drop
New insights

Local conductivity drop

Kr  RLD  Flux  Soil