Identification of the heterogeneity in water transport through the unsaturated zone of lysimeters using 18-Oxygen

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Objective

• modelling transport processes in the unsaturated zone
• application of environmental isotopes $\delta^{18}$O
• quantification of preferential flow
• description of transport heterogeneity
• influence of vegetation on heterogeneity
• introduction of vulnerability diagrams
Methods

parallel flow system
- matrix flow: \( Q_m(t), C_m(t) \)
  \( \rightarrow \) Richard’s Equation, CDE
- preferential flow: \( Q_c(t), C_c(t) \)
  \( \rightarrow \) Piston Flow

fraction of preferential flow
- \( p(t) = \frac{Q_c(t)}{Q_m(t)} \)
- \( C_c(t) = C_m(t) - C_m(t) \)

\[ \omega(\tau_i) = \left( p \int_{\tau_i}^{\tau_{i+1}} g_{PFM}(\tau) d\tau + (1-p) \int_{\tau_i}^{\tau_{i+1}} g_{DM}(\tau) d\tau \right) \times 100\% \]
for \( i = 1, N \)

Vulnerability diagram

\( \omega(\tau_i) \): vulnerability
\( \tau \): transit time of tracer particle [T]
\( p \): mean fraction of direct flow

\( g(\cdot) \): weighting function \( \rightarrow \) transit time distribution function

PPM: Piston Flow Model
DM: Dispersion Model
Lumped parameter approach

\[ C_{\text{out}}(t) = \int_{0}^{t} C_{\text{inp}}(\tau) \cdot g(t - \tau) \, d\tau \]

direct flow  \rightarrow piston flow model (PFM)

matrix flow  \rightarrow dispersion-model (DM)

\[ g(\tau) = \delta(\tau - t^*) \]

assumed parameter: \( t^* = 0 \)

\[ g(\tau) = \frac{1}{\sqrt{4\pi(P_D)^* \cdot \frac{\tau}{t^*}}} \exp \left[ - \frac{(1 - \frac{\tau}{t^*})^2}{4(P_D)^* \cdot \frac{\tau}{t^*}} \right] \]

fitting parameter: \( t^*, P_D^* = D/(vz) \)

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Material

- lysimeter at Wagna research station
- maize monoculture
- 1992-2000
  - precipitation
  - leachate
  - isotopes
  - climate data
  \( \rightarrow \) ETp (Allen et al., 1998)
Isotope transport

- Introduction
- Methods
- Material
- Results
- Summary

Lumped parameter approach

- Introduction
- Methods
- Material
- Results
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Vulnerability diagrams

- fallow/intercrop
- maize monoculture

Water content

mean water content [cm³ cm⁻³]
Qc (mm)

mean water content  Qc
Summary

- The presented conceptual model combining hydrological with isotope data enables the separation and quantification of preferential and matrix flow.
- The amount of preferential flow varies between maize vegetation and fallow/intercrop periods.
- Preferential flow is accompanied by an increase of mean water content.
- The fraction of preferential flow is related to the water discharge.
- Determination of flow parameters from the lumped parameter approach together with the fractions of preferential and matrix flow give information about water flux heterogeneity.
- Vulnerability diagrams are constructed based on transit time distributions and are a helpful tool for developing groundwater protection strategies more efficiently.
Thank you for your attention