Simultaneous non-invasive measurement of soil moisture and biomass dynamics using the cosmic-ray neutron probe

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Cosmic-ray neutron sensing for simultaneous soil water content and biomass quantification in drought conditions. Water Resources Research, in revision

Cosmic-ray neutron sensing

 Soil moisture is inversely proportional to the neutron intensity

Neutron energy spectra near the surface

Thermal neutrons
Fast neutrons
Evaporation neutrons
Primary neutrons

Thermal neutron counter
Fast neutron counter

Using appropriate shielding materials the CRNS probe can be made sensitive to different neutron energies (thermal and fast neutrons)

Network of cosmic-ray neutron probes

• Within TERENO and TR32 a network of 14 cosmic-ray neutron probes is operated in the Rur catchment since 2012, with the aim to:
  – Better understand soil moisture dynamics (e.g. controlling factors and scaling properties)
  – Validation of satellite missions (e.g. SMOS, SMAP)
  – Hydrological modelling purposes (e.g. calibration, validation, data assimilation)

Biomass influences the calibration

Problem: For crops, biomass dynamics need to be assessed
Hypothesis: The relationship between thermal and fast neutron \( N_r \) contains biomass information

Biomass correction function:
\[ N_r, \text{corr} = -r \times AGB_{\text{dry}} + N_0 \]

Sugar beet experiment in 2016

Experimental setup at the TERENO test site Selhausen (1 CRS1000, 3 CRS2000/B, 1 cross calibrator)

EMI map by Rudolph et al. (2015)
Climate and thermal/fast neutron time series

Soil moisture and biomass water equivalent

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Climate and thermal/fast neutron time series

- Biomass water equivalent: hydrogen in plant tissue and plant water
- Two calibration variants: using 1 day during bare soil conditions - using the whole measurement period

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Calibration day

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Biomass correction of soil moisture estimates

- The calibration parameter \( N_0 \) correlates with \( N_r \)
- Comparison of 3 correction methods:
  - regression function between \( N_r \) and \( N_0 \)
  - correction function of Baatz et al. (2015)
  - correction using in-situ measured BWE

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Biomass correction using BWE tot estimates

- In-situ measured BWE tot
- \( N_r \)-derived BWE tot

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Aboveground biomass water equivalent

- The neutron ratio \( N_r \) correlates well with aboveground biomass water equivalent (BWEa)
- \( N_r \)-derived BWEa corresponds well with in-situ measurements, but deviations during precipitation events.
- Interpolating periods with precipitation ≥ 1.5 mm (indicated by red lines) reduces RMSE

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\( N_r \)-derived dry aboveground biomass

- Based on measured fresh/dry biomass ratios

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- Deviations due to the influence of precipitation events and uncertainties in the plant water content

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- Underestimation of plant water?
Conclusions

- Using the thermal/fast neutron-ratio we were able to:
  - Increase the accuracy of cosmic-ray neutron derived soil moisture (RMSE increased from >10 Vol.% to 1.3 Vol.%)  
  - Determine dry aboveground biomass dynamics with an accuracy of 0.14 kg/m²  
- Simultaneous non-invasive measurement of soil water content and aboveground biomass using cosmic-ray neutron sensing seems possible