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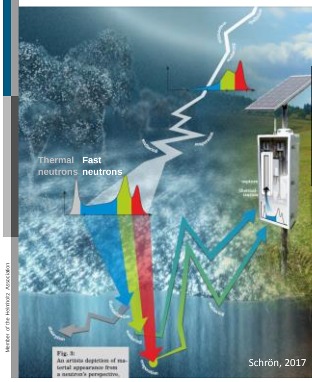
Simultaneous non-invasive measurement of soil moisture and biomass dynamics using the cosmic-ray neutron probe

Heye Bogena, Jannis Jakobi, Johan A. Huisman and Harry Vereecken

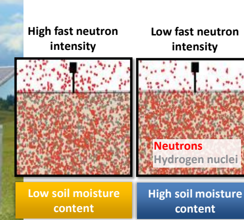
Jakobi, J., J.A. Huisman, H. Vereecken, B. Diekkrüger and H.R. Bogena (2018): Cosmic-ray neutron sensing for simultaneous soil water content and biomass quantification in drought conditions. Water Resources Research, in revision

Forschungszentrum Jülich GmbH, Agrosphere Institute (IBG-3), Germany

Cosmic-ray neutron sensing

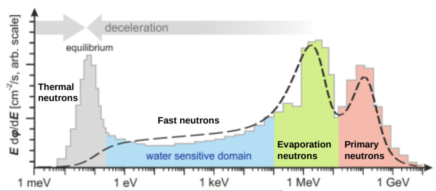


Schrön, 2017

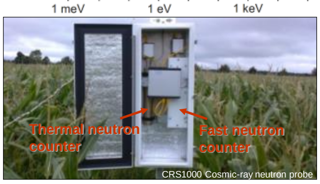


- ⇨ Soil moisture is inversely proportional to the neutron intensity
- ⇨ Non-invasive measurement
- ⇨ Covers field scale (~20 ha)

Neutron energy spectra near the surface

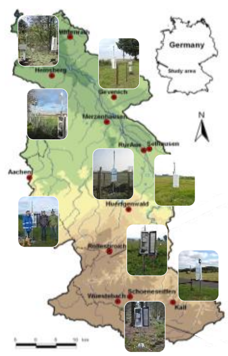


Köhli et al., 2015



⇨ 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)

TERENO TERRESTRIAL ENVIRONMENTAL OBSERVATORIES

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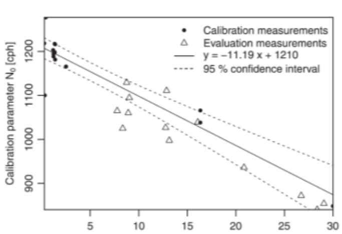
Biomass influences the calibration



N_0 calibration function:

$$\theta = \frac{a_0}{(N_{measured}/N_0) - a_1} - a_2$$

Biomass correction function:

$$N_{0,corr} = -rAGB_{dry} + N_0$$

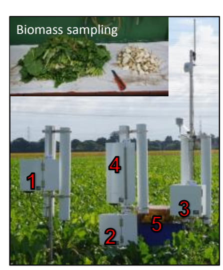
r = reduction factor

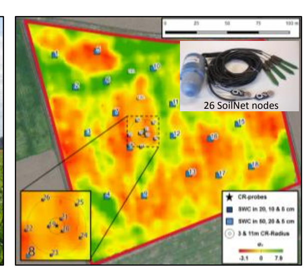
Baatz et al., WRR, 2015

⇨ **Problem:** For crops, biomass dynamics need to be assessed

⇨ **Hypothesis:** The **relationship between thermal and fast neutron (N_r)** contains biomass information

Sugar beet experiment in 2016

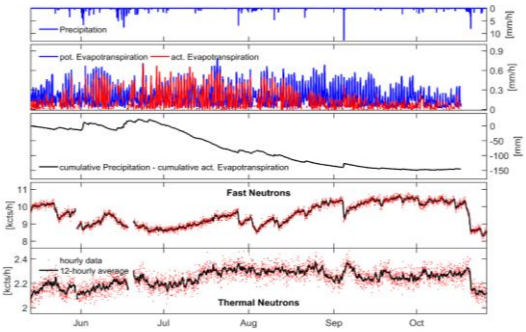




Experimental setup at the TERENO test site Selhausen
(1 CRS1000, 3 CRS2000/B, 1 cross calibrator)

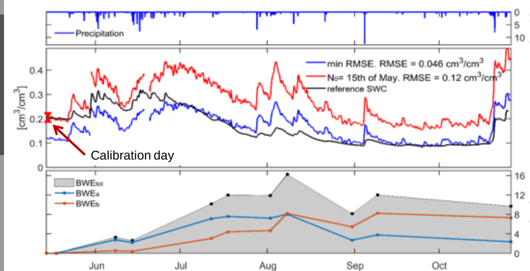
EMI map by Rudolph et al. (2015)

Climate and thermal/fast neutron time series

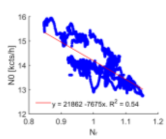


Soil moisture and biomass water equivalent

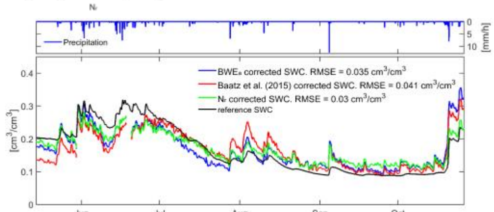
- ⇨ Biomass water equivalent: hydrogen in plant tissue and plant water
- ⇨ Two calibration variants: - using 1 day during bare soil conditions
  - using the whole measurement period



Biomass correction of soil moisture estimates

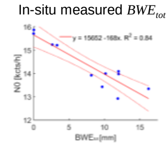


- ⇨ The calibration parameter N_0 correlates with N_r
- ⇨ Comparison of 3 correction methods:
  - regression function between N_r and N_0
  - correction function of Baatz et al. (2015)
  - correction using in-situ measured BWE_a

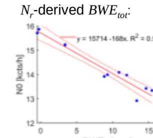


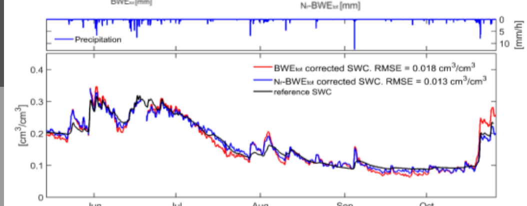
Biomass correction using BWE_{tot} estimates

In-situ measured BWE_{tot}:

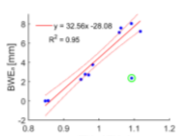


N_r-derived BWE_{tot}:

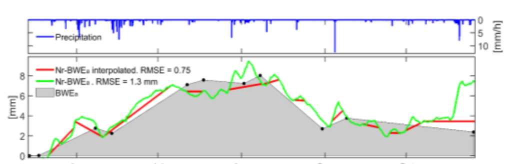




Aboveground biomass water equivalent

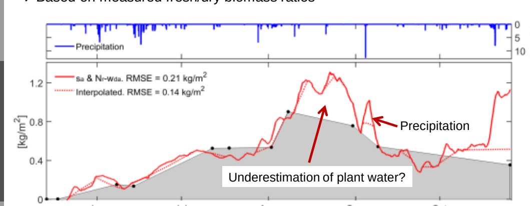


- ⇨ The neutron ratio N_r correlates well with aboveground biomass water equivalent (BWE_a)
- ⇨ N_r-derived BWE_a corresponds well with in-situ measurements, but deviations during precipitation events.
- ⇨ Interpolating periods with precipitation ≥ 1.5 mm (indicated by red lines) reduces RMSE



N_r-derived dry aboveground biomass

- ⇨ Based on measured fresh/dry biomass ratios



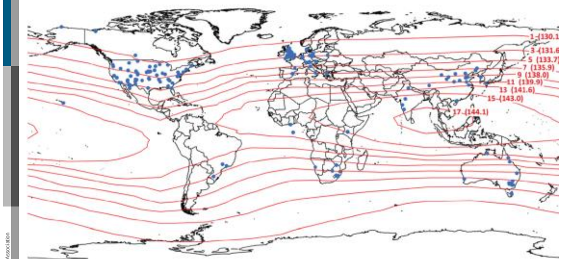
- ⇨ Deviations due to the influence of precipitation events and uncertainties in the plant water content

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

Global network of cosmic-ray neutron probes

⇨ ~200 CRNS stations worldwide



Andreasen et al., 2017, Vadose Zone J.