# Estimation of Soil Water Content at Intermediate Field Scale Using Cosmic-Ray Neutrons

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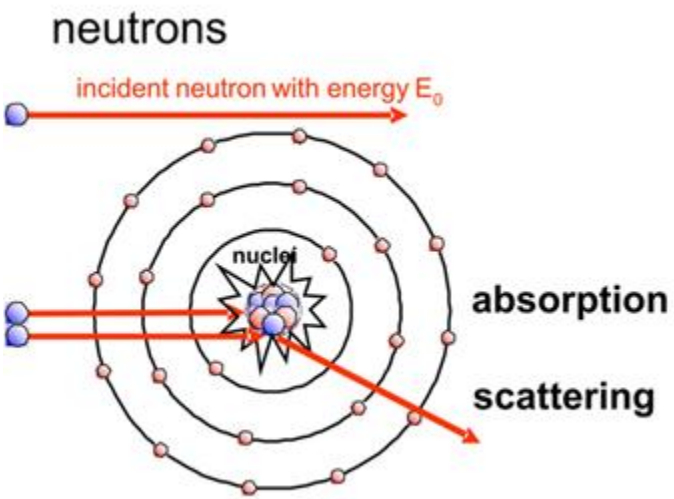
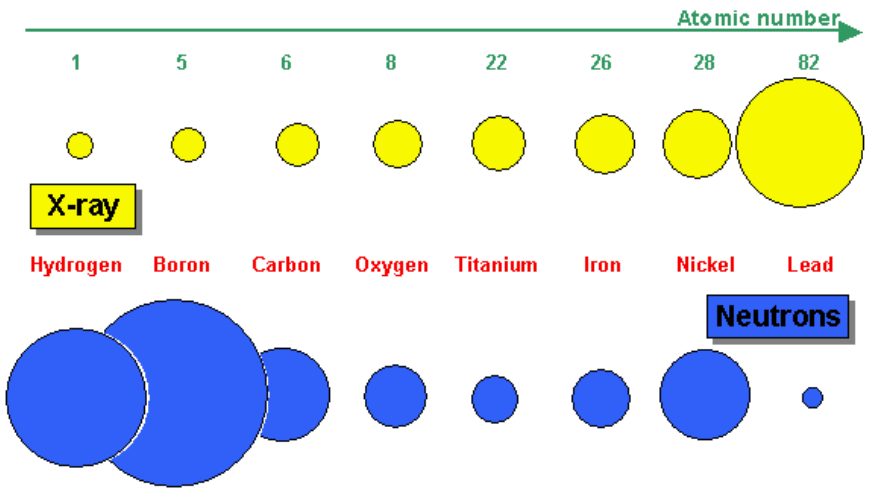
# Neutrons ?

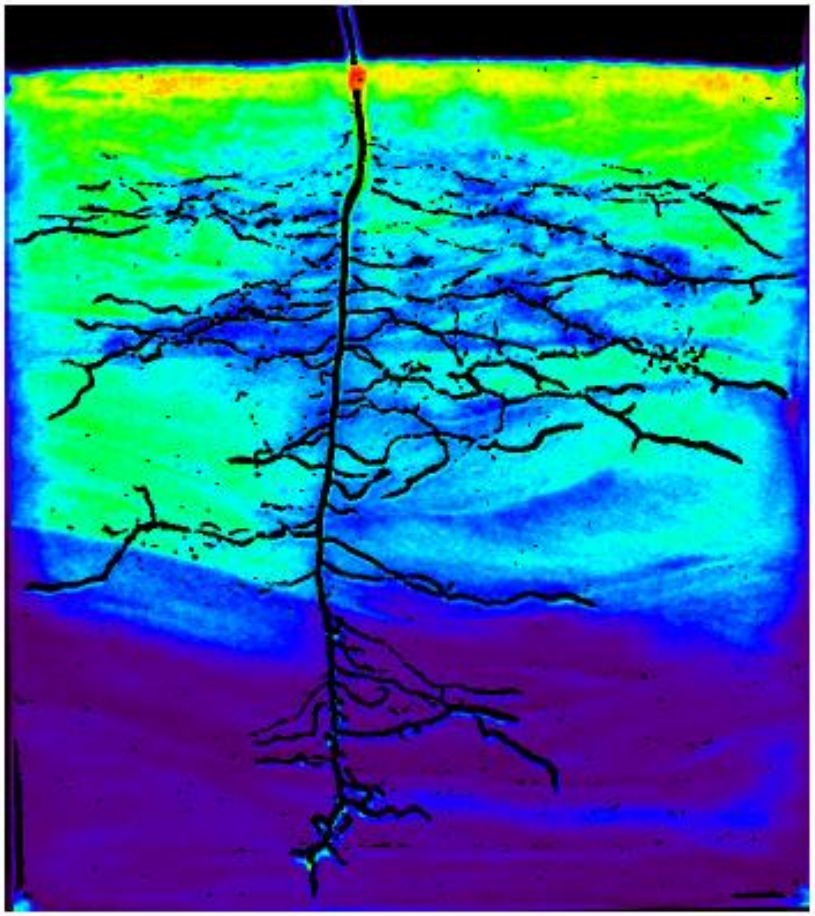
| | |
|---|---|
| Cold: | 0.5meV - 2 meV, 13 Å - 6.4 Å |
| Thermal: | 2meV - 100 meV, 6.4 Å - 1 Å |
| Epithermal: | 100 meV - 1eV, 1 Å - 0.3 Å |
| Intermediate: | 1eV - 0.8MeV |
| Fast: | > 0.8MeV |

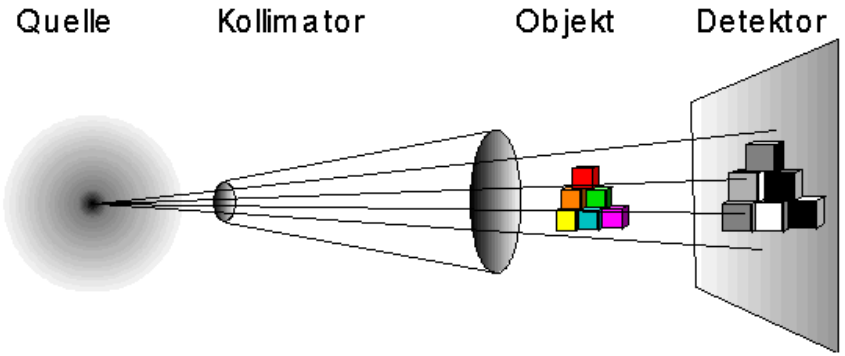


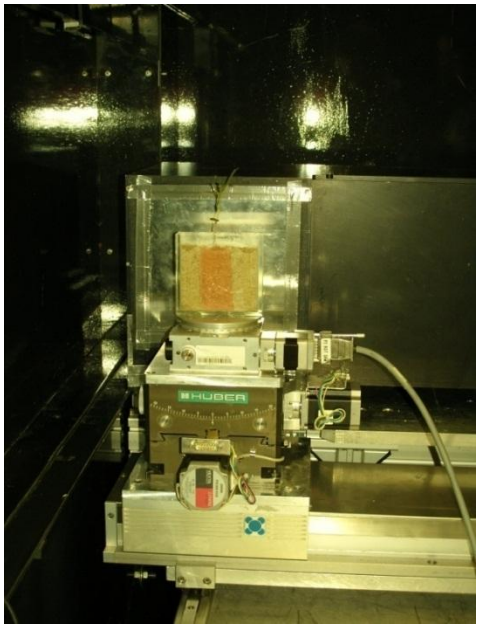



# Neutron radiography of a plant-soil system

→ Root structure and water content distribution



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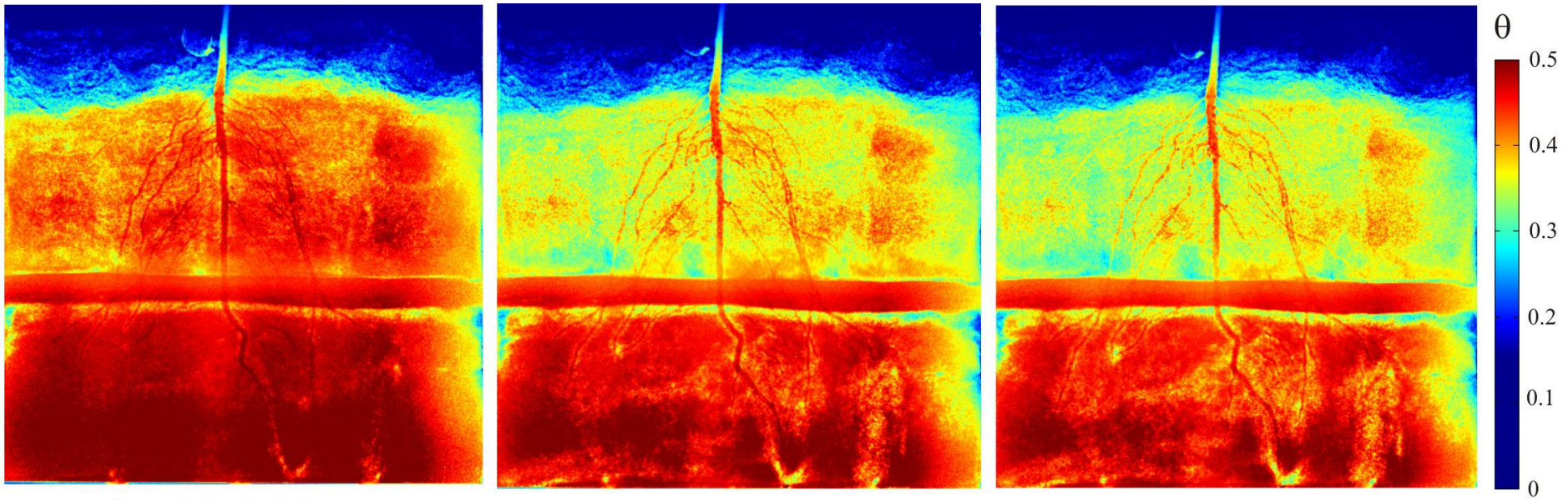
# Root water uptake after wetting

***(N. Rudolph et al., submitted to Journal of Soils and Sediments)***




day 19, 9:45 pm

day 20, 17:40 pm

day 21, 10 am

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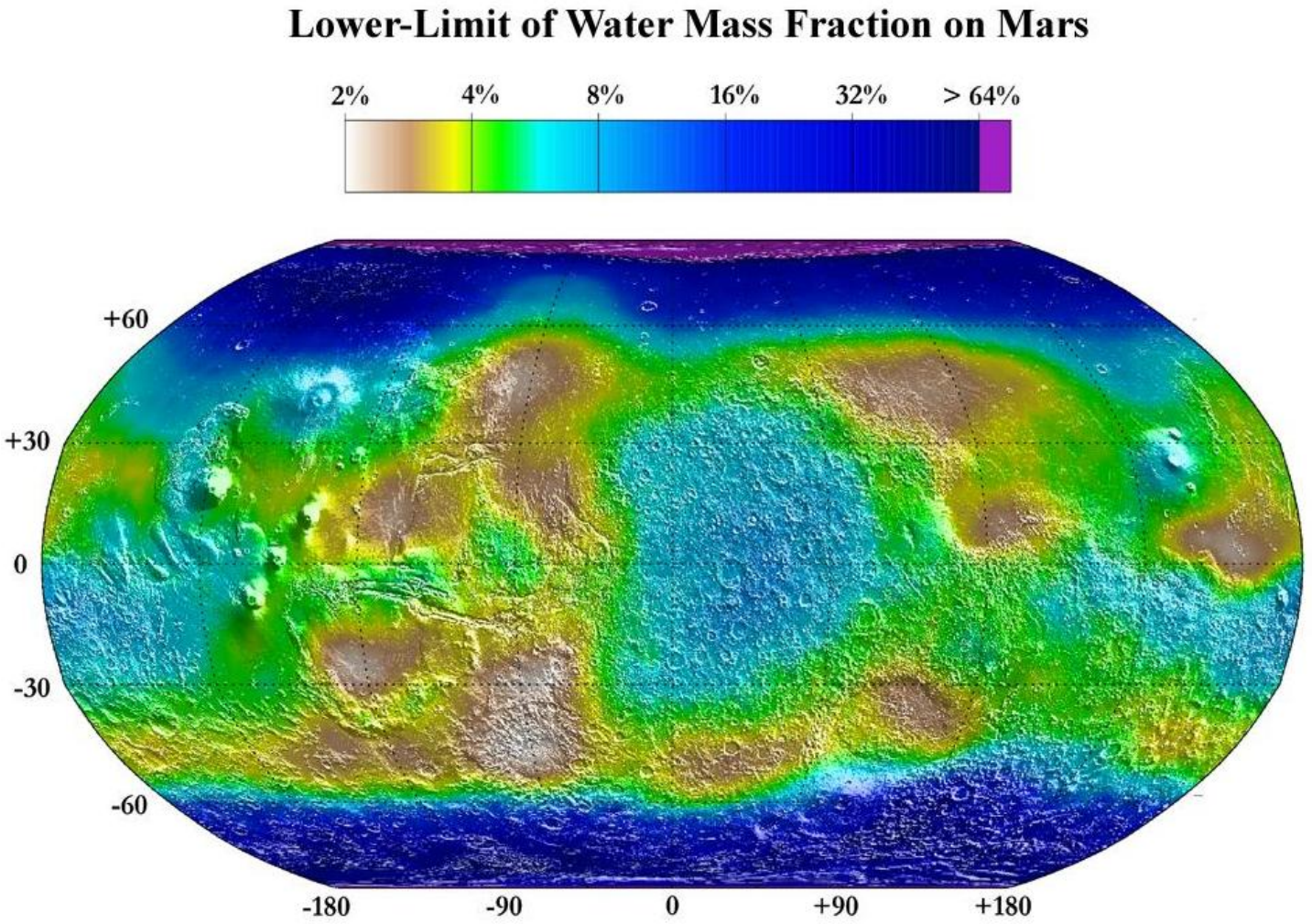
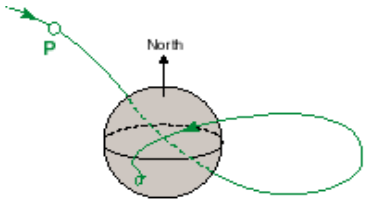
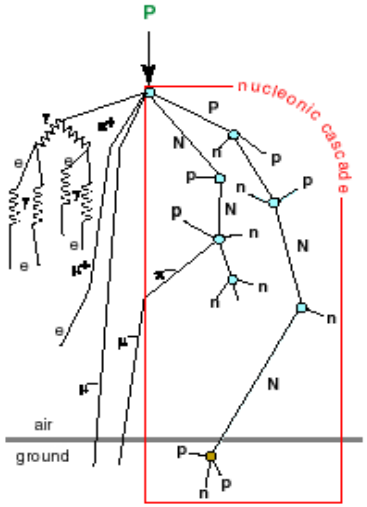
# NASA 2001 Mars Odyssey Satelliten Mission searching for water on Mars surface – by neutrons



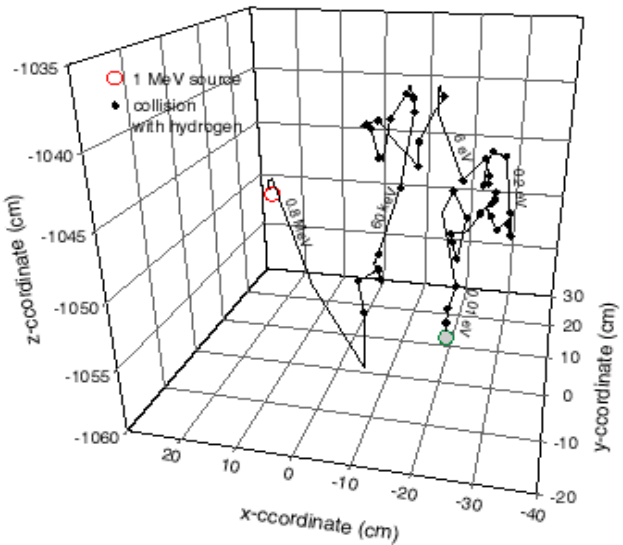
# Where do “cosmic-ray” neutrons come from?




**Primary high energy particles from space & sun**




**Secondary cosmic radiation reaching the surface**




**Slowing down at the surface and production of secondary neutrons**

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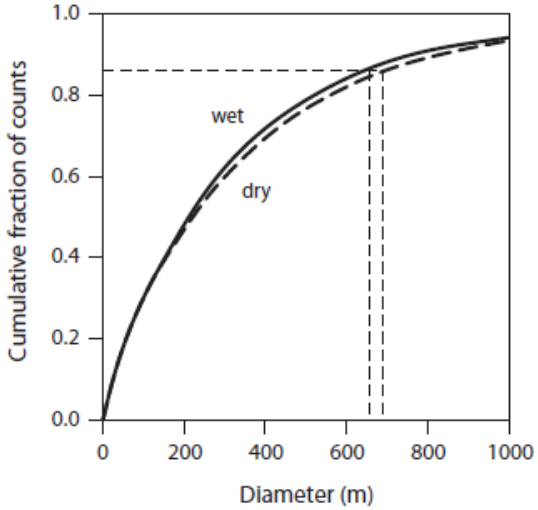
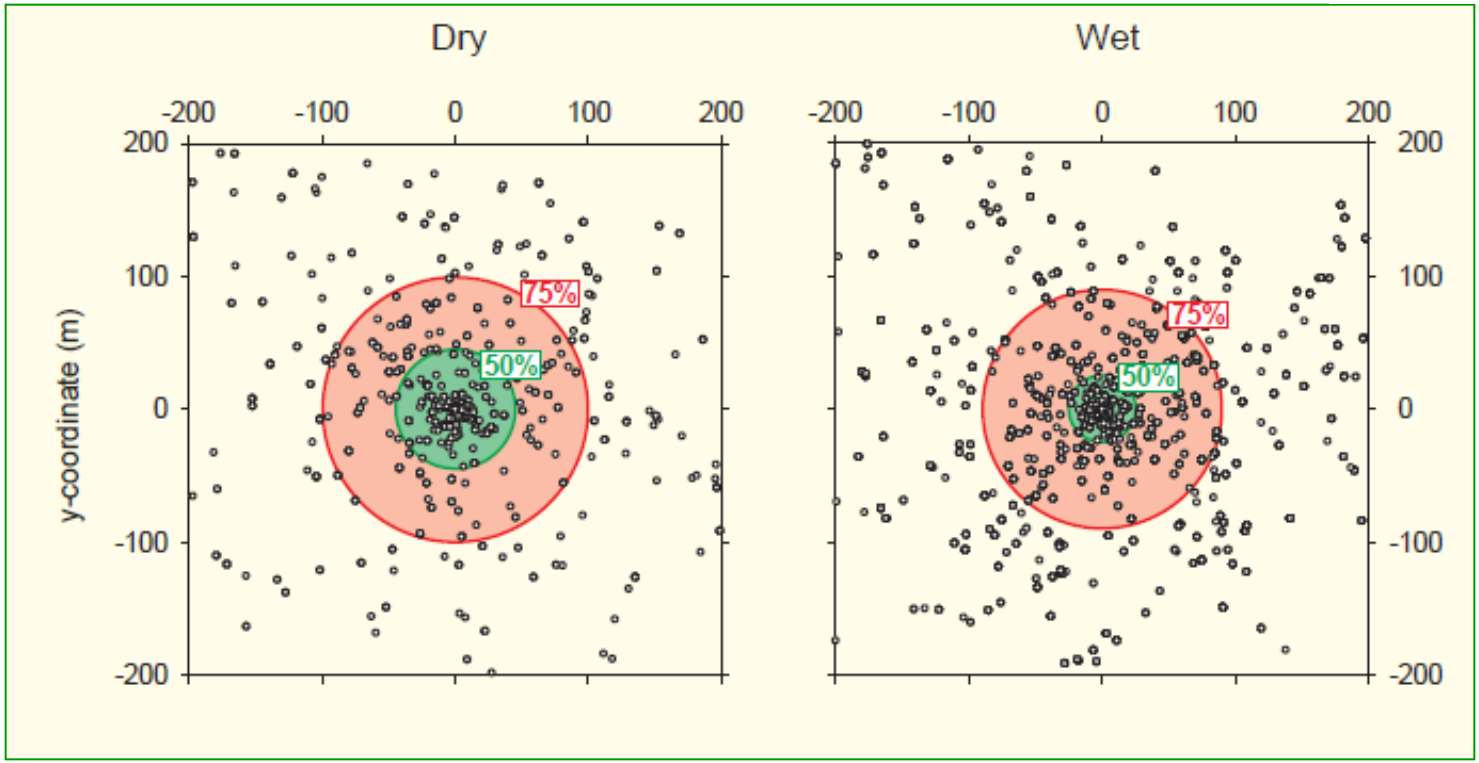
# Above-ground detection of secondary neutrons
# Horizontal extent of measured area – "Footprint"




(Extracted from Zreda et al., 2005)

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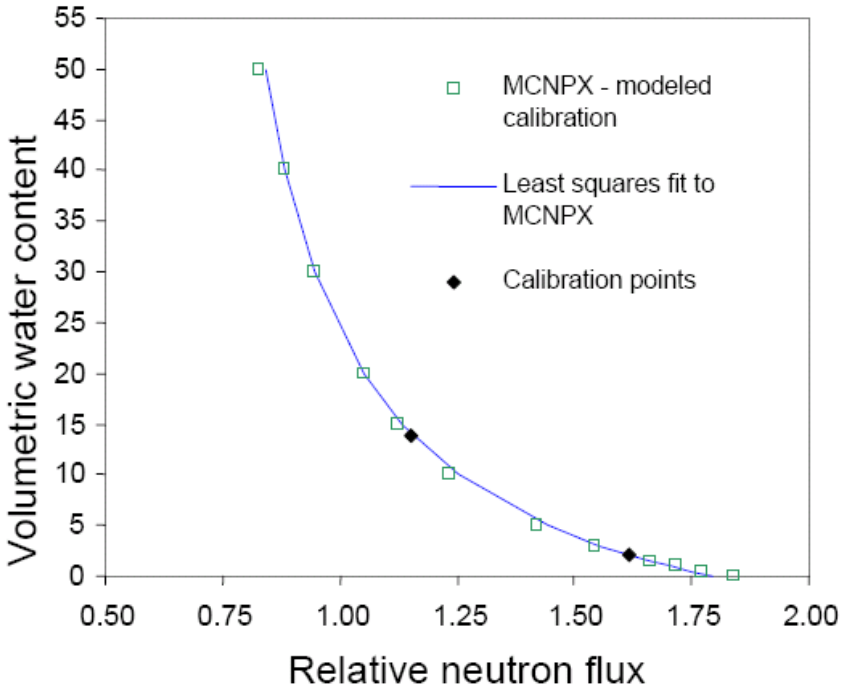
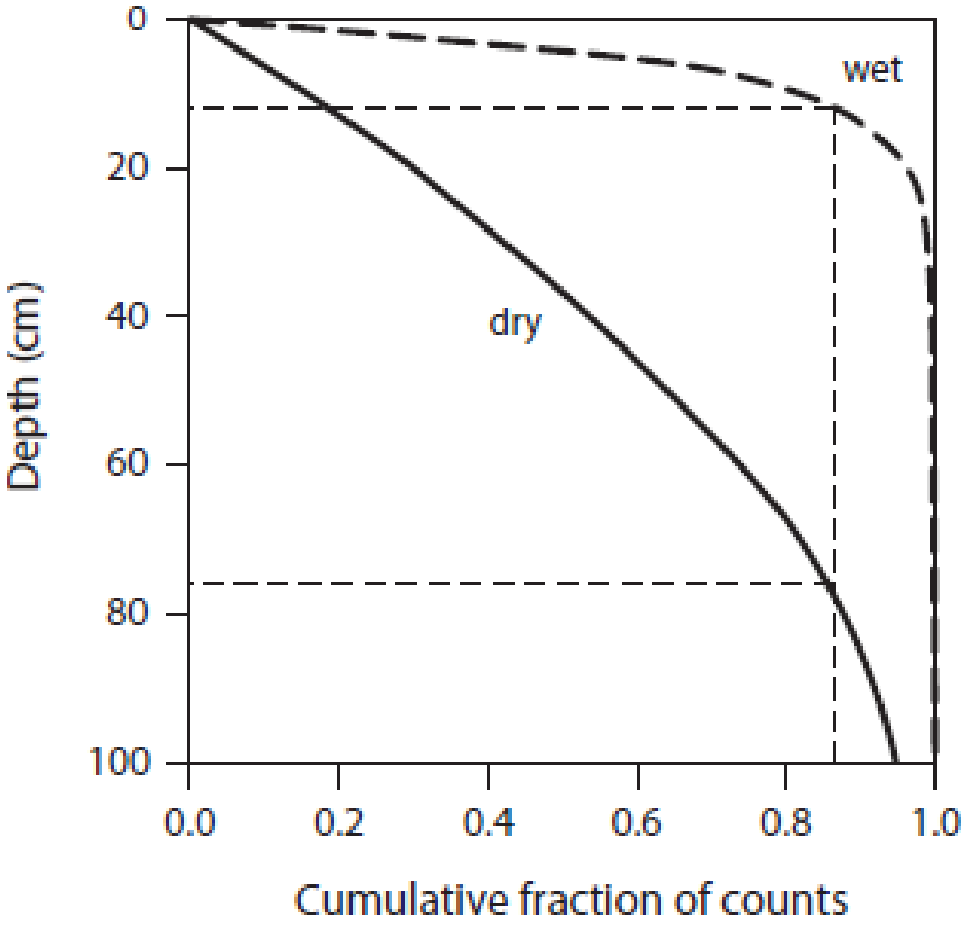
# Vertical integration depth for above-ground neutrons




(Extracted from Zreda et al., 2008)

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# Quantitative estimate of soil moisture

$$\theta(N) = \frac{a_o}{\left(\frac{N}{N_o} - a_1\right)} - a_2$$

| | |
|---|---|
| $\boldsymbol{\theta}$ | areal mean volumetric water content in the entire footprint |
| $N$ | neutron counting rate corrected due to atmospheric pressure |
| $No$ | *neutron* counting rate monitored under dry soil conditions |
| $a_i$ | fitting parameters |

$$N = N_{raw} \cdot \left[\beta(P - Po)\right]$$

| | |
|---|---|
| $N_{raw}$ | neutron counting rate integrated in a 1-hr period |
| $\beta$ | atmospheric attenuation coefficient [$mb^{-1}$] |
| $P$ | hourly mean local pressure [mb] |
| $Po$ | long-term mean local pressure [mb] |

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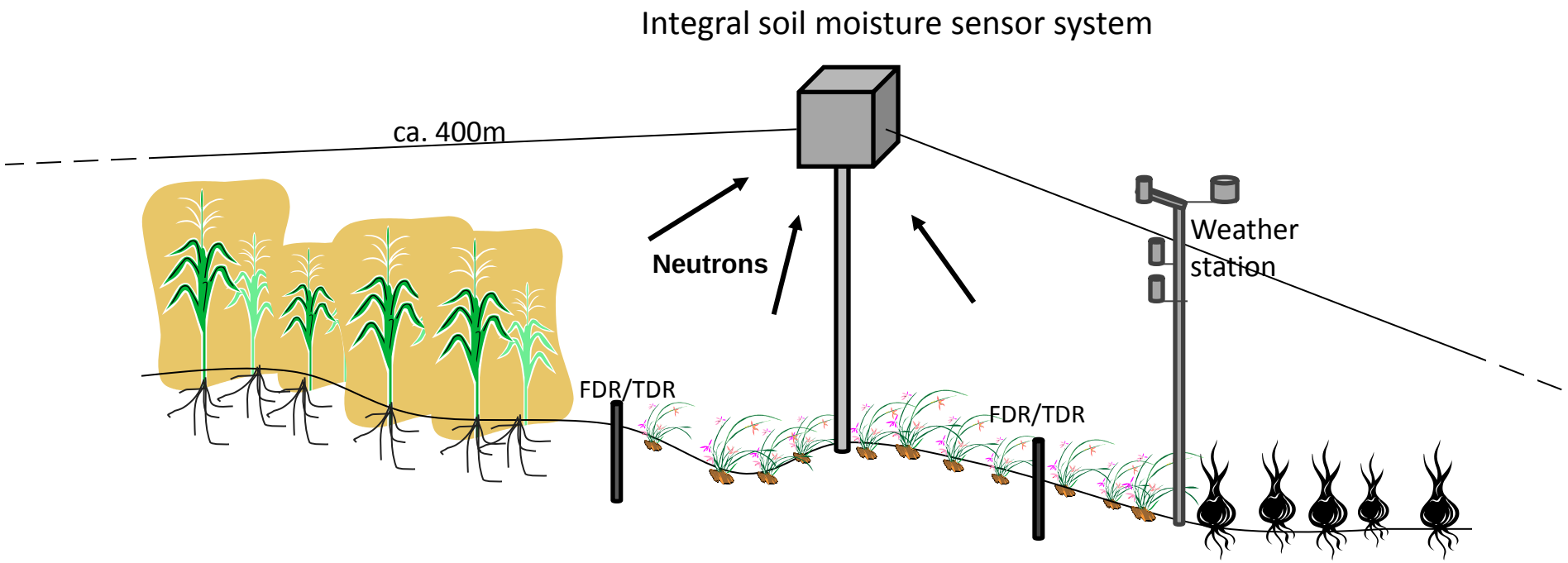
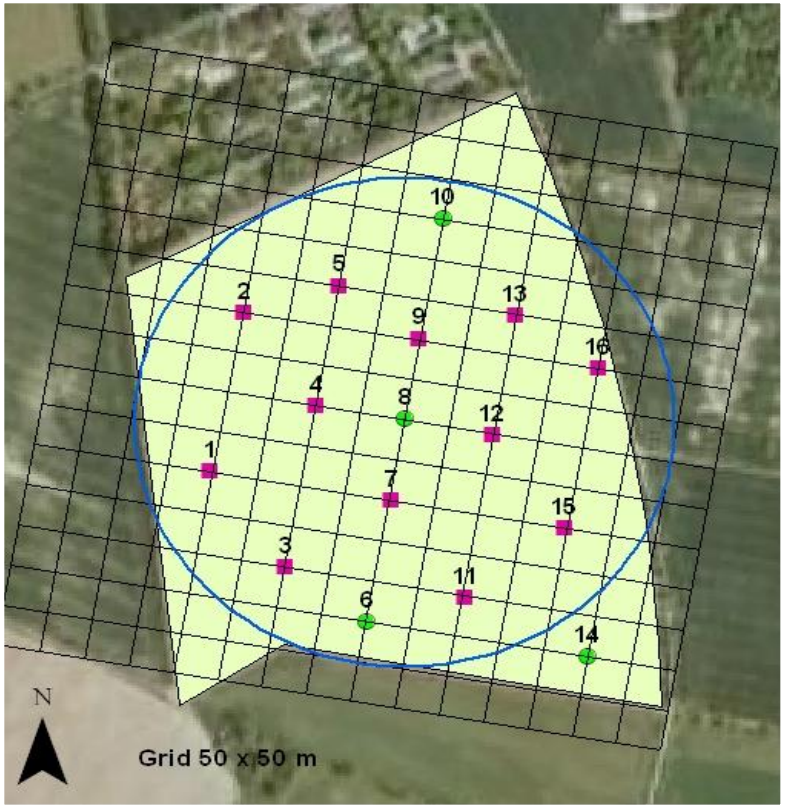
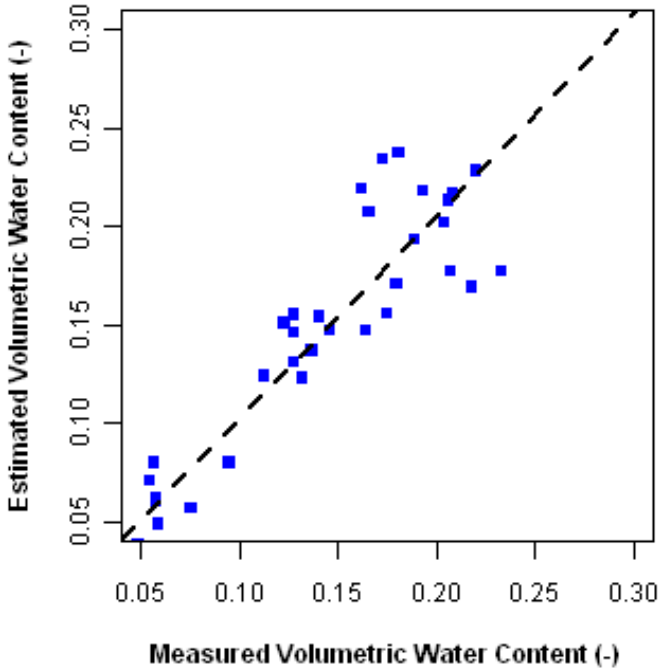
# Field test of Cosmic-Ray Method



# Field cropped with maize

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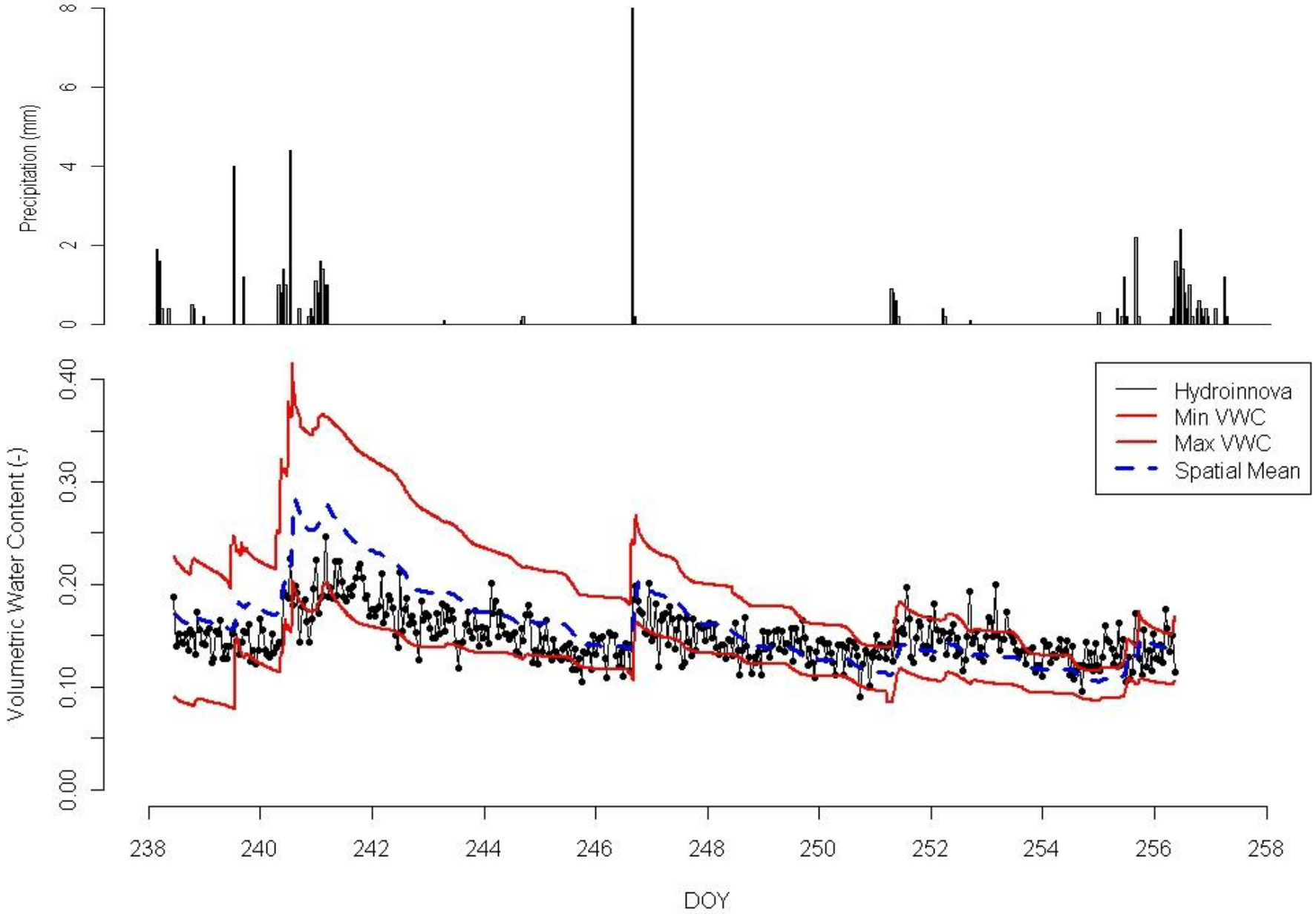
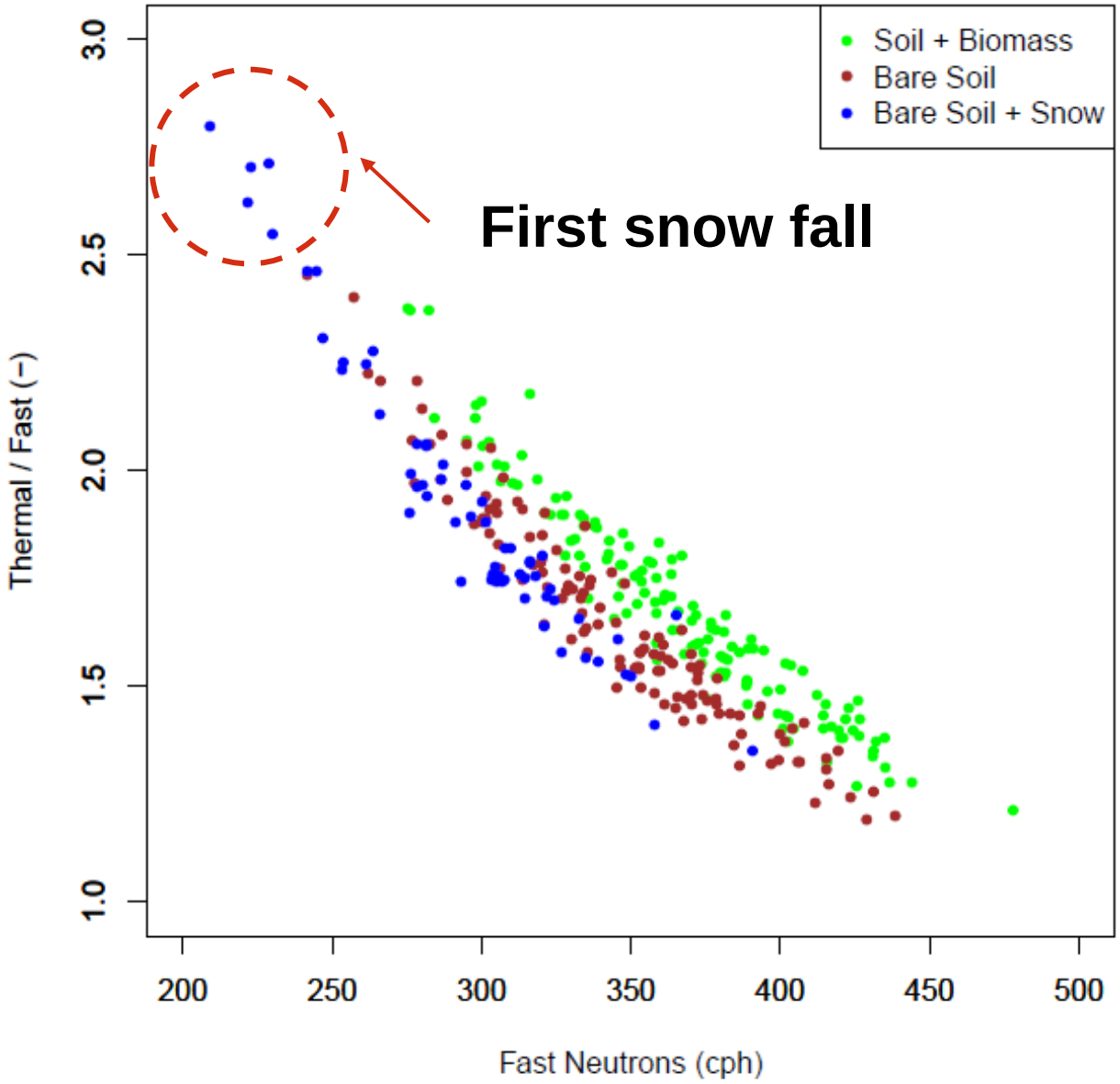
# Integral soil moisture and precipitation



# Impact of snow

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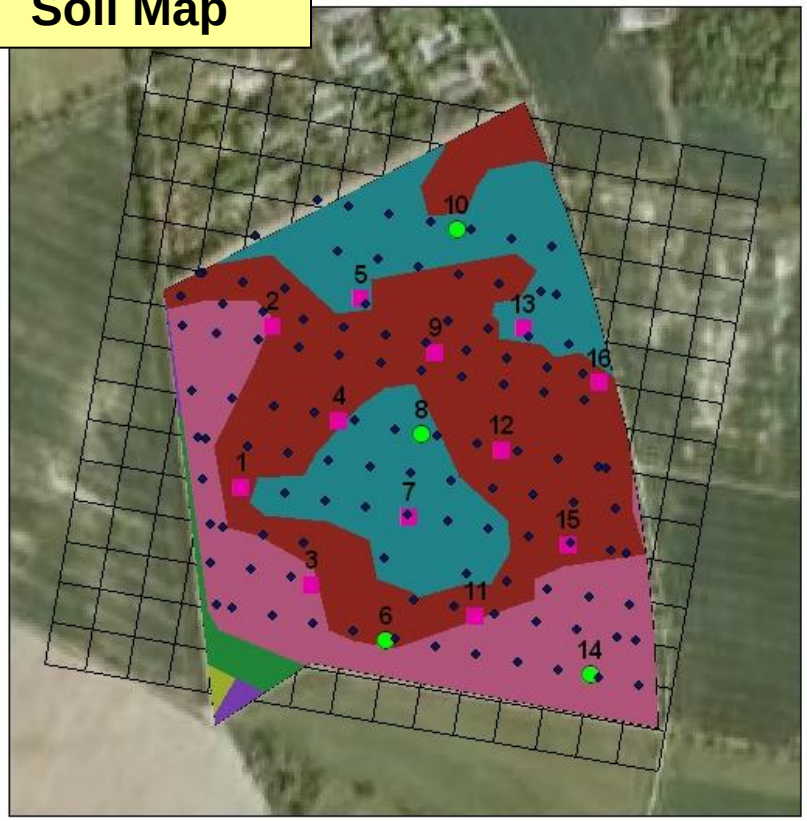
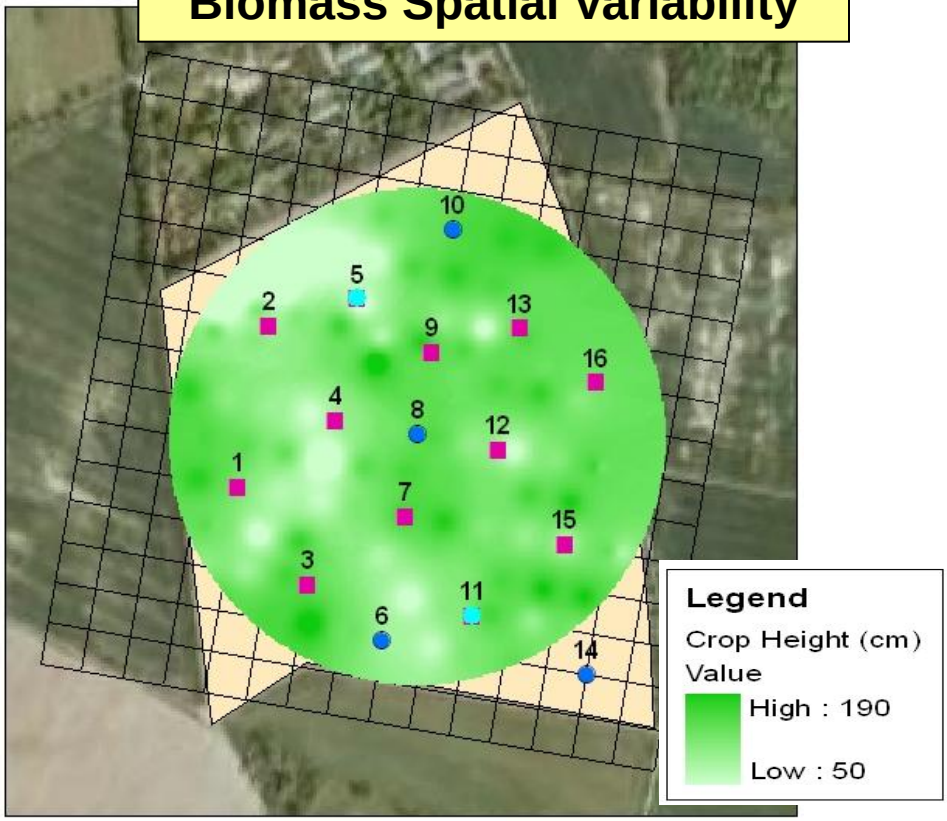
# What is Influence of Biomass on Neutron Counting Rates?

**Soil Map**




**Biomass Spatial Variability**




**Mean Height: 143 cm**

Dry Mass Density: 2475 g/m$^2$

Mean Plant Water Content: 1.84 Ton/Ton

Total Plant Water: 1291 m$^3$

**Respect Soil Moisture: 5.71 %**

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# Conclusions and outlook

- CRS can close a gap between local soil moisture measurements and remote sensing
- Sensitivity to water is high
- Integrates water mass over reasonable depth
- Issues to be addressed:
  - Quantitative separation of snow contrib.
  - Impact of different forms of biomass
  - Quantitative use of the data for modelling of soil moisture and groundwater recharge estimation

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# Thanks to you, …

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TERENO
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