Fostering the understanding of sub-footprint heterogeneity in Cosmic-Ray Neutron Sensing, challenges of irrigation monitoring

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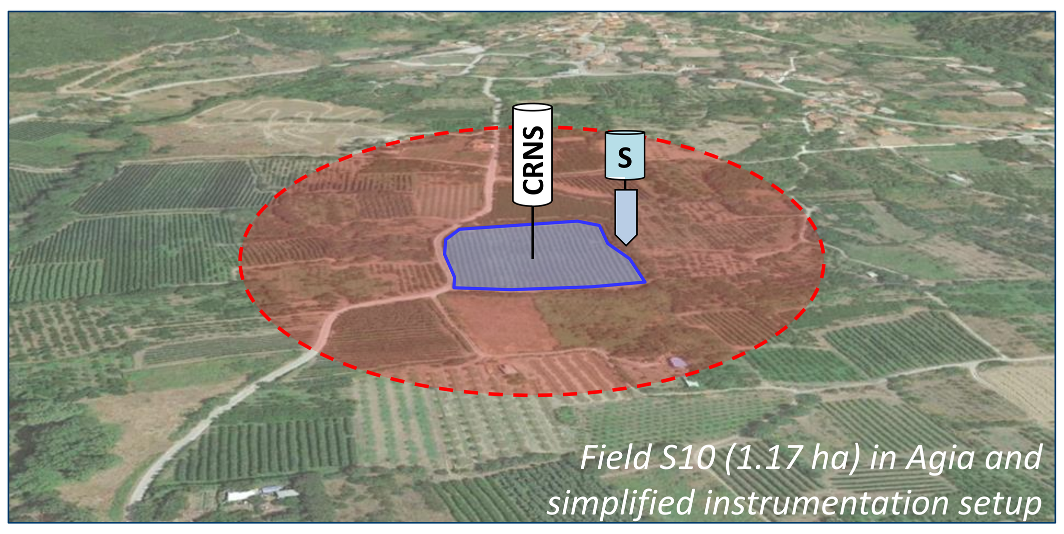
Soil moisture (SM) monitoring with cosmic-ray neutron sensors (CRNS)

- To improve irrigation management, help reduce water consumption, and mitigating crop losses, accurate soil moisture (SM) estimation is key.
- Cosmic ray neutron sensors (CRNS) are a promising method in informing irrigation practices due to their large sensed volume (footprint of ~130-210 m radius and ~15-85 cm depth).
- Sub-footprint heterogeneities are still subject of study and, as a CRNS provides one single estimation of SM over tens of hectares, a small irrigated field (~1-2 ha) is challenging to monitor.
- We tested a novel CRNS correction in a ~1 ha irrigated field and we observed measurements over a 14-ha field irrigated in separate lines.

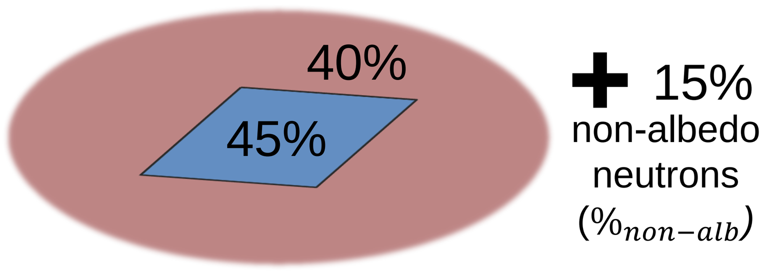
Pilot apple orchard (Agia, Greece)

- An apple orchard in Agia (Greece) was equipped with 12 SoilNet nodes of SM sensors (at 3 depths), four hydrometers to record irrigation, a compact meteorological station, and a CRNS.



Field S10 (1.17 ha) in Agia and simplified instrumentation setup

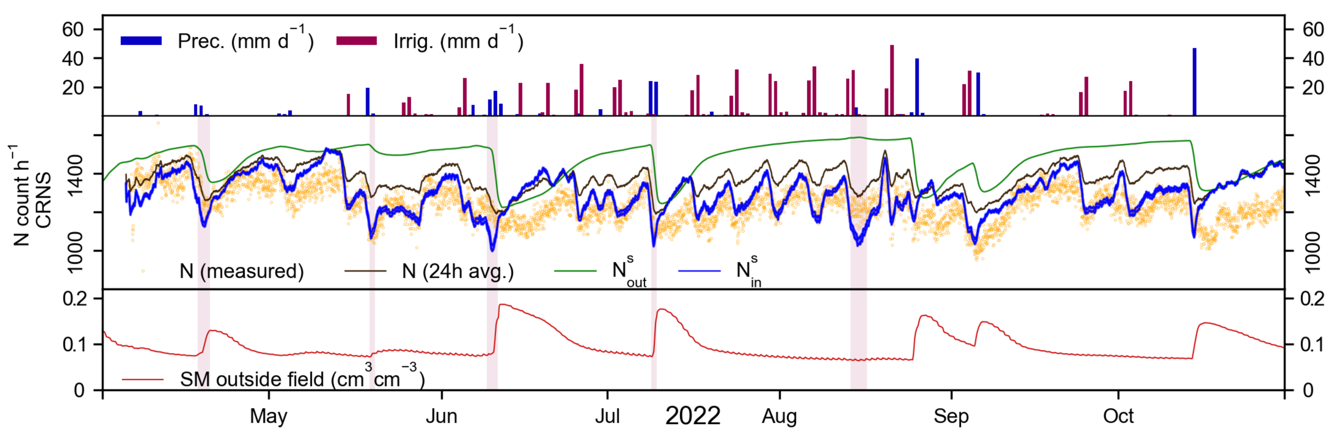
- An additional SM node was installed outside the field to measure SM in the non-irrigated area (Θ_{out}) and thus estimate a synthetic neutron count (N^{s}_{out}) for such area.
- The contribution to the neutron count N of the irrigated area ($\%_{in}$) and of its surroundings ($\%_{out}$) are obtained using neutron transport simulations (URANOS model).
- Four URANOS simulations are sufficient to apply the method



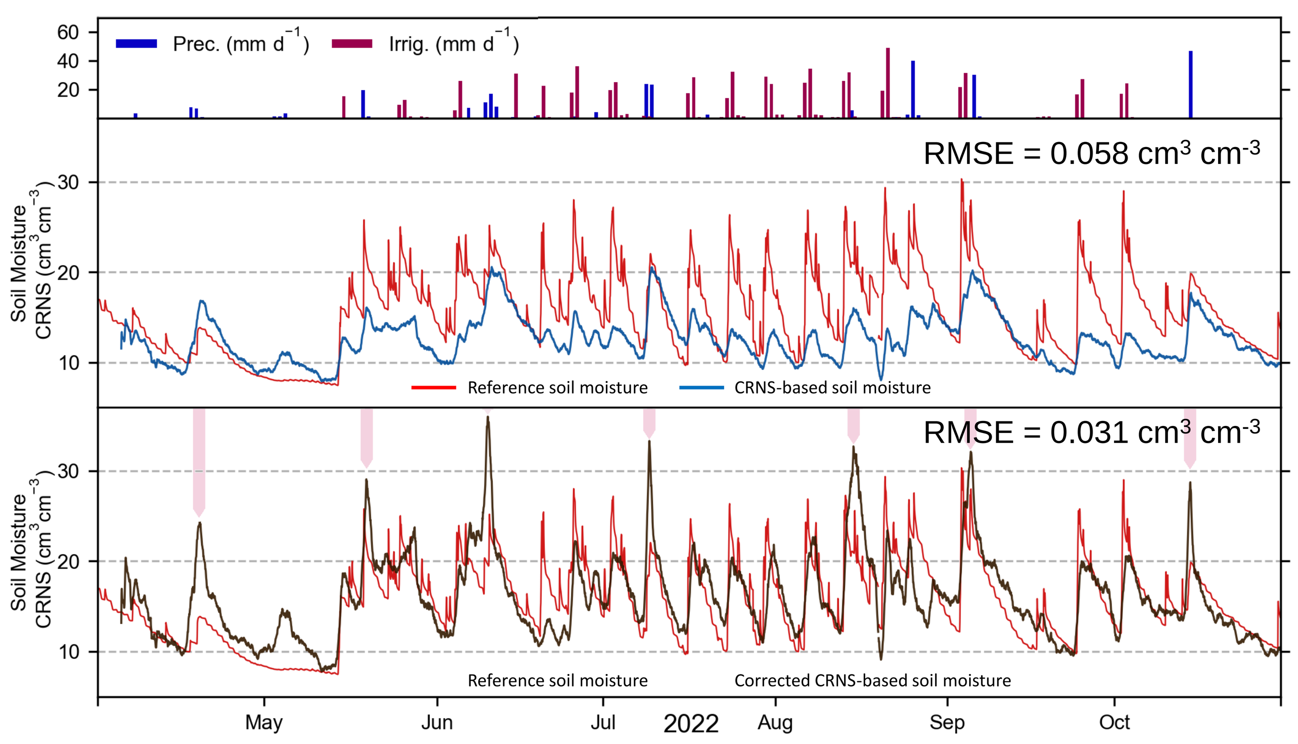
Example of contribution to the count rate of neutrons that originate a) inside the field (45%), b) outside the field (40%), and c) non albedo neutrons (15%)

Starting from measured N, calculate:

- Portion of non-albedo neutrons $N_{non-alb} = N/100 * \%_{non-alb}$
- Weight of outside-origin neutrons $K_{out} = N^{s}_{out}/100 * \%_{out}$
- Weight of inside-origin neutrons $K_{in} = N - K_{out} - N_{non-alb}$
- Synthetic neutron count of the target field $N^{s}_{in} = K_{in} * 100/\%_{in}$



Measured N and synthetic N^{s}_{out} obtained from the SM sensor outside the field. In blue, the synthetic N^{s}_{in} for the irrigated field.



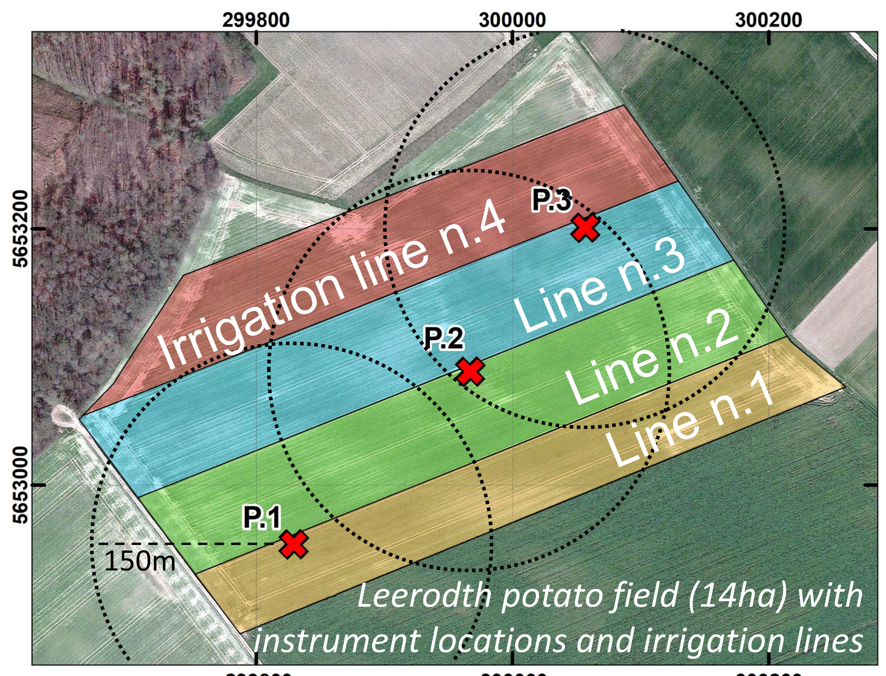
SM estimated by the CRNS by using a standard approach.

SM estimated by the CRNS when the proposed correction is applied. Red arrow show local overestimations.

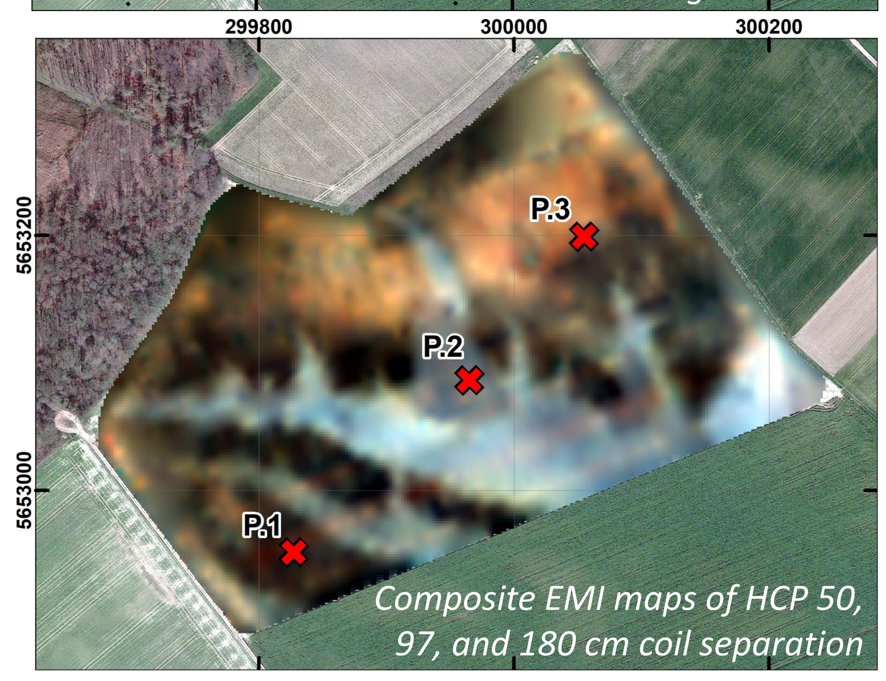
- RMSE reduced (0.053 to 0.031) and SM dynamics are improved
- Few overestimations caused by supporting sensor position (too deep)

Pilot potato field (Leerodth, Germany)

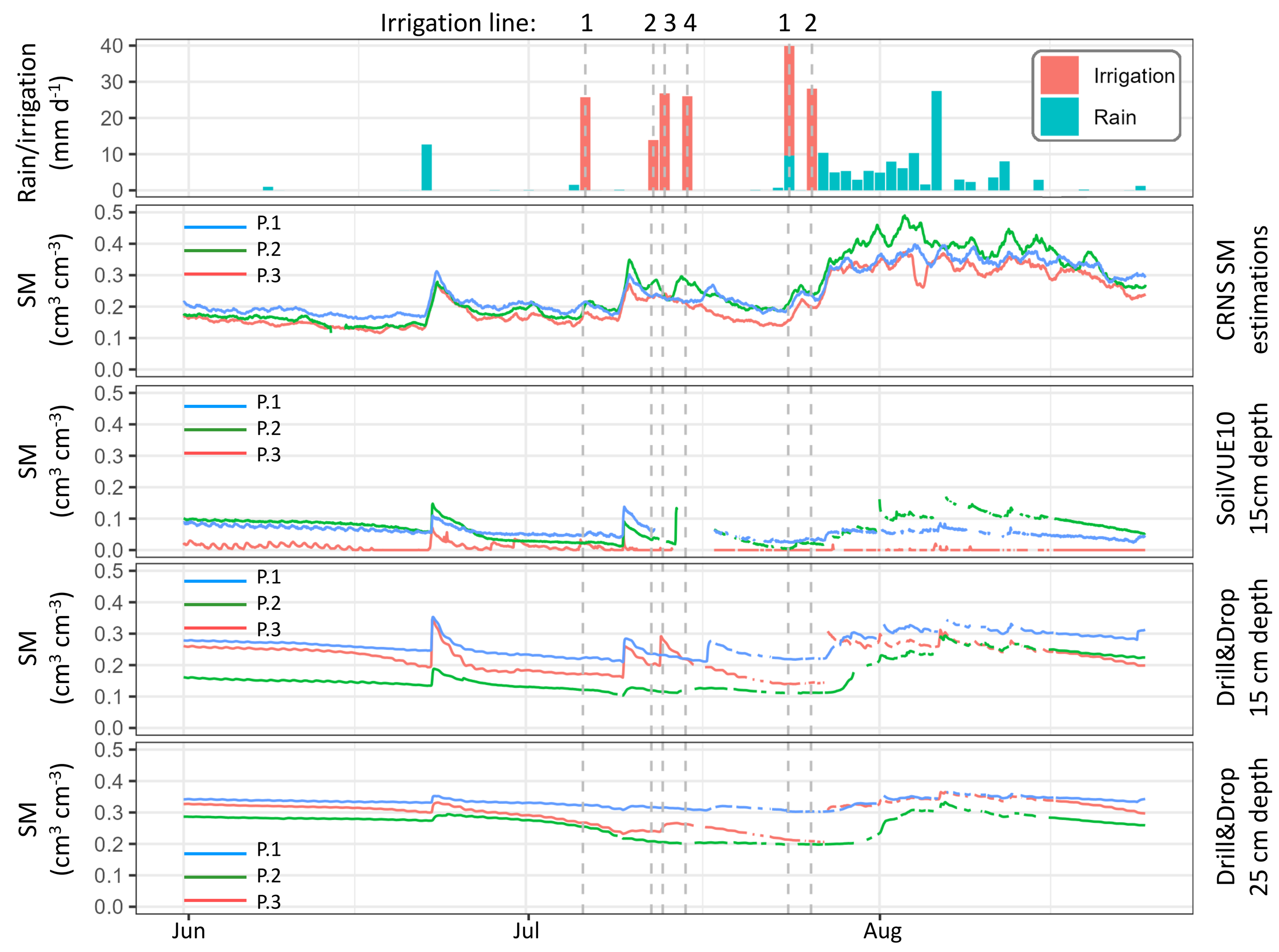
- A potato field of 14 ha in Leerodth, was equipped with 3 CRNS from Styx Neutronica GmbH (Germany). Two had one detector tube (P.1 and P.3) and one had two detector tubes (p.2).
- At each CRNS location, two point-scale SM sensors were installed:
  - SoilVUE10 (5, 10, 20, 30, 40, 50 cm depth) from Campbell Scientific Inc. (USA)
  - Drill&Drop (5, 15, 25, 35, 45, 55 cm depth) from Sentek Pty Ltd. (Australia).
- A meteorological station was installed at location p.2.
- Electromagnetic induction (EMI) measurements were obtained to select appropriate locations.



Leerodth potato field (14ha) with instrument locations and irrigation lines



Composite EMI maps of HCP 50, 97, and 180 cm coil separation



- Estimations from the three CRNS can appear similar during irrigation
- Point-scale SM sensors affected by local effects (e.g., loss of soil contact)
- CRNS may be more suited to estimate a generalized SM value

Advantages and limitations

- CRNS could replace a dense sensor network, which generally is more costly and difficult to manage
- Simplified and ad-hoc URANOS simulations provide similar results, and the former could reduce computation effort and increase standardization
- Use a single supporting sensor to correct multiple CRNSS
- Use a second CRNS or other CRNS in the area to perform correction
- Challenging in case of a highly heterogeneous SM distribution

Conclusions & outlook

- CRNS can monitor and inform irrigation in small irrigated fields (~1 ha) and could sometimes replace a dense sensor network
- CRNS can offer a less site-dependent and more meaningful estimation of SM in certain agricultural contexts
- Further studies are needed to standardize the methodology and test results for different environments and irrigation methods

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