EGU25-12351, updated on 17 Dec 2025
https://doi.org/10.5194/egusphere-egu25-12351
EGU General Assembly 2025

Irrigation Management and Soil Moisture Monitoring with Cosmic-Ray Neutron Sensors: Lessons Learned and Future Opportunities

Heye Bogena[1], Cosimo Brogi[1], Felix Nieberding[1], Andre Daccache[2], Lena Scheiffele[3], and Salar Saeed Dogar[1]

[1]Forschungszentrum Jülich GmbH, Agrosphere Institute (IBG-3), Juelich, Germany (h.bogena@fz-juelich.de)
[2]University of California Davis, BAE, Davis, United States of America
[3]University of Potsdam, Institute of Environmental Science and Geography, Subsurface Hydrology, Potsdam-Golm, Germany

Cosmic Ray Neutron Sensing (CRNS) is attracting attention in irrigation management. CRNS can non-invasively and accurately measure soil moisture (SM) in the root zone at the field scale, thus addressing scale and logistics issues typical of point-scale sensor networks. CRNS are effectively used to inform large pivot irrigation systems but most agricultural landscapes in Europe and elsewhere consist of highly diversified and small fields. These are challenging for CRNS as the measured signal integrates an area of ~200m radius where multiple fields, soil heterogeneities, or variable amount of water applications can be found.

In this work, we present results from three case studies, and we develop and test solutions to improve CRNS accuracy in irrigated contexts. In 2023, a potato field in Leerodt (Germany) where strip irrigation is practiced was equipped with three CRNS (with moderators and thermal shielding), three meteorological stations, and six profile SM probes measuring at six different depths (up to 60 cm). In the same year, in Davis (California, USA), two CRNS with a 15 mm moderator, one of which also had a thermal shielding, were installed in an alfalfa field where flood irrigation is practiced. These were supported by meteorological measurements and point-scale TDR sensors. Similarly, a CRNS installed in a winter wheat field in Oehna (Germany) where pivot irrigation is applied. As the origin and propagation of neutrons detected by a CRNS cannot be inferred from the measured signal, we used the URANOS model to analyze neutron transport in the three case studies under varying soil moisture scenarios. To account for soil heterogeneity in the Leerodt study, we assessed the spatial distribution of soil characteristics by integrating soil sampling and Electromagnetic Induction (EMI) measurements in a machine-learning framework.

The Leerodt study showed that CRNS outperformed point-scale sensors, which were strongly affected by soil erosion in the top 10 cm. However, CRNS was unexpectedly sensitive only to nearby irrigation. Here, key insights on sub-footprint heterogeneity and soil roughness were gained through the analysis of URANOS simulations. In the Davis study, CRNS effectively monitored irrigation but also showed unexpected sensitivities to the irrigation of distant fields. Again, important insights were gained thanks to URANOS simulations. In the Oehna study, large quantitative differences between the CRNS and point-scale sensors were observed. However, the

CRNS provided clear responses to irrigation that can outperform the information provided by the point-scale devices. Overall, the limitations of CRNS-based irrigation management in complex agricultural environments can generally be overcome through a synergetic use of measurements and modelling. Nonetheless, more efforts are needed to improve the understanding of the underlying processes and to standardize measurement procedures, which ultimately requires the involvement not only of researchers but also of manufacturers and stakeholders.