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Potential and limitations of cosmic-ray neutron sensors for irrigation management in small fields

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Given the expected increase of droughts related to climate change, soil moisture (SM) monitoring will likely become essential for farmers as it helps to reduce water consumption while mitigating crop losses. Cosmic-Ray Neutron Sensing (CRNS) is a promising SM monitoring method that is based on the negative correlation between fast neutrons originating from cosmic radiation and SM content. As CRNS integrates SM over a large radius of ~130-210 m with a penetration depth of ~15-85 cm, it has advantages over point-scale and remote-sensing methods. However, it is yet unclear how well CRNS can monitor areas with complex SM heterogeneity, such as small irrigated fields. In this study, two CRNS equipped with a novel gadolinium oxide thermal shielding were installed in two small (~1.2 ha) irrigated apple orchards located in the Pinios Hydrologic Observatory (Greece). Each CRNS was supported by an Atmos41 all-in-one climate station, by water meters measuring irrigation timing and amounts, and by a network of 12 wireless SM measurement nodes (SoilNet) that monitored SM at 5, 20 and 50 cm depth. The results showed that the CRNS was sensitive to the weekly irrigation events, but that it showed a general underestimation of the magnitude of SM fluctuations caused by the irrigation, which resulted in a RMSE of 0.058 cm^3 cm^{-3}. To better understand these results, we used the URANOS model to simulate neutron transport for a CRNS placed in the centre of a square irrigated field of varying dimensions (0.5 to 8 ha). The simulation results showed that CRNS can be used to monitor irrigation in fields as small as 0.5 ha in certain SM conditions and that a gadolinium-based thermal shielding provides the best monitoring results due to the much-reduced detection of thermal neutrons. Nonetheless, a considerable number of detected neutrons (above 60%) can originate outside the target field if the irrigated field is small, and in such cases a CRNS may not be able to clearly distinguish irrigation from SM variations in the surroundings. In an attempt to correct for such SM variations not related to irrigation, an additional SoilNet node was installed outside one of the two irrigated apple orchards in September 2021. By combining the results of neutron transport simulations with the information provided by this additional SoilNet node, a correction of CRNS-derived SM was developed that better captures both timing and magnitude of SM changes (RMSE reduced to 0.031 cm^3 cm^{-3}). These results show that the combination of real-world studies with neutron transport simulations can help to establish CRNS as a reliable tool in

irrigation management.