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Challenges and solutions for cosmic-ray neutron sensing in heterogeneous soil moisture situations related to irrigation practices

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Water availability is a key challenge in agriculture, especially given the expected increase of droughts related to climate change. Soil moisture (SM) sensors can be used to collect information on water availability in a reliable and accurate way. However, due to their very small measuring volume, the installation of multiple sensors is required. In addition, in-situ sensors may need to be removed during field management and connecting cables are often damaged by rodents and other wilderness animals. Hence, the demand for SM sensors that do not have such limitations will increase in the upcoming years. A promising non-invasive technique to monitor SM is cosmic-ray neutron sensing (CRNS), which is based on the negative correlation between fast neutrons originating from cosmic radiation and SM content. With its large measuring footprint of ~130-210m, CRNS can efficiently cover the field-scale. However, heterogeneous agricultural management (e.g., irrigation) can lead to abrupt SM differences, which pose a challenge for the analysis of CRNS data. Here, we investigate the effects of small-scale soil moisture patterns on the CRNS signal by using both modelling approaches and field studies. The neutron transport model URANOS was used to simulate the neutron signal of a CRNS station located in irrigated plots of different sizes (from 1 to 8 ha) with different soil moisture (from 5 and 50 Vol.%) inside and outside such a plot. A total of 400 different scenarios were simulated and the response functions of multiple detector types were further considered. In addition, two CRNS with Gadolinium shielding were installed in two irrigated apple orchards of ~1.2 ha located in the Pinios Hydrologic Observatory (Greece) in the context of the H2020 ATLAS project. Reference soil moisture was determined using 25 SoilNet stations, each with 6 SM sensors installed in pairs at 5, 20 and 50 cm depth and water potential sensors at 20 cm depth. The orchards were also equipped with two Atmos41 climate stations and eight water meters for irrigation monitoring. The CRNS were calibrated using either soil samples or the SM measured by the SoilNet network. In the URANOS simulations, the percentage of neutrons detected by the CRNS that are representative of an irrigated plot varied between 45 and 90% and was strongly influenced by both the dimension and SM of the irrigated plot. As expected, the CRNS footprint decreased considerably with increasing

SM but did not appear to be influenced by the plot dimension. SM variation within the irrigated plot strongly affected the neutron energy at detection, which was not the case for SM variations outside the plot. The instrumented fields corroborated the URANOS findings and the performance of the local CRNS was dependent on a) the timing and intensity of irrigation and precipitation, b) the CRNS calibration strategy, and c) the management of the surrounding fields. These results provide novel and meaningful information on the impact of horizontal SM patterns on CRNS measurements, which will help to make CRNS more useful in irrigated agriculture.