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Impact and relevance of soil density changes on cosmic-ray neutron sensing for soil water estimation

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Cosmic ray neutron sensor (CRNS) technology is becoming increasingly popular for monitoring volumetric soil water content (SWC) at the field (hectare) scale in a variety of environments. Applications include permanently installed (stationary) or the use of mobile (rover, trains, etc.) platforms. In agricultural settings, permanently installed CRNS have proven particularly useful for providing time series of footprint average SWC estimates. To derive the SWC product at a site, CRNS needs to be calibrated using gravimetric SWC, soil organic matter and bulk density (BD). Those variables may in the best case be derived from a large number of soil samples, collected ideally on multiple occasions and under a range of hydrometeorological conditions. Most CRNS applications use an average site-specific value of bulk density derived for a site from ≥1 field calibration and it is considered static over time.

However, while this is a safe assumption for many environments, in agricultural settings, management activities (e.g. tillage) may introduce substantial changes in BD over time. This may affect the accuracy of the CRNS SWC estimates, which in turn could affect management decisions (e.g. on irrigation) or modelling efforts, relying on these SWC inputs.

The importance of BD as a source of uncertainty in CRNS SWC estimation has been recognized with dedicated laboratory and neutron simulation experiments quantifying the effects. However, field-based studies are lacking. Therefore, the objective of this work is to quantify the impact and relevance of temporal variability in soil bulk density on the estimation of CRNS SWC in a variety of environments with different level of agricultural land use management. We used data from three sites (Scotland, Germany and China) with stationary CRNS, where BD was sampled on ≥3 or more occasions for sensor calibration. The sites display a varying intensity of land use management, cover different soil types and contrasting weather conditions. We quantify the differences in estimates of SWC by using the range of average BD values at a site and compare these differences to other sources of uncertainty (e.g. the integration time of neutron counts). We additionally consider existing theories on the interaction of neutrons and soil bulk density to evaluate the impact of BD changes. Finally, we make recommendations on when BD variability and thus its sampling over time may become important for the derivation of CRNS SWC outputs.