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Cosmic-Ray Neutrons for Estimation of Areal Mean Soil Moisture in Agricultural and Forest Sites

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One of the new measurement technologies recently introduced for soil moisture measurements, the cosmic-ray neutrons method, is evaluated in this research at small catchment scale. Secondary neutron fluxes, product of the interaction of primary cosmic-rays at the land-surface, are strongly moderated by the presence of water in or above soil (soil moisture, snow and biomass water). Neutron counts at the ground/air interface represent a valuable observation at intermediate spatial scale which can be used to quantify stored water while distinguishing different water holding compartments at the land surface.
Our main objective was to evaluate suitable calibration technique for the estimation of areal mean values of soil moisture at the small catchment scale (∼30 ha). Spatial coverage of the cosmic-ray method (horizontal footprint and vertical penetration), temporal resolution and accuracy for soil moisture estimation were also objectives of this research. Two different hydrological settings in Germany were considered in order to investigate cosmic-ray method: (1) an agricultural field with sandy soil (Bornim, Brandenburg) and (2) a forest site (Wüstebach, FZ Jülich, North Rhine-Westphalia). In the case of the agricultural field, the measurement period started when the field was cropped with corn, then again after harvest, and also measurements were continued when soil was covered by snowfall during winter. The forest site is characterized by an alkaline- and nutrient-poor predominantly brown soil with gley, pseudogley or half-bog in the wet parts. Vegetation in the forest site is mainly spruce, ground vegetation is species-poor and slightly developed (mainly fern, grass, and moss; few shrubs and bushes).
In both fields, two cosmic-ray neutron probes, consisting of a probe with moderated and bare counters and another probe only with a moderated counter, were used to monitor neutron fluxes at the ground/air interface. Neutron counts were integrated over a 1-hour time interval. The values of soil moisture used for the calibration of cosmic-ray probes were measured from classical monitoring networks. Subsequently, exponential relationship between soil moisture and relative neutron fluxes were calibrated by modifying three empirical field parameters. Temporal variability of soil moisture was correlated with variability of meteorological conditions in both sites.
Our field observations suggested that the cosmic-ray method responded well to fast hydrological events (e.g. short and intense precipitation events in agricultural site). At the forest site, a significant fluctuation of vertical resolution in the cosmic-ray method was observed, cosmic-ray probes accurately predicted soil moisture at the topsoil layer under wet conditions (close to saturation) and afterwards when soil moisture decreased. All these observations suggest that the new approach using cosmic-ray neutrons can contribute additional data for hydrological processes at the intermediate scale between point measurements and large scale measurements for different vegetation. Further work is needed in order to validate the method in different hydrological and geographical scenarios.