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EGU25-15709, updated on 07 Apr 2025
https://doi.org/10.5194/egusphere-egu25-15709
EGU General Assembly 2025

Cosmic Rays Neutron Sensing for soil moisture monitoring in vineyard with variable soil conditions

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Cosmic Rays Neutron Sensing (CRNS) is a well-known method in Hydrology that allows to measure soil water content on a large scale and in depth. It is based on the detection of cosmogenic neutrons, particles generated by the interaction of cosmic rays with the atmosphere, after their interaction with the soil where they can be effectively absorbed by water molecules. The signal collected by a single CRNS probe in terms of neutron count rate is sensitive to soil moisture within a volume spanning up to a dozen hectares and up to 50 cm depth, in real-time, positioning itself in a horizontal spatial scale in between point measurements and satellites.

In order to evaluate the effectiveness of CRNS to give information about soil moisture in an agricultural system with different soil conditions, a site in the Alto Monferrato vine-growing area (Piedmont, NW Italy) was equipped with a Finapp CRNS probe since August 2023. The site has two vineyard-field-scale plots with inter-rows managed with conventional tillage (CT) and grass cover (GC), respectively. More than 20 sensors are located in different positions and depths (from 10 to 50 cm) in the vineyard, including the STEMS network that is part of the International Soil Moisture Network. Precipitation measurements on site are available over more than 20 years, show that 2023 was very dry, with Standardized Precipitation Index lower than -1 for most of the year, whereas 2024 was increasingly wet, with exception of first two months of the year.

Available soil moisture data from CRNS and sensors have been compared until autumn 2024, using statistical indexes such as the efficiency coefficient of Nash and Sutcliffe (NSE), root mean square error of residuals (RMSE) and the coefficient of determination of the linear regression (R^2). The analysis was carried out separately for the two years, which were considered respectively dry and wet.

Statistics showed that in the last 5 months of 2023 (dry period) there was a good agreement of soil moisture values measured by sensors between 10 and 20 cm of depth with both soil management, with different results according to the position, the best reported in the middle of the GC inter-row at depth of 20 cm (R^2=0.913, NSE=0.756, RMSE=0.25). The results for 2024, which was a wetter year, showed great variability, such as the values recorded by the sensors, with

unsatisfactory statistics, since best values for indexes were obtained for the sensor placed in the middle of CT inter-row (R^2=0.598, NSE=0.485, RMSE=0.118).

Thus, in the dry period the CRNS probe gave good information on soil moisture conditions in the most superficial layer disregarding the soil management of the vineyard. On the contrary, the difficulty in having good agreement in wet conditions can be due to the high spatial variability of soil moisture both in the horizontal and in-depth directions, soil saturation and ponding, in addition to variable conditions of soil conditions (i.e. soil density) depending to soil management and tractor traffic during the growing season.