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Mobile Soil Moisture Sensing in High Elevations: Applications of the Cosmic Ray Neutron Sensor Technique in Heterogeneous Terrain

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Abstract

The use of the Cosmic Ray Neutron Sensor (CRNS) for the detection of field-scale soil moisture (~20 ha) has been the subject of a multitude research applications over the past decade. One exciting area within agriculture aims to provide soil moisture and soil property information for irrigation scheduling. The CRNS technology exists in both a stationary and mobile form. The use of a mobile CRNS opens possibilities for application in many diverse environments. This work details the use of a mobile 'backpack' CRNS device in high elevation heterogeneous terrain in the alpine mountains of western Austria. This research demonstrates the utilization of established calibration and validation techniques associated with the use of the CRNS within difficult to reach landscapes that are either inaccessible or impractical to both the stationary CRNS and other more traditional soil moisture sensing technology. Field work was conducted during the summer of 2016 and 2017 in the Rauris valley of the Austrian Alps at three field sites located at different representative elevations within the same Rauris watershed. Calibrations of the 'backpack' CRNS were performed at each site along with data validation via in-situ Time Domain Reflectometry (TDR) and gravimetric soil sampling. Validation data show that the relationship between in-situ soil moisture data determined via TDR and soil sampling and soil moisture data determined via the mobile CRNS is strong (RMSE ~ <2.5 % volumetric). The efficacy of this technique in remote alpine landscapes shows great potential for use in early warning systems for landslides and flooding, watershed hydrology, and high elevation agricultural water management.

Keywords

Mobile Cosmic Ray Neutron Sensor, Soil Water Management, High Elevation, Austria, Field Scale Soil Moisture, Hydrogeophysics, Catchment Hydrology.

Introduction

As pressure on agricultural regions increases alongside population growth and environmental change, the need for sustainable approaches to land and resource use become all the more important. Lands usually set aside as protected have become increasingly desirable as a source of arable soil. As such, determining the best practices to ensure the integrity of the land while maintaining adequate productivity is critical. The incorporation of new technologies designed to provide valuable environmental data is an important step for informed decision making. Here, the use of one such technology, the Cosmic Ray Neutron Sensor (CRNS). The CRNS is a soil moisture sensing device capable of detecting the presence of soil hydrogen over a large area (~ 20 ha). This device has a mobile 'backpack' version that can be taken to remote locations not easily accessible by its larger stationary counterpart. Here, the application, calibration, and validation of this technology in the sensing of soil moisture in high elevation heterogeneous terrain within the alpine regions of western Austria is explored. Protected ecosystems are often located within remote locations and exhibit variable terrain. Therefore, sustainable agriculture in such areas can benefit from the application of highly mobile easy to use technology to provide farmers and decision makers with the information they need.

Methods

The primary objectives of this work were to demonstrate the functionality of the mobile CRNS backpack device, calibrate the CRNS device, and validate the CRNS soil moisture data. This was carried out within the Rauris Valley of the Austrian Alps during two consecutive field campaigns in the summers of 2016 and 2017. Field sites were selected within the same Rauris watershed at three different elevations. This was done to achieve as representative a sample as possible. The highest elevation (~1700 m) was located in a high alpine meadow (alm) at the top of the valley ridge. The middle elevation (~1400 m) was located in another alm within the same watershed. The lowest elevation (~900 m) was located at the valley floor. In addition, two study sites located in central Austria were included.

The first is located near Petzenkirchen, Austria and the second near Grabenegg, Austria (both about 300 m). These two sites served as a low elevation control for the high alpine environments studied near Rauris. Each alpine study site contained one of two land uses, the first and most common being cattle grazing, and the second being the harvest of hay. Land use of the central Austrian sites consisted of mostly maize cultivation. Each location exhibited very different soil type, hydrology, topography, and vegetation density with the lower elevations having thicker darker soils with increased vegetation cover.

The mobile CRNS backpack was taken to the centre of each site where it was placed and subsequently turned on. The CRNS relies on the detection of incoming cosmic ray particles (neutrons) from outer space. These neutrons have a high affinity to be absorbed by hydrogen atoms in the atmosphere and soil. By detecting these neutrons, a relationship can be made between neutron counts and soil moisture (soil moisture being the primary source of environmental hydrogen). However, a calibration process must be performed for each new CRNS device deployed. This calibration procedure is designed to quantify sources of hydrogen within the footprint of the device other than that within soil moisture (water vapour, lattice water, soil organic compounds, etc.). To do this in-situ soil samples must be taken in a radial pattern (see Fig. 1) within the footprint and ambient humidity and temperature must be determined. These soil samples are taken at six depths ranging from 5 cm to 30 cm (30 cm being the theoretical maximum depth the CRNS can detect). The samples are sealed and later analysed for gravimetric water content and volumetric water content once bulk density is determined via standard ring sampling of undisturbed samples. Soil lattice water (water plants cannot access) and soil organic compounds (another hydrogen source) are quantified from these in-situ soil samples via a specialty laboratory located in Canada. Once soil sampling was carried out at each study site around the centre point (where the CRNS was located), the resulting information was used to calibrate the signal of the CRNS device as well as for validation purposes.

Results

Three main analyses were carried out, the first compared the volumetric soil moisture values determined from in-situ sampling (used as a 'true' soil moisture value) with the soil moisture values determined via the CRNS device (Fig. 2). The second compared the sum (in g/g) of all hydrogen (gravimetric soil moisture, lattice water, organic compounds, etc.) with calibrated counts of neutrons (counts without the signal of non-soil moisture hydrogen) to determine the fit with the CRNS calibration function curve (Fig. 3). Lastly, the penetration depth (depth the CRNS can detect) was compared to the soil moisture determined via the CRNS device (Fig. 4).

Results indicate that at each of the three study sites the CRNS is a reasonable predictor of soil moisture. Additionally, the CRNS follows the calibration function (as it should in ideal conditions) at the lower elevation control sites (Pezenkirchen and Grabenegg) but did not follow as closely at the alpine areas (Fig. 3). Lastly, the penetration depth of the CRNS is dependent on soil moisture first and foremost and varies very little between all sites studied at all elevations.

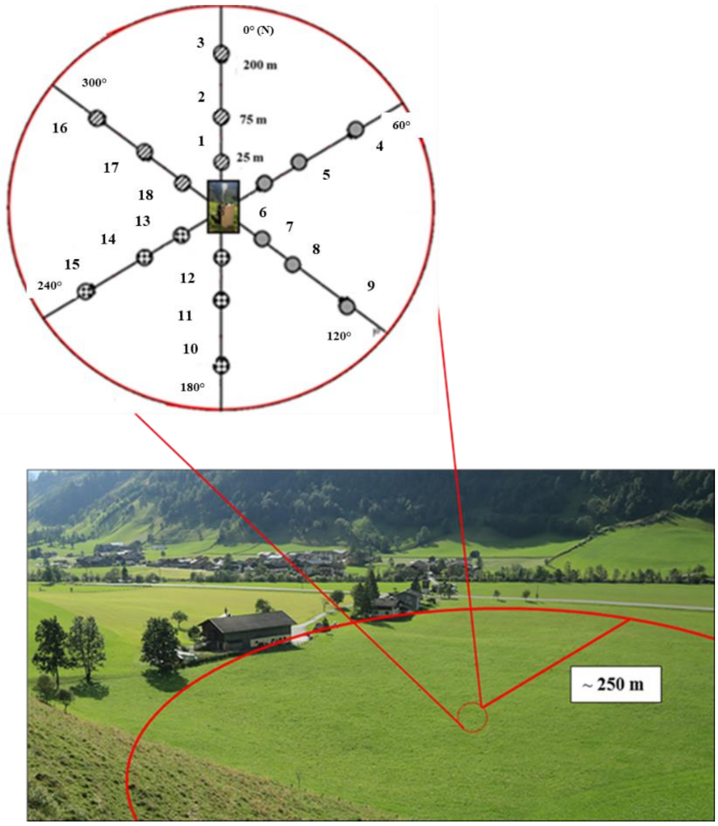

Figure 1: Illustration of the CRNS footprint and sampling pattern. Each dot represents a sampling location with the backpack CRNS at the centre.

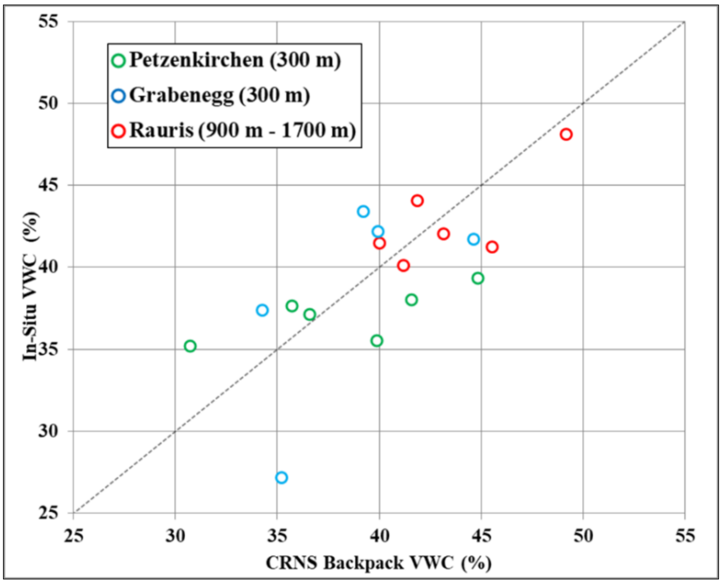

Figure 2: Graph depicting a comparison of in-situ soil moisture values (determined from traditional soil sampling) and CRNS soil moisture values.

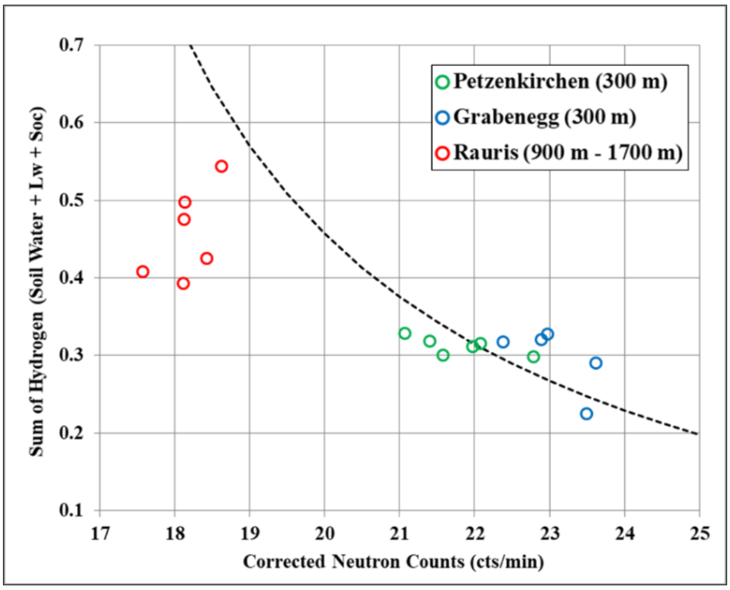

Figure 3: Graph depicting a comparison of the sum of hydrogen (soil water, lattice water, and organic carbon compounds containing hydrogen) and corrected neutron counting rates (from the CRNS device).

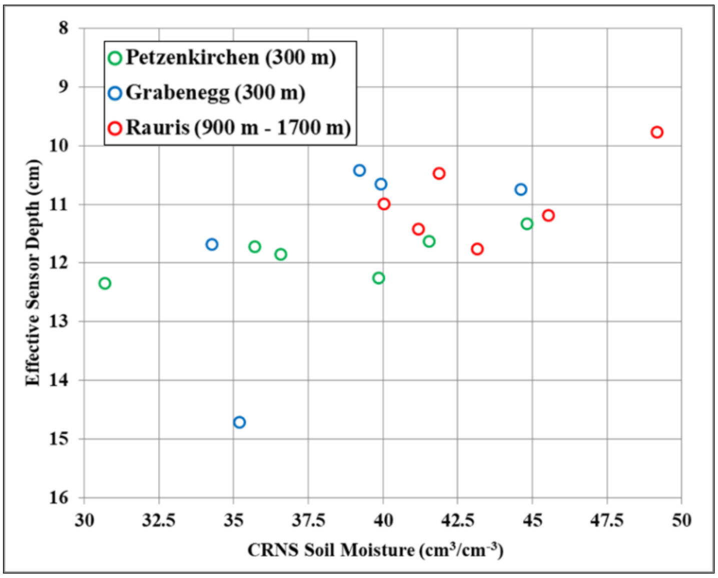

Figure 4: Graph depicting a comparison of the effective sensor depth of the CRNS device and the soil moisture values determined from the same CRNS device.

Discussion and Conclusion

The use of new technologies in sustainable agricultural practice is an important part of precision agriculture. Here, the CRNS is shown to be a reliable predictor of soil moisture when compared with in-situ soil sampling. However, further work in high elevation mountainous environments is needed (see Fig. 3). The drift of data in Fig. 3 is likely due to the fact that the soils in the high mountain sites were almost perpetually saturated with water. This is known to cause a slight bias in the CRNS calibration function. Additional work is planned to account for this error. Ensuring that agricultural productivity in protected environments remains sustainable and productive will require information on in-situ conditions such as soil moisture content. The CRNS can provide this information over large areas and entire watersheds due to its large footprint and mobile nature. The analyses shown in this work illustrate its effectiveness as a soil water sensor and its behaviour in new and variable landscapes.

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