Potential and limitations of cosmic-ray neutron sensors for irrigation management in small fields

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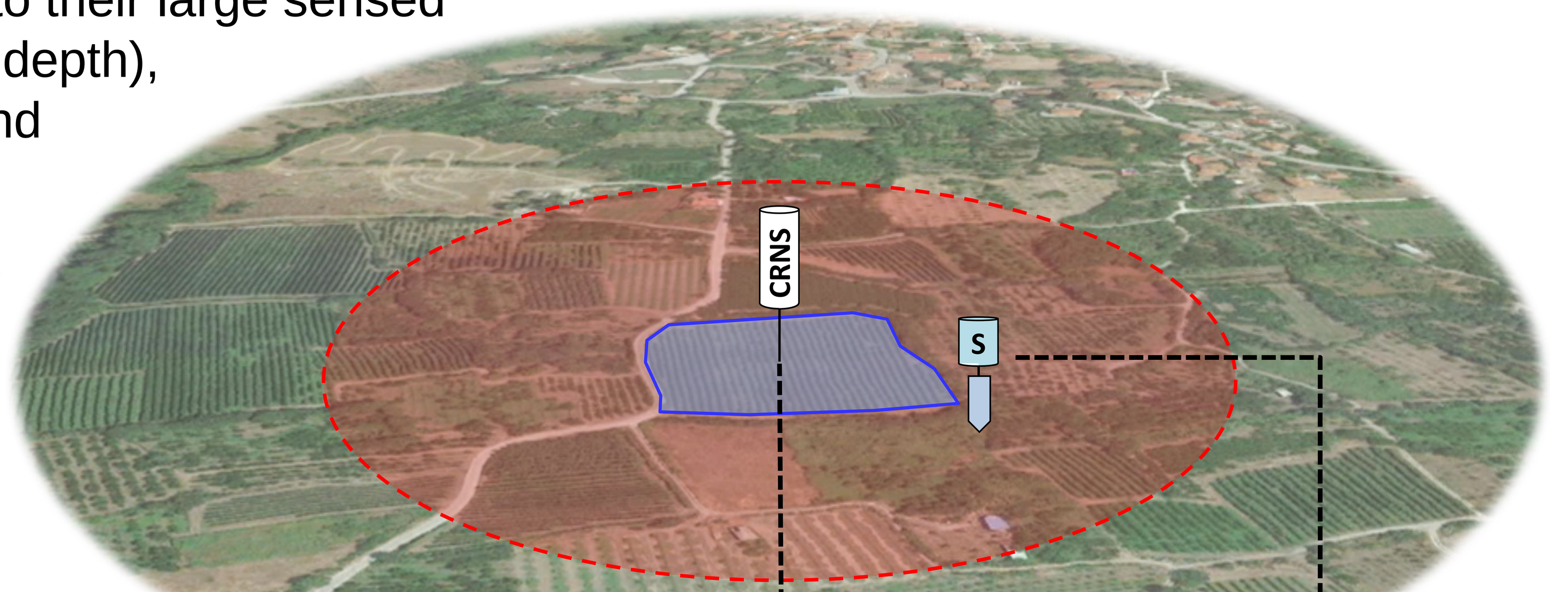
Introduction

Soil moisture (SM) monitoring is key in irrigation management as it helps reduce water consumption while mitigating crop losses.

Cosmic ray neutron sensors (CRNS), due to their large sensed volume (~130-210 m radius and ~15-85 cm depth), are a promising method in SM monitoring and irrigation management.

Unfortunately, a CRNS provides one single estimation of SM for the measured area, and complex sub-footprint heterogeneities, such as small irrigated fields (~1-2 ha), are challenging to disentangle.

In this work, we test a novel correction for irrigation monitoring with CRNS in small (~1 ha) irrigated fields.

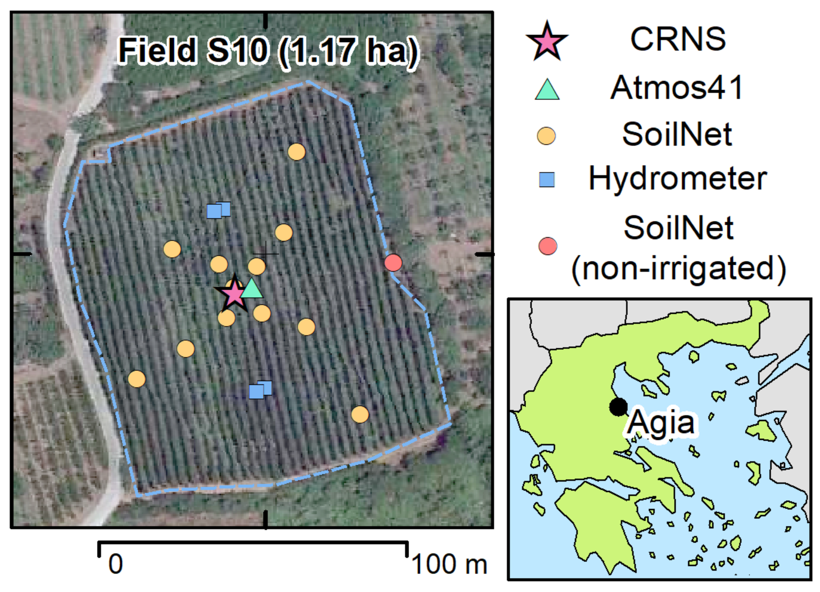


Provides neutron count rate (N) and SM (Θ) for the surrounding area.

How to isolate N_{in}^{S} and obtain Θ_{in} *for the irrigated field?*

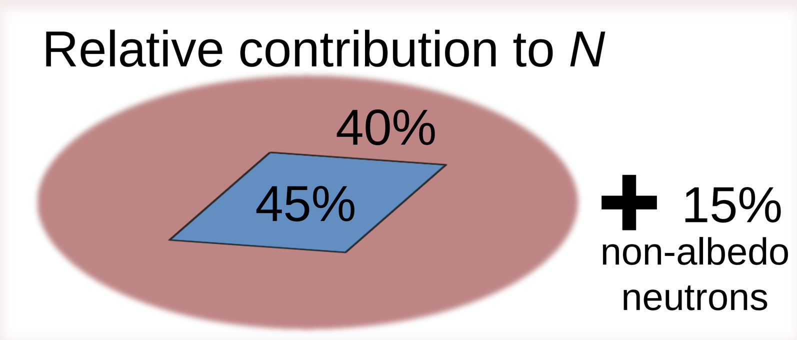
Pilot apple orchard (Agia, Greece)

The pilot field is in Agia (Greece). It is a 1.17 ha apple orchard equipped with sprinkle irrigation.



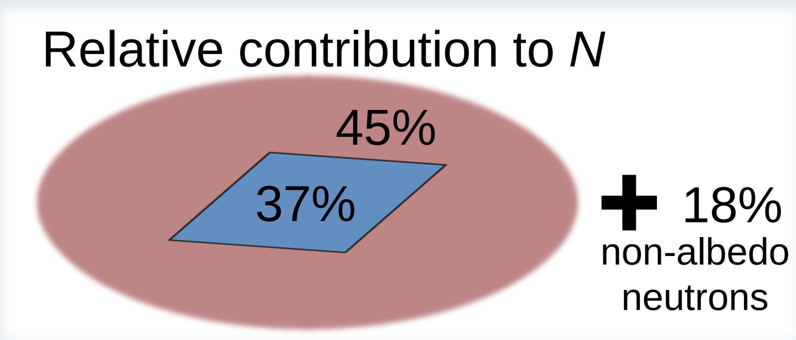
- The pilot field is equipped with 12 nodes of SM sensors (at 3 depths), four hydrometers, a meteorological station, and a CRNS.
- An additional SM node is located outside the field. This is used to measure SM in the non-irrigated area (Θ_{out}) and thus estimate a synthetic neutron count (N_{out}^{S}) for such area.

Assume minimum SM in the target field



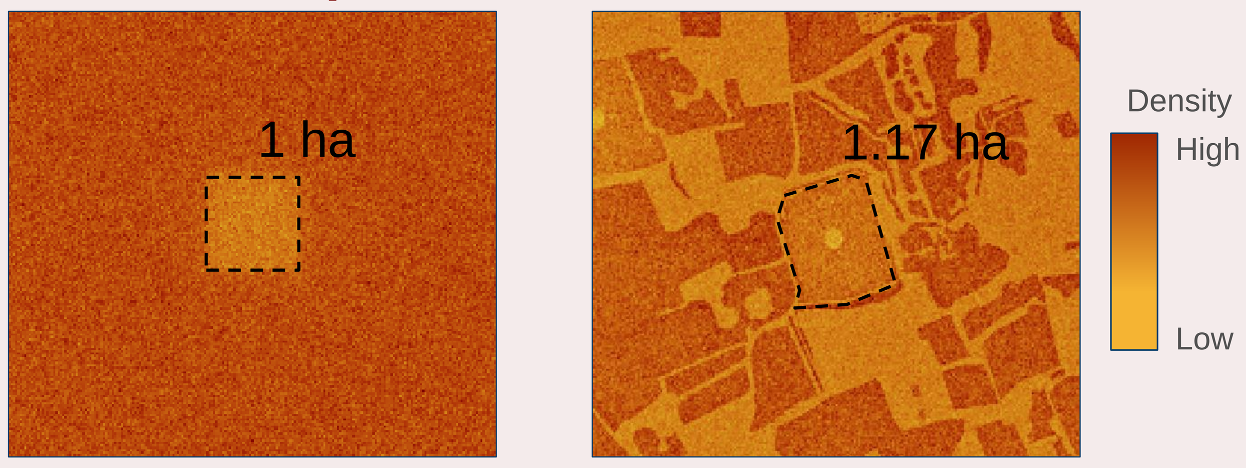
- The contribution to N of the irrigated area and of its surroundings are obtained using neutron transport simulations
- Four simulations are sufficient to apply the correction method

Assume maximum SM in the target field



- The same process is applied using contributions that assume a wet target field instead of dry
- The two synthetic N_{in}^{S} (for wet and dry) are averaged to obtain a single SM value Θ_{in}

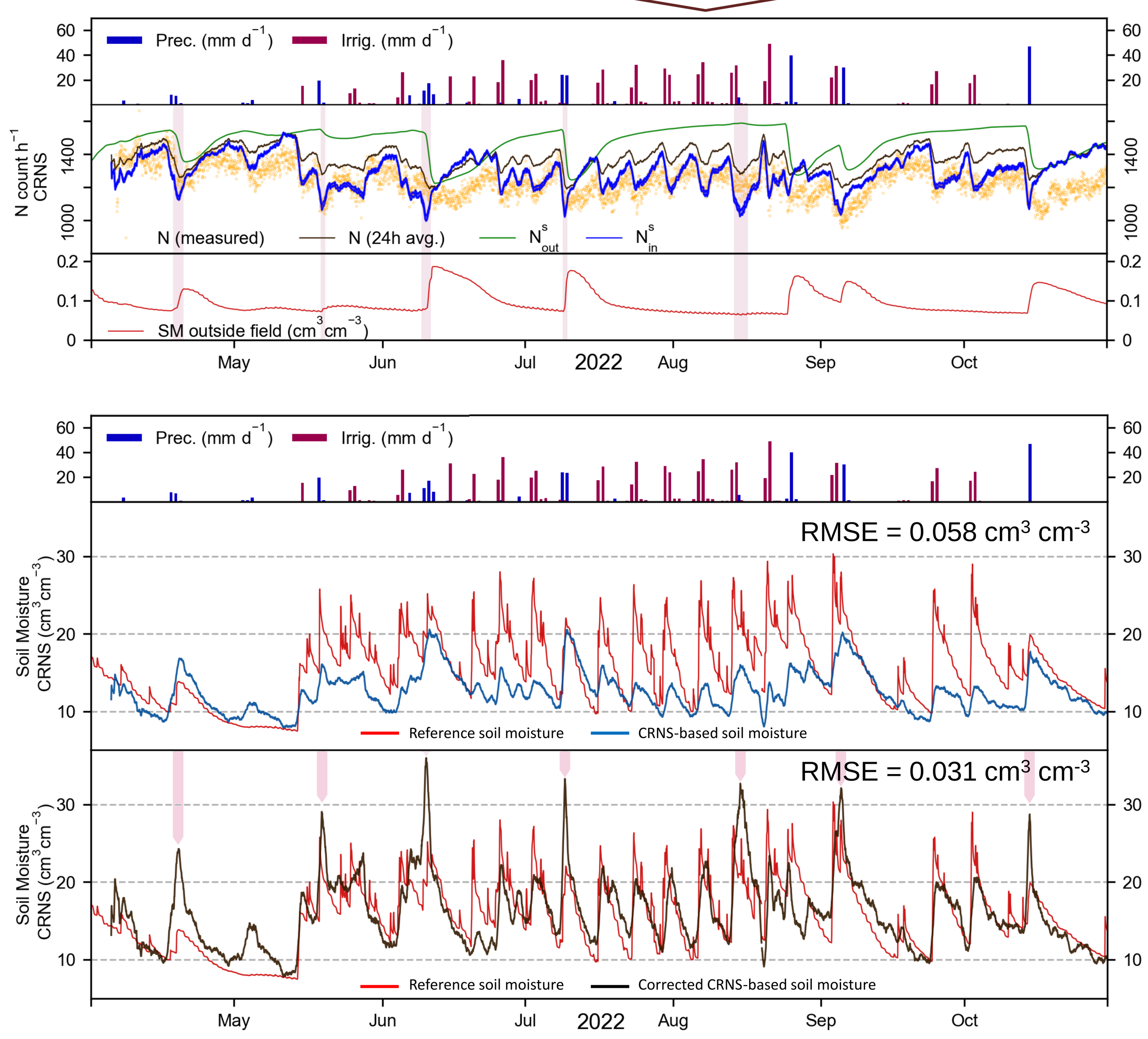
Neutron transport simulations:



Intensity of environmental neutrons obtained with URANOS simulations of neutron transport for a simplified 1 ha field scenario (left) and for the area that surrounds the pilot field (right).

Starting from measured *N*, calculate:

- Portion of non-albedo neutrons $N_{non-alb} = N/100 * \%_{non-alb}$
- Weight of outside-origin neutrons $K_{out} = N_{out}^{S}/100 * \%_{out}$
- Weight of inside-origin neutrons $K_{in} = N - K_{out} - N_{non-alb}$
- Synthetic neutron count of the target field $N_{in}^{S} = K_{in} * 100/\%_{in}$



Measured N and synthetic N_{out}^{S} obtained from the SM sensor outside the field. In blue, the synthetic N_{in}^{S} for the irrigated field.

SM estimated by the CRNS by using a standard approach.

SM estimated by the CRNS when the proposed correction is applied. Red arrow show local overestimations.

Advantages and limitations

CRNS in place of dense sensor network in irrigation monitoring:

- A dense sensor network generally needs to be removed during agricultural management and is more costly to maintain
- The proposed correction allows to use a CRNS in fields considerably smaller than the CRNS footprint

Neutron transport simulations:

- Simplified neutron transport simulations provide similar results to those obtained using simulations tailored to the target area
- Reduce computation effort and increase standardization

Use of additional supporting SM sensors:

- Reduce costs by correcting multiple CRNS with one supporting sensor
- Use a second CRNS or other CRNS in the area to perform correction
- Challenging in case of a highly heterogeneous SM distribution

Conclusions & outlook

- CRNS can monitor and inform irrigation in small irrigated fields (~1 ha) when supported by an additional inexpensive SM sensor
- CRNS, when corrected, could replace a dense sensor network
- Further studies are needed to standardize the methodology and test results for different environments and irrigation methods

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