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Comment on gi-2022-11

Anonymous Referee #1

Referee comment on "Feasibility of irrigation monitoring with cosmic-ray neutron sensors" by Cosimo Brogi et al., Geosci. Instrum. Method. Data Syst. Discuss., https://doi.org/10.5194/gi-2022-11-RC1, 2022

This study investigates the feasibility of soil moisture (sm) detection with cosmic-ray neutron sensors (CRNS) in the center of a squared irrigated field. The authors investigate the sm-neutron relationship and the footprint radius for various scenarios of detector shielding material, field sizes, and combinations of soil moisture conditions in the inner and the outer areas. They conclude that different thickness of HDPE material influences the footprint radius and the detector sensitivity, with HDPE 25mm + Gadolinium leading to the highest sensitvity to soil moisture changes and to the largest footprint radius. Moreover, they found that soil moisture from the outer fields substantially influences the CRNS sensitivity to the irrigated field, especially for small fields.

The study is very will written and highly relevant, being the first of its kind to study various detector thicknesses and gadolinium shields with regards to the neutron-soil moisture relationship. This will be a very important information for CRNS users and suppliers in order to significantly improve the sensor performance. Furthermore, the investigation of irrigation support is also very relevant for current and future CRNS applications. However, this study is only theoretical and limited to a very specific geometry (CRNS within a squared irrigated field). Nevertheless, it is a good step forward.

Major concerns with this study should be clarified before publication of this manuscript, particularly regarding the model assumptions, the consistency of the argumentation, and the integrity and applicability of the conclusions. Please address also the minor comments and the specific comments below.

Major concerns:

- The authors seem to change the water content of the irrigated soil in the whole soil column (up to 160 cm depth). However, it is highly unrealistic to assume vertically homogenous wetting of the soil due to surface irrigation! Hence, I wonder how useful the results of this study are for practical applications. In the real world, surface irrigation adds moisture only to the first few centimeters of the soil, or decimeters, depending on typical depth of the roots and the hoses. This would leave a large part of the vertical footprint dry, such that the results obtained in this study might significanlty overestimate the actual sensitivity of CRNS to irrigated soil.

- The authors conclude that 25 mm HDPE+Gd is the best shielding variant for CRNS detectors (L359) without studying other HDPE thicknesses together with Gd. It is indeed interesting to see gadolinium used for the first time in a sophisticated analysis of detector sensitivity to footprint and soil moisture changes. However, the authors used Gd only in the 25 mm HDPE setup. In order to distinguish and better understand the effects of HDPE and Gd on the variables of interest, and to find the best performing detector design, it would be necessary to simulate Gd shielding also for different HDPE thickness.
- The authors conclude that outer sm is an important factor for irrigation monitoring with CRNS by considering only one shielding option that provides the largest footprint. In section 3.4 and 3.5 the impact for inner sm changes on the neutron detector sensitivity is investigated, but only for 25 mm HDPE-Gd (mentioned in 3.4, not mentioned in 3.5). In the same study, the authors find that different shielding options have different footprint radii. So, I would expect that shielding options with lower footprint radii would lead to less impact of the outer sm. Please elaborate on this and whether different shielding options could be recommended for smaller fields than for larger fields to reduce the influence. This might change your conclusion. Also, use this opportunity to join the two otherwise separate parts of "shielding/footprint analysis" and "sm/area analysis", in order to demonstrate that a combination of those two studies in a single paper could actually lead to a greater benefit.
- The authors suggest that sm measurements outside the irrigated area are needed to properly estimate sm inside with CRNS. But in this case, what is the added value of CRNS compared to using the suggested number of additional sensors and putting them inside from the start?
- The study is limited to one specific case of field geometry: a CRNS detector in the center of a square-shaped irrigated field surrounded by a homogeneous field on all sides. Although simulations of various shielding types and square sizes are scientifically interesting, the transferability of the results to practical field geometries might be very limited. I would recommend to better communicate this limitation, at first by improving Figure 1 with a detector symbol in the center and scales in meters. Second, by providing real-world examples where this scenario could be applicable (I would rather think that radial field geometries would have been a better choice, e.g. for pivot irrigation). Third, by discussing potential deviations and uncertainties of the results if the sensor location would not be ideally centric, or if the field shape is a circle instead of a square. This would allow users to get a better idea whether the results would be still applicable to a certain degree, or whether completely new simulations would be necessary for every single deviation from the presented ideal case.

Minor comments

- The authors mention that sm change outside can be larger than sm change from irrigation inside. However, it is not clear in which scenarios it is actually realistic to assume that sm changes "only" outside. Most of the time, precipitation occurs within CRNS footprints rather homogeneously. So the only cases I could image of sm changing outside (and not inside) is that these fields are also irrigated, and with a completely different schedule. You could communicate more openly that this is a special case, and only in this case the sm-outside issue becomes relevant.

- The authors seem to assume that only neutrons that originated from the inner area carry its sm signal (L211). However, Köhli et al. 2015 mentioned a few intermediate interactions of neutrons from longer distances with the soil on their way to the detector. In this context, it seems that neutrons from outer regions could carry signals from the inner regions, too. In this case the authors are encouraged to reconsider their assumption.
- Minimum soil moisture used in this study is 0.05 m^3/m^3, while irrigation might be particularly interesting in extremely arid regions, where sm below 0.05 can exist. Given the very steep neutrons-sm function, there is a potentially significant performance increase of CRNS for dry soils. Can you add ~0.03 m^3/m^3 to your analysis?
- Nomograms for the presentation of the results are very hard to read (e.g. Fig 3). I can understand the authors idea to put both, the inner and the outer sm on the two axes, but it took me several minutes starring at the plot to understand what they are showing. And now that I understand it, I still find it hard to read out what fraction of neutrons comes from the inner or the outer part for a given soil moisture condition. Especially since both relative neutrons are not adding up to 100% (due to direct neutrons?). So, I would strongly suggest to reconsider these graphs, focusing on the main message, which probably is: "How do neutrons from inner and outer areas compare?". If two variables need to be compared, try to show them in the same plot. And since they add up to a total neutron count (or to 100% inlcuding direct neutrons), the usage of stacked barplots might be good choice. One advantage of a N-over-SM plot would also be that the curves could be easily compared with the conventional N(SM) functions to show how this function changes for different irrigation pattern. Just like in Figure 9. Consider replacing Fig 3 with Fig 9 or at least refering to it.
- Parts of the introduction are unnecessary or not clear. There are long paragraphs about food security and irrigation in general, point-to-large scale sensors, CRNS detectors in general and their multifaceted applications from snow to regional modeling, and so forth. All this sounds like a great literature review, but it is out of scope in large parts. Instead, in the end of the introduction the very important concept of "energy dependent response function" is just mentioned, while it has never been introduced. Please consider shorteing the introduction and provide a more concise structure with a focus on the actual topic: simulation of multiple neutron detector variants in heterogeneous irrigated terrain. Unclear: the argumentation about thermal neutrons, how are they different from epithermal neutrons, and why is it necessary to exclude them? Here would be a good spot to elaborate on energy response functions. See also the 16 specific comments below.

Specific comments:

- L47: I don't see how Andreasen et al. 2016 demonstrates that CRNS can close gap between point and large scales. Please double-check the reference and think about providing references related to the footprint and in comparison with actual point measurements (for example, Heistermann et al. 2021, doi:10.5194/hess-25-4807-2021)
- L49: "cosmic-ray radiation" is tautologous.
- L50: "The detected neutrons are generally in the thermal ... or epithermal ...". Please rephrase to avoid questions like: What means "generally"? Can a detector directly detect epithermal neutrons? Is a spectrometer involved? Can you provide a reference

for the energy sensitivity?

- L52: Consider adding a references that is less than 10 years old, e.g., Köhli et al. 2021, doi:10.3389/frwa.2020.544847
- L56: "dry soils have a higher neutron density" - Please rephrase. Is it the soil that "has" this neuton density, or the atomic nuclei inside the silicate atoms? Or the air above the soil?
- L49-57: The whole paragraph: you start with telling that CRNS is both, thermal and epithermal. Are all these statemens in the text (sensitivity to sm, snow, vegetation, ...) refererring to thermal, to epithermal, or both? Do they behave equally? If no, how are thermal neutrons different? If yes, why do you want to exclude them?
- L60: I don't see how Schrön et al. 2017 uses multiple counter tubes to achieve higher count rates. Do you mean Schrön et al. 2018, doi:10.5194/gi-7-83-2018 ?
- L64: "... prevent the detection of thermal neutrons" - Not clear: why should the detection of thermal neutrons be prevented? Please restructure this paragraph to explain why thermal neutrons behave differently and why they are not useful for soil moisture monitoring.
- L69-70: You argue that CRNS does not need to be removed during harvest. Is the instrument of infinitesimal size? If not, what is the spatial extent of the apparature including anchoring, and how can a farmer pull around it? Please consider reporting about pros and cons of CRNS more objectively.
- L75: What is "rover-based"?
- L77: I don't see how Dong et al. 2014 and Jakobi et al. 2020 discuss drought and flood events. Consider rephrasing.
- L82: "areas with different SM content can be overlooked by a single CRNS" - Please rephrase. Almost all nearby areas do influence the detector signal integratively, so "overlooked" is probably wrong wording.
- L87: "detection of irrigation-related SM variations might not be possible" - Are Li et al. showing that it is not "possible", or are they merely showing that the irrigation signal is within the noise level of typical CRNS detectors? If the latter, there might be chance to detect even small sm changes with better detectors? E.g., higher count rate or improved shielding? I think there is a good chance here to use Li et al. 2019 for motivating your study! Consider rephrasing.
- L93: Again Li et al.? Consider merging the two occurances.
- L103-106: Three occurances of Köhli et al. 2015 within four lines with mainly identical contexts. Please consider rephrasing.
- L109: "energy dependent response function" - What is this? Please elaborate in the paragraphs above.
- L121: "measure neutrons in the thermal to fast energy regimes" - Can you be more specific or provide a reference?
- L124: Why is Bogena et al. 2022 a good reference for the influence of additional hydrogen pools on CRNS? Consider adding Iwema et al. 2021, doi:10.1002/hyp.14419 and Baroni et al. 2018, doi:10.1016/j.jhydrol.2018.07.053
- L126: "a CRNS" - Here you use CRNS as singular, but the grammar in most of your sentences suggests that CRNS is plural. Please clarify.
- L126-132: Unnecessarily detailed on how the detector, the electronics, the meteo station and the antenna work. Consider removing this part from the manuscript (which is about a theoretical, simulated detector).
- L138: "The footprint is assumed to be circular" - Schattan et al. 2019 as well as Schrön et al. 2022 showed that it can be asymmetric depending on the site heterogeneity. This could be also relevant for your study on irrigation, especially if only parts of the outer fields are irrigated. So, is this radial symmetric assumption necessary for your study?
- Figure 1: Please indicate the detector position (e.g. with a point) and add scales (in meters) to the inner area box (hectares alone are not very easy to grasp)
- L194-197: These statements sound like results, rather than methods. Or are they already established knowledge? Then please provide references.
- L199: Consider adding Rasche et al. 2021, doi:10.5194/hess-25-6547-2021, as a

reference for the discussion on thermal neutrons and their behaviour in heterogenous terrain.

- L201: Why "either"? Can't you use the same neutron for both, count rate calculation and footprint calcuation?
- L214: As you have mentioned also on other places, consider adding Schrön et al. 2022, as they seem to have demonstrated exactly that.
- L215: "Here, it is assumed that having a relatively small R86 is beneficial when monitoring irrigation in small fields" - Please rephrase, what does this assumption imply?
- Eq 1: Please elaborate more on where this equation comes from. It looks like you are propagating the error of N1-N2 (which is the change of neutrons upon detection), where the error of Ni is 1/sqrt(Ni)?
- L232: The cited preprint is not a good reference here. Can you refer to a study which presents typical irrigation intervals?
- L248: "inimum and maximum percentages of detected neutrons" - Is this relative to all albedo neutrons, or to all detected neutrons (including non-albedo neutrons)? Please clarify.
- Figure 5: Since panel f) shows a difference rather than the actual value of R86, the colorscale should be completely different. However, it still has blue and yellow colors just like the colormap from the other panels. Please make f) more distinguishable, by choosing a more distinguishable colormap (e.g., red-white-black). Moreover, using terrain colormaps for R86 is not a good choice. Blue stands for water, but low radii have nothing to do with water. Try to use a more linear colormap (e.g., greyscales), or none.
- Figure 6: Can you add conventional N(sm) functions for the purely homogenous case for comparison?
- Figure 8: Why are some bars larger for higher sm than others at lower sm? Is this an effect of the simulation uncertainty? Can you provide an errorbar for the bars?
- Figure B1: % relative to what? Can you add the signal of a completely bare sensor (0 mm HDPE)?
- The reference list is sorted by first author name, but for the same author it is not sorted by publication year. This makes searching for references very cumbersome, especially for extensivley used author names (such as Bogena et al.). It should be fixed during typesetting.
- With regard to the previous comment, please double-check whether such a high number of rather general references on soil moisture are necessary for this very specific manuscript about neutron detector simulations and irrigation.