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Reply on RC2

Mandy Kasner et al.

Author comment on "On soil bulk density and its influence to soil moisture estimation with cosmic-ray neutrons" by Mandy Kasner et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-123-AC2, 2022

Dear Reviewer 2,

thank you very much for your critical and positive review. We will briefly respond to your concerns in the interactive discussion. (RC=reviewer comment, AR=author response)

 # Overall comments

> RC2.1: "The presentation is reasonably good, with some additional details required. The English language is generally quite good, but should be improved. However, as it appears to me, there seems to be some major inconsistency between the theory and the presentation of results, and at times the text contradicts the plotted results. Attempting to untangle this is a major distraction from the message of the paper. Moreover, as presented currently I believe that the results are most likely incorrect, but will be corrected easily."

AR: Thank you for sharing your impression. We believe that the reviewer misinterpreted the slope of the curve of equation 3, which led to an apparent inconsistency with the rest of the text and results. In the detailed response below we will try to solve this misconception, proving that the theory is indeed consistent with the simulations.

Large parts of this review refer to apparent inconsistencies of the figures, texts, and conclusions with equation 3. These comments are seemingly all based on an initial misconception, which can be quickly solved (see next section). However, we admit that a typo in line 177 ("decreasing" instead of "increasing") may have led to this substantial confusion. We apologise for this mistake will be fix the sentence in the revision.

> RC2.1: "The Discussion and Results present the increase of neutron counts with increasing bulk density (decreasing porosity) – whereas the theory (Equation 3) suggests that solid matter will scatter more efficiently than the much lower density air in the pore spaces, which implies to me that the neutron count should decrease with increasing bulk density (BD). Perhaps I am wrong, and misunderstand something here?"

AR: Your are referring to equation 3 (or the simplified equation 4), where N is proportional to a combination of cross sections, densities, and energy loss quantifiers. Here, the slope of the curve (N over s) highly depends on the weighting factors ξ_s and ξ_w in the denominator. It is 1 for $\xi_s = \xi_w$, <1 for $\xi_s > \xi_w$, and >1 for $\xi_s < \xi_w$. According to Köhli et al.

2021, the variable xi represents the energy loss per collision, and can be estimated with $\xi=2/(A+1)$, where A is the atomic mass number. For hydrogen, $\xi(A=1)=1$, and for Silicon, $\xi(A=28)=0.07$. Hence, $\xi_s << \xi_w$.

For a quick illustration of how this influences N, let $a=s*\Sigma_s$ and $b=w*\Sigma_w$, then $N \sim (a+b)/(a*\xi_s + b*\xi_w)$. With $\xi_s << \xi_w$ this reduces roughly to $N\sim(a+b)/b = 1+a/b$, i.e., $N \sim s$. Using rough values for all the variables, the following link shows this relationship plotted: https://tinyurl.com/neutronsoliddensityplot

Since the theory indeed confirms our simulation results, we can be assured that the plots and conclusions are correct. However, we realize that better understanding of the theoretical part is critical for the readers, so we will consider improving the explanations and guidance on interpreting the theoretical concepts.

> RC2.2: "But the text is also contradictory in places e.g. P.7, L.176-77:
"The highest neutron intensity can be achieved for very dry and dense soils, while it decreases with increasing soil bulk density (or decreasing porosity)."

AR: You are right that this sentence contradicts itself. We meant, that neutron intensity *increases* with increasing soil bulk density. Sorry for the confusion, it will be changed in the revision.

> RC2.3: "However, I have doubts whether the plots are correct? For Fig.2 & Fig.3 (and subsequent plots with BD/porosity x-axis) – I believe that all the x-axes labels are reversed? Making this assumption, the results would make physical sense, otherwise, as above the results do not match (or are opposite to) the theory presented, as I understand it.
The later text does match the plots, so I am really left wondering if all the discussion and presentation of results has to be revised, as well as the plots… or else explain what I am missing and why we should expect higher neutron counts with higher BD?

AR: The plots are correct and do confirm the theory (see above). The text will be double-checked for potentially confusing formulations.

> RC2.4: "The paper is written in the future tense (e.g. P.2, L.54-55), this not the conventional way to report scientific experiments.
Take more care with the use of tenses, and prepositions e.g. Title change "influence to soil moisture" to "influence on soil moisture". English should be generally improved and errors removed."

AR: Thank you, we will improve the writing upon revision of the manuscript.

> RC2.5: "Section 2.4 Experimental Concept: Where are the tanks located? - how did you control the surrounding environment? Could there have been other non-constant hydrogen pools in the surrounding 100 to 200m?

AR: The tanks were located inside a large, air-conditioned hall, build and surrounded by concrete. This way we expect no influence external weather conditions. Between 5 and 50 meters, scientists and cars have been present but with only minor rearrangement during the experiment period. This might be a valid source of systematic uncertainty, but it is constant and very hard to quantify. We will elaborate on the measurement setup in more detail.

> RC2.6: "5, L.139-L.140 specify the CRNS detector type (make & model). Why only a 60 minute counting period? Why not longer to improve the count statistics?

AR: The detector has been specified as the one used for roving in Schrön et al. 2018, with roughly 10x more count rate than CRS1000 detectors. The measurement period is short because we tryed to minimize the risk of water loss due to evaporation during the day. Our main goal was to keep the soil water content constant between the two experiments (dense and loose), so we removed the soil and repacked it within one day, leaving only about 60 minutes time for each of the two measurements. We will better describe this approach in the text.

> RC2.7: "L.191 were the neutron counts first corrected in any way? For example, for changes in atmospheric pressure, air humidity, incoming neutron intensity? Otherwise, neutron counts made at different times cannot be directly compared!"

AR: Yes, we corrected the neutron counts according to standard procedures. We will add this information to the revised manuscript.

> RC2.8: "Table 1. Are the neutron counts assigned to the correct porosities? Whilst data here matches Fig.3, it does not agree with the theory (Eq. 3)"

AR: We are glad to report that the data is consistent with equation 3, see the explanation above.

> RC2.9: "L.240-242 Is this the right way round? Here both BD and SM vary - so which has the more dominant effect on penetration depth?"

AR: We agree that this example is challenging to interpret. We will provide a more clear example that shows the different contributions of soil moisture and bulk density on the penetration depth. However, this is just a side note and based on already published literature (see D86 in Schrön et al. 2017).

> RC2.10: "13, L.293 understimate (?) --> increased porosity should increase counts! Leading to underestimate of SM??.... and Fig.5 Why don't counts increase with porosity? I don't think this is correct?
Summary & Conclusions: (2.) "On average, neutron count rates decrease by −1% for every +10% increase in porosity". This appears contrary to Eq.3 ? I would expect an increase in count rate. As per Point 1 above, much of this text needs revising if indeed the plot x-axes are reversed."

AR: Also here the text is consistent with the results and theory (see above).