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Reply on RC3

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-AC3, 2022

Dear Reviewer 3,

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

 # Comments

> RC3.0: "I believe that the impact of soil bulk density is an impact factor that needs to be considered at least for some applications when converting neutron counts into soil moisture and as such, the study is highly relevant and important and ultimately warrants publication. However, the manuscript is not ready for publication in its present form as far as the analysis, presentation and language are concerned. The authors need to make a thorough effort in improving the text and make it consistent both internally and in relation to the presented figures. During my reading of the manuscript, I noted language issues at several places but I will only mention some of them below."

AR: Thanks for sharing your impression on the manuscript. We thank the reviewer for pointing out some language and writing issues, which will be solved during the revision. However, we have not been able to identify issues with the analysis based on this review.

> RC3.1: "l. 50: Perhaps a bit unusual to start out with the hypothesis that that neutron intensity is unaffected by soil bulk density. The whole idea of the manuscript is to document that the opposite is the case, so it would be more intuitively to state that the objective of the work is to analyze and quantify the impact of soil bulk density on neutron counts and how to take this impact into consideration to obtain reliable estimates of soil moisture.

AR: We agree and will reformulate the last paragraphs of the introduction according to the suggestions from Reviewer 1. The reason why we initially decided to start with the negative hypothesis (that neutrons are invariant against change of soil bulk density) was that this has been the hitherto common assumption in CRNS literature. However, we understand that a more straight-forward description of the hypotheses would be more comprehensive.

> RC3.2: "Section 2.4 Experimental concept: I believe that the reported experiments are very interesting in order to gain experimental evidence of the impact of soil bulk density.

The experiments are indeed a comprehensive endeavor and I would like to know a bit more details on the setup perhaps by an accompanying figure, which also shows the position of the CRNS detector."

AR: Thanks for the suggestion, also the other reviewers asked for a more elaborate description of the experiment. Initially, we did not plan to elaborate more on the experiment, since the main focus of this manuscript is the theory (and simulations). But we agree that the lab experiment is a unique setup which deserves more detailed explanations. Accordingly, we will expand the corresponding description in the revised manuscript.

> RC3.3: "I anticipate that the packings were done with dry sands. How did you then add water afterwards to obtain uniform moisture contents in the packings?"

AR: The sand has not been purely dry, but exhibited a measurable soil water content as mentioned in the table. In order to minimize the change of water content while repacking the sand for the second experiment (due to evaporation, for instance), we removed and reinserted the sand within a few hours period. This way, we were able to keep the soil moisture rather constant. This will be clarified in the revised text.

> RC3.4: "Could there be environmental factors affecting the results?

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, few scientists and cars may have been busy during the experiment period. This might be source of systematic uncertainty, but it is very hard to quantify. We will elaborate on the measurement setup in more detail.

> RC3.5: "l. 142: I suppose this should be for the loose experiment?

AR: Yes, this refers to the loose soil. We will clarify the text accordingly.

> RC3.6: "l. 155: In line 126 it is stated that the grain density in the simulations is 2.86 g/cm3 but now a value of 2.65 g/ cm3 is assumed? Any inconsistency here?"

AR: Line 126 refers to the density of the pure solid soil material (SiO_2 + Al_2O_3), which is the default parameter in URANOS simulations. Line 155 refers to the particle density of quartz (SiO_2), which is the accepted standard value for average soils. We agree that this is confusing, but this will only change the way how porosity and bulk density are converted by the two approaches, while principle results and conclusion of the study are not impacted. We will resolve this apparent inconsistency in the revised manuscript by adapting the porosity presentation and by pointing out that it is important to know about the two different parameters when comparing URANOS soil porosity with conventionally converted measurements.

> RC3.7: "Figure 1: In my printout, water and air have the same signature. Please make the two phases mutually discernable."

AR: We have optimized this figure to show maximum contrast and readability even for handicapped readers or grey-scale printers. Air has a pure white face color, solid soil is pure black, while water has a black dotted texture. The different signatures should also be clearly visible in black-and-white printouts. Please let us know how the contrast can be even further improved.

> RC3.7: "l. 164: It is 4 units of soil and 1 unit of water giving a ratio of 4. Please be consistent how you refer to this ratio throughout the manuscript."

AR: This is a typo, thanks for pointing this out. It will be fixed in the revised manuscript.

> RC3.7: "l. 165: equal 20 vol% porosity?"

AR: Yes, we will add "porosity" here.

> RC3.8: "l. 177: This sentence is contradictory to Figure 2. Intuitively I would think the sentence is right."

AR: This is an unfortunate typo, which also led to large confusion by Reviewer 2. It should read "it increases with increasing soil bulk density" and will be fixed.

> RC3.9: "l. 183: I am not sure I see a flat slope in Figure 3."

AR: We tried to say that the slope is constant, not flat, compared to the much more curved slopes of dry soils. We will correct the word in the revision.

> RC3.10: "Figure 3b: In Figure 3a the counts become higher for lower soil moisture contents but the opposite is the case in Figure 3b, which does not make sense.

AR: The plot is correct, as the low number of hydrogen and the high number of oxygen almost equally influence the neutron response. It is a notable example of the complex and non-linear relationship between neutrons and water content in the extreme dry regime. Please see section 4.2 for an elaborate discussion on this effect. We observed this opposing behaviour for soil moisture below 5%. To make it more visible, we split the figure into two panels.

> RC3.11: "Section 3.3 Evidence in the sand box experiment: There are some conflicting statements in this section regarding counts. Do the counts increase significantly (l. 193) or are they the same (l. 205)? What is the learning from the experiments given that some the controlling parameters are not constant?"

AR: This sentence refers to the topsoil experiment, where the deviation between the two solid-water ratio is very small. We apologize for the confusing statement. Since the experiment involved filling, unfilling, and compacting of 2 m^3 of soil, it is almost impossible to exactly keep the soil moisture values constant. Nevertheless, we tried our best to reduce the risk for water evaporation during this process be refilling the box as fast as possible (within a few hours time). The learning from the experiments is very clear, as the first experiment provided a larger ratio change together with a larger change of neutron counts (confirming the N-bulk_density relationship), while the second experiment provided almost no change of the ratio together with almost no change of neutron counts (confirming our constant-ratio hypothesis).

> RC3.12: "l. 284-300: Please revise these lines as well as the figures. There are conflicting figure numbers and porosity numbers and some of the referred numbers of counts and soil moisture I do not see."

AR: The figure references are correct, but the writing is indeed a bit confusing. We will rephrase the text to describe the figures in a clearer way. Indeed, there is a typo in the schematic shown in Fig. 6, it should say "45%" porosity at the top and "35%" at the bottom.

> RC3.13: "l. 315: Impressive perhaps a bit exaggerated."

AR: We agree that this is speculation and will rephrase it in the revision.

> RC3.14: "l. 324-325: This is an important statement which perhaps should be emphasized even more."

AR: We believe that this statement does not require further discussion, but we will consider to slightly elaborate on this matter in the revised text. It has been made clear by Köhli et al. (2021) that the Koe function has been developed using different model assumptions than the Desilets equation. However, the performance of the Koe function regarding soil moisture and air humidity has been shown to be better than for the Desilets equation, particularly under extreme conditions. Hence, we base our study on the most recent state-of-the-art simulations by Köhli et al. (2021). In the present study we look at an additional aspect -- the influence of bulk density -- which has not been accounted for in previous studies. We acknowlegde that the usage of URANOS to investigate this effect is not as fair for the Des function as for Koe function, but it would not make sense to use deprecated model assumptions just to investigate the influence of bulk density on the Des function, while it has already been shown that the Des function has substantial issues on its own. Nevertheless, we decided to keep the comparison to the Desilets function in this study, in order to assess the potential impact on previous studies and their results using the Des function.