Response to Anonymous Referee #3

We would like to thank Anonymous Referee #3 for their feedback on our paper. The responses to his/her substantive comments are provided below, whereas comments relating to purely editorial matters will be addressed in the revised manuscript.

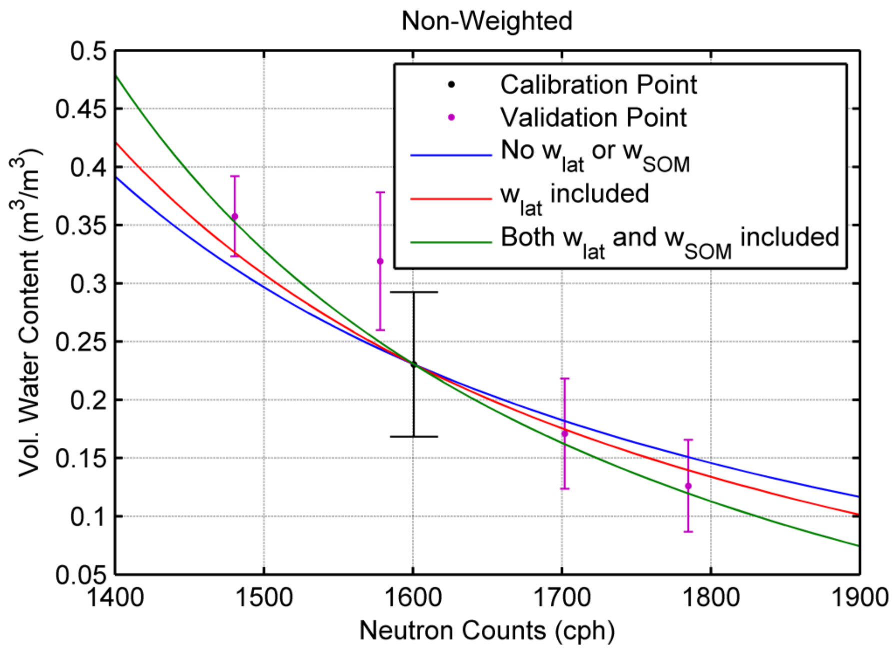
In this paper the authors investigate in how far one can use cosmic-ray neutron probes to determine root zone soil moisture down to a depth of 110 cm. Since the cosmic-ray neutron probes are generally only sensitive to soil moisture changes within the upper 30 to 70 cm, the authors test several methods in an attempt to couple the areally averaged shallow soil moisture variation with point measurements of soil moisture at depth to also receive areally averaged soil moisture at depth.

The approach deserves attention since it tackles one of the main problems of the cosmic-ray neutron probe method – the relatively shallow effective measurement depth. If it was indeed possible to extend the shallow soil measurements to cover the entire root zone this would be a big improvement. Therefore, I think that this manuscript is well-suited for publication in the HESS journal.

The main problem (it is a minor one) that I had with the manuscript is the sometimes changing categorization of the different methods: Upscaling vs. modeling, four estimation techniques vs. three evaluated techniques. Other than that the authors should probably test whether
(1) the inclusion of lattice water and soil organic matter,
(2) the use of the new footprint weighting (by Köhli et al., 2015) or
(3) adding another calibration date for the cosmic-ray neutron probe (see Iwema et al., 2015)
would affect their results/conclusions.

> Response: As suggested, we have investigated the impact of these three points upon the calculation of soil moisture and effective depth. Using our data, we constructed Figure AC 3-1 to be similar to that of Figure 9 in Hawdon et al. (2014). Our results show that inclusion of lattice water and soil organic matter considerably improves the agreement with the validation measurements. The effect of using the footprint weighting method of Köhli et al. (2015) is shown in Figure AC 3-1 (panel b), where it can be seen that this also improved the agreement with the validation measurements. Owing to the good agreement between the calibration function and the validation measurement points, this figure further demonstrates that there would be little advantage to incorporating additional calibration dates at this field site (at least for the ranges of moisture that we encountered during the validation measurement dates).

Upon revision of our manuscript, we will update all CRNP soil moisture estimates from the new equation. We have already confirmed that these updates do not affect any of the findings from this paper.



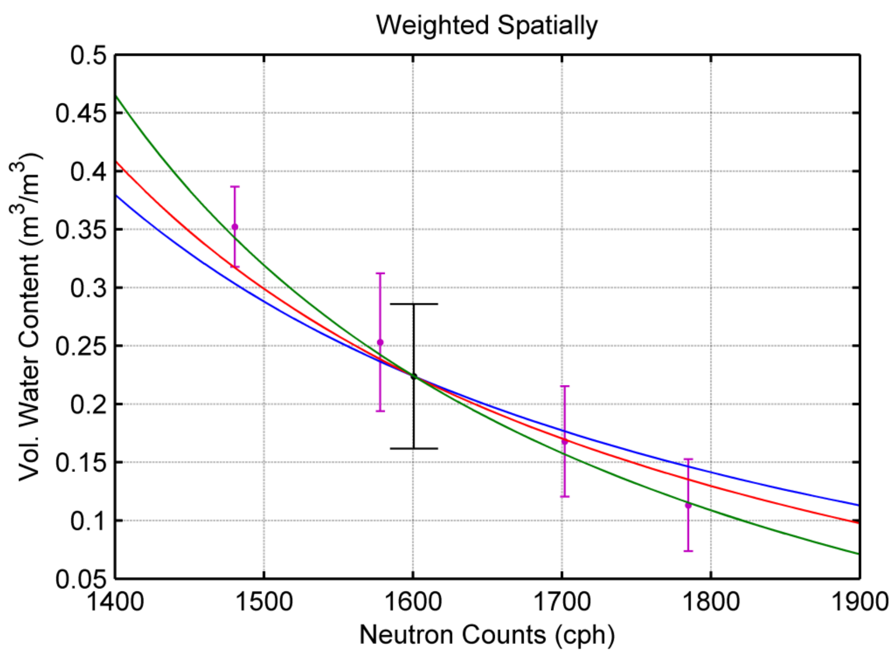


Figure AC 3-1. Effect of considering additional hydrogen pools upon the CRNP calibration equation for (a) non-weighted samples, and (b) spatially weighted samples.

p. 12790, l. 10: New results by Köhli et al. (2015) suggest that the areal footprint is more in the range of 350^2 m^2.

Response: In this case, the $500^2 m^2$ area listed in the abstract refers to the area of land being studied at the pasture site, rather than the area represented by the CRNP. We will clarify the text in the revised manuscript.

The following 3 comments relate to the content of the abstract:

p. 12790, l. 12: What do you mean by 'accounted for'?

p. 12790, l. 18: What does 'the exponential filter' do?

p. 12790, l. 23-24: It is concluded that the exponential filter method has the most potential because…? This is important and should be in the abstract (it's your main conclusion after all).

Response: We will restructure the abstract during revision of the manuscript to provide clarity on these editorial issues.

p. 12791, l. 25-p. 12793, l. 12: Throughout the introduction (and abstract) I am getting a little confused with your lists of approaches. In the abstract you mention 1) time stability, 2) landscape unit monitor and 3) exponential filter. In the intro you mention 1) upscaling point measurements and 2) modelling and then 1) averaging point measurements, 2) a single time-stable location and 3) disaggregating into landscape units. Can you maybe use subcategories with a different index (in case some of them are actually subcategories)?

p. 12796, l. 10: Oh, another sub-list. And this time there are four estimation techniques. Maybe use a), b), c) and d) for these four throughout the manuscript while using 1) and 2) to distinguish between 'upscaling' and 'modeling' approaches. This still leaves the 1), 2) and 3) from the abstract (which correspond to b), c) and d), I guess).

p. 12803, l. 20: So here the section 3.3.3 Exponential filter is a subsection of 3.3 Upscaling methods while on page 12792, l. 1 you clearly distinguish between (1) upscaling point measurements and (2) modeling. This further adds to my initial confusion about the structure of your manuscript.

Response: This is a good suggestion for clarification. In the revised manuscript, we will simplify the terminology and adopt the following hierarchical structure:

- Upscaling Techniques
  - n-point averaging
  - single time stable location
  - landscape units

Modelling Techniques

Exponential filter

p. 12791, l. 25: The effective measurement depth is less than 30 cm for most soils under wet conditions, for dry conditions the effective measurement depth can be a lot deeper (down to 70 cm).

Response: This is an important point, and we will revise the text to provide more discussion about this. It appears there is little consensus on what the maximum effective measurement depth of the CRNP actually is. Based on the literature, even under dry conditions, maximum reported depths are often on the order of 30 cm (with the exception of pure sand containing very little lattice water or soil organic matter). A few specific examples from the literature are reported below:

-Lv et al. (2014): Sandy soil in Utah forest; volumetric water content ranges from 0.08–0.2 cm^3/cm^3; measurement depth ranges from 20–30 cm.

-Franz et al. (2012), Table 2: Sandy loam at Santa Rita Experimental Range in Arizona; volumetric water content ranges from 0.05 to 0.15 cm^3/cm^3; measurement depth ranges from 20–35 cm.

-Hawdon et al. (2014), Table 3: 7 of 9 Australian sites have average effective measurement depth less than 30 cm and maximum depth over entire record less than 35 cm. The remaining two locations were sand, with the sum of lattice water and soil organic matter being < 0.01 g/g, and had slightly deeper measurement depths (Daly: average depth of 35 cm, range of 15–46 cm).

p. 12794, l. 19: This equation has been updated and you should use the newer version that also considers the influence of soil organic matter, root biomass and lattice water. See for example Lv et al. (2014).

Response: As previously discussed in this response, the updated equation has improved our agreement with the validation measurements and we will include updated figures in the revised paper.

p. 12795, l. 5: Köhli et al. (2015) also introduced a new distance-weighting scheme that you should use to give modified weights to the samples you took from different distances. Now that the actual footprint diameter is smaller than you assumed, the weights from the more distant soil samples should be reduced.

Response: Thanks for this useful suggestion. The revised footprint radius (Köhli et al. 2015) ranges from 240m to 130m, as a function of humidity and soil moisture. As previously discussed in this response, we have applied the weighting function of Köhli et al. (2015) to the validation and calibration soil samples. The updated figure will appear in the revised manuscript.

p. 12801, l. 2: Recent publications by Lv et al. (2014) and Iwema et al. (2015) suggest that the standard calibration function of Desilets et al. (2010) is actually variable from one location to another and should therefore be calibrated at two different dates (preferably one when soil moisture is high and another one when soil moisture is low). A new calibration function could increase the variability of the soil moisture time series measured by the cosmic-ray neutron probe so that it would match better with you gravimetric soil samples (Figure 2).

Response: As previously discussed in the response, we have shown that the updated calibration function matches the validation measurement dates very well, thus a second calibration date does not seem to be necessary for our study site.

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