The reviewer's comment is written in bold. The reply of the authors is written in non-bold.

The manuscript presents a novel approach to calibrate CRNS for soil moisture estimation using a data-driven, inverse modeling technique. This method promises to address site-specific and sensor-specific variations that are often overlooked in traditional analytical methods. The idea is innovative and highly relevant to the field.

Thank you for the positive overall evaluation of the manuscript and for agreeing with us on the novelty of the calibration approach. We appreciate your time and effort in reviewing the manuscript. In the forthcoming revision we will consider each of your suggestions and implement the necessary changes.

However, there are several areas where the manuscript could be improved:

Comment:

1. The manuscript briefly talked about traditional analytical methods, but including additional details about these in methodology section would enhance its comprehensiveness. A short summary or explanation of how traditional methods are practically implemented, alongside their limitations, could enrich the manuscript significantly. Similarly, further clarification on the forward model used in the inverse method (possibly included in response to the first reviewer's comment) would be beneficial. This inclusion should highlight how analytical method calculate the soil moisture and how the newer approach will calculate. These short or one paragraph would be especially helpful for new readers to better understand the methodology.

We agree with the reviewer that the points stated will improve the accessibility of the novelty to readers.

Starting with the forward model, we present a more complete description of the objective function for the inversion routine which is also in line with the comment by Todd Caldwell:

"The forward model used for estimating the parameters beta, omega, and psi is based on the combination of scaling functions for atmospheric pressure, absolute air humidity, and incoming neutron intensity, as detailed in Equations (1), (2), and (3). The forward model computes the neutron flux N at time t by applying these scaling factors to the observed neutron flux $N_{t-1,obs}$ of the previous time step (t-1). This previous time step essentially serves as reference condition:

$$N_{t,est} = N_{t-1,obs} \times exp\{beta(P_t - P_{t-1})\} \times \{1 + omega \times (abs_t - abs_{t-1})\} \times \{1 + psi \times (Inc_t - Inc_{t-1})\} \quad (4)$$

Parameters beta, omega and psi are the free parameters to be optimized. N, P, abs and Inc represent vectors of n days, and $N_{t,est}$ is the neutron flux estimated by using the corrections.

To optimize the three parameters, we use an inversion approach that minimizes the root mean square error (RMSE) between the observed neutron flux $N_{t,obs}$ and the estimated neutron flux $N_{t,est}$:

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(N_{t,obs} - N_{t,est}\right)^2} \quad (5)$$

where n represents the total number of days."

We further will add a more detailed explanation on how traditional methods are implemented. This will briefly touch on the limitations of the traditional methods as well. Briefly, because it is elaborated in more detail in the introduction. However, it is needed to note these limitations in the methods section as well. We will add:

“2.1.1 Scaling parameters

Traditional semi-analytical methods estimate scaling parameters for air humidity, atmospheric pressure, and incoming neutron intensity primarily using Monte Carlo neutron particle simulations, limited CRNS measurement data, and NMDB data (see e.g. Köhli et al., 2023; Desilets et al., 2010; Dorman, 2004; McJannet and Desilets, 2023; Rosolem et al., 2013; Desilets and Zreda, 2003). These approaches laid the foundation for soil moisture estimation from CRNS by providing generalized scaling parameter estimates. However, they rely on strong correlations with global variables such as cutoff rigidity, latitude, and elevation, using data from relatively few reference stations scattered across the globe. While effective for global first estimates, these methods are limited in their ability to account for site-specific and sensor-specific characteristics, potentially resulting in inaccuracies in soil moisture estimation. In contrast, we propose a data-driven approach that directly calculates scaling parameters from observational data, enabling robust calibration tailored to local conditions, as detailed in the following subsections.”

2. The abstract could be improved by adding the exact results. Specifically mentioning the strong correlations and higher variability.

Thank you for noting the need to clarify the abstract and include detailed results. We will change it towards:

“Cosmic ray neutron sensors (CRNS) are state-of-the-art tools for field-scale soil moisture measurements, yet uncertainties persist due to traditional methods for estimating scaling parameters that often lack the appropriate ability to account for site-specific and sensor-specific characteristics. This study introduces a novel, data-driven approach to estimate key scaling parameters (beta, psi, and omega) by directly calculating them from measurement data, emphasizing local environmental factors and sensor attributes. The method demonstrates reliability and robustness, with strong correlations between estimated scaling parameters and environmental factors such as cutoff rigidity, latitude, and elevation, and consistency with semi-analytical methods, such as an R^2 of 0.46 for beta. The study also reveals systematically higher variability in calibration parameters than previously assumed, highlighting the importance of this method, data quality, and careful selection of NMDB reference sites. The new method reduced RMSE by up to 25%, with differences in soil moisture estimates between traditional and data-driven methods easily reaching 0.04 m^3/m^3 and up to 0.12 m^3/m^3 under certain conditions. The sensitivity analysis showed that soil moisture estimation is most influenced by scaling parameters in the wet end of the soil moisture spectrum. We anticipate that the improved soil moisture accuracy achieved with our method will lead to better decisions in agriculture, hydrology, and climate monitoring. Future research should focus on further refining these scaling methods to increase the quality of CRNS data in order to further improve the accuracy of CRNS-based soil moisture estimates.”

Overall, the research article is well-written and presents a novel and valuable contribution to CRNS calibration methods.

Thank you.