Responses to reviewers RC1 comments:

We are sincerely grateful to our first referee hereafter called RC1 and to Steven Evett, hereafter called RC2, for taking their time to read, comment and help to improve our manuscript.

General

The authors reworked the MS with a lot of efforts and generally responded adequately on the remarks and suggestions. Language checking has been performed too, as was proposed by both reviewers.

Below are evaluations or remarks (in orange) on the responses (in blue).

RC1: "Introduction needs to be extended including more recent references and findings on this topic. At the end of the introduction readers expect clear objectives of the study, or a list of research questions. These need to be addressed in the Discussion and Conclusions."

References were added. The objectives have been clearly stated at the end of the introduction and addressed in the discussion and conclusion sections.

References were indeed added in the text, but no reference list was found at the end of manuscript version 2, so I could not check the full references…

Indeed, objectives were formulated (paragraph 75) and tackled in Discussion and Conclusion.

RC1: "In Material and Methods, clearly describe the test sites and sampling procedure, and inform the reader of the type of soil and its clay and organic content by depth layer in a table. Also, clearly describe the laboratory setup and refer to the protocol in Appendix A. Describe the statistical analysis, and introduce some measures for assessing bias and precision to evaluate the recalibration performance".

The M&M section was rewritten, reorganized and enriched with the requested information. We do not have soil analyses for each pit and depth. However, we included table 1 with the soil data that we have for FR-Aur site only. It is beyond the scope of this paper to establish a correspondence between soil composition, soil texture or soil density, and the calibration constants. The scope of this paper is only to suggest a check and soil-specific calibration using the soil of each planned SWC sensor implementation. Thereby, we do not need to know why the commercial sensors with the factory calibration constants overestimate or underestimate the real SWC. As it is rather difficult to work with clayey soil, we are suggesting a protocol that allows us to successfully conduct a calibration campaign. The introduction and conclusion were clarified. The quality levels of the calibrations were evaluated using the determination coefficient between soil-specific calibrated SWC estimation and Real SWC (R^2, see Eq. 4.). Then, the error made on SWC estimation relative to real SWC with the use of analog or digital FDR sensors factory settings was calculated using Eq. 3. There is not one emplacement where a factory-calibrated sensor is providing SWC within ICOS mandatory 0.05 m3/m3 accuracy. Different locations imply different calibration coefficients, which may be close to each other or not, unpredictable before the actual local calibration.

OK Thank you for rewriting this section. Still a bit strange that you do not have texture data for both sites, the more since this study is all about recalibrating the sensors due to the high clay content.

But you added references describing the general soil texture and clay mineralogy on the region, so this is already informative to the reader.

TYPO ! Near P150 “(at filed capacity)” => must be field capacity

P165 Soil samples were collected in duplicate

Thanks for adding in Table 2 the SWC sensors specifications.

RC1: “In Results & Discussion section use Tables to evaluate the performance after recalibration, but also to show the difference between using the real part or modulus of dielectric permittivity

We added table 3 to support the performance of FDR sensors after recalibration. We also extended the results to a comparison between real part and modulus of the permittivity-based sensing.

Great !

RC1: “Provide in Discussion some answers to “What is acceptable accuracy of SWC measurements?” and “What is the minimum set of replicate samples per depth needed for proper recalibration?”

According to the ICOS protocol (Op de Beeck and al. reference added), the SWC probe should have at least 0.05 (m3/m3) accuracy over the whole expected SWC range sensed into four pits. We added this information inside the introduction and Mat & Meth sections (see lines 68 and 129).

Thank you for adding this accuracy threshold. It is very important to indicate that without soil specific calibration you cannot meet this level.

In paragraph 310 you write: “For example, for a real SWC value of 0.25 m^3m^{-3} at 30 cm depth, the relative error decreases to -5.6 and -5.5 % for estimated SWC with digital and analog FDR sensors respectively, with R^2 values of 0.987.”

So, then then the absolute bias is ~ 0.014 $m^3m^{-3.}$ Can you confirm that over the whole SWC range and depths, you are well below 0.05 $m^3m^{-3.}$ If so, I would put it explicitly in the text and conclusions, because then your goal is reached.

RC1: “In Conclusion: how are your research questions answered and objectives reached ?”

We have rewritten the conclusion to reflect more clearly how the objectives of our research were met.

RC1: “Below you can find comments by Line, also for the numerous typo’s. Hope these can help you to improve the MS.”

We are grateful to RC1 for his suggestions and we modified our manuscript in consequence.

RC1: “L26. Accuracy of 3%, do you mean 3% absolute (so volume %), or 3% relative compared to the gravimetrically determined SWC ?”

The value of “3%” is coming from the SWC sensors manufacturer’s manuals and some of them, but not all, present that this is an absolute error of 0.03 m3/m3. We modified this value to the “0.03 m3/m3” value (see line 32)

RC1: “L27. What do you mean by “points” ? Measurement locations ?”

"points" means "other soil features" cited in the next sentence. Text modified (see line 34) RC1: “L37. Remove “usually”, OM is never represented in a soil textural triangle” We are aware that OM is never represented in a soil textural triangle. We modified the sentence to clarify our message (see line 46).

RC1: “L71. choose the right probes for specific soils such as clayey soils => what are the specification of such rods ? Explained further ?

“ This point was raised in the previous sentence "ionic soil, such as clayey soil, requires a real part dielectric constant based probe.” This point was developed for better clarity. (see lines 109-113) Table 2 with sensor specifications was added. RC1: “L75. but even for a particular pit and particular depth for accurate SWC measurements. => see paper: https://www.mdpi.com/2076-3417/11/24/11620”

This reference was added into the text. RC1: “L79-85: I suggest to put the applied sensors in a table listing their characteristics (also rod lengths), as for example in Table 1 of https://essd.copernicus.org/articles/12/683/2020/”

Characteristics of sensors were added in table 2. RC1: “L86-92. Nice ‘home made apparatus” – Have you checked bulk density differences compared to conventional volumetric sampling ? is the sample really taken by pneumatic hammering ? Or just pneumatic forcing into the soil ? What if there is a stone content in the soil ? How do you cope with samples containing coarse fragments ?”

Point by point:

- Thank you.

- The conventional volumetric sampling we know is to enforce a collar of a known volume into the soil, withdraw it, and crush the contained soil to liberate it from the collar making it unusable for further SWC measurement. Both methods use a collar or a sampler forced to the soil. The sampler forced into the soil may seem to be highly invasive and potentially compact the soil sample. However, the sampler was designed to minimize eventual compaction (a figure with the sampler sectional draw was added). Also, when the sampler was enforced to the soil, the soil sample surface inside the sampler was at an equal level as the surrounding soil surface which was plaid for compaction exemption.

OK

- Sampler enforced with a 5j perforator (added to the text).

- Stones are present on the Fr-Aur station (a few percent), We have a chance to not encounter any stone problem, nor during sample collection or further calibration process. However, it was planned that in case of sample collection impossibility due to a stone to collect another adjacent sample. In the case of SWC sensor insertion to the soil sample impossibility, it was planned to use the second sample (two samples by location were withdrawn). Of course, it is not impossible that both samples contain stones preventing them to be used but this was highly improbable on FR-Aur. - The aim of the soil sample collection and the further use for calibration was to work as close as possible to the real conditions. Consequently, we do not discard any coarse elements from the soil samples. As we work on clayey soil, the only coarse elements are the stones.

OK, but since stone content was low, this was not really a problem.

RC1: "L95. So from Figure 2 I conclude you have 4 replicate SWC pits in FR_Aur and 5 in FR-Lam ? Please specify. Landuse is cropland ?"

Correct, we have four pits on FR-Aur and 5 pits on Fr-Lam and both stations are cropland stations. Specifications were added to the text.

Thanks !

RC1: "L 98. Refer to ICOS programme (https://www.icos-cp.eu/)" Reference added into the figure 1 (ex fig. 2) description.

RC1: "L105. As an illustration for this paper, some FR-Aur results are shown. Where ? Please refer to figure or table".

The whole text of this paper presents only the results of the FR-Aur soil calibration for more clarity. FR-Lam soil calibration is qualitatively comparable but not complete. RC1: "L106. Why are samples taken differently in the topsoil (vertically) compared to the subsoil layers ? I would take them all horizontally for a study. "

Explanations were added to the text (see lines162). The "surface" sensors are vertically enforced to the soil and other depth sensors are placed horizontally so soil samples were collected according to the SWC sensors' placements.

RC1: "L105-109. Here you do not mention any hammering ? Just pressure."

Word "forced" was added to the text (see line 154).

RC1: " L110 "was near water-saturated" – water saturation, but probably you mean the soil was at "field capacity"."

The expression "at field capacity" was added to the text (see line 149). Please note that the "water-saturated soil" expression is also used.

RC1: "L119. List the properties of the analog and digital FDR probes in the instrument table please, so that the reader knows which devices these are."

See Table 2. OK, thanks for adding.

RC1: “L128. Cracking is indeed one of the biggest problems of FDR measurements in clayey soils. You can avoid it in the lab, but how to cope with this in the field (especially topsoil) ?”

When the circularly distributed rod probes are used (it is the case with our sensors) the macro cracks mainly form around the probes as the soil is maintained by the rods. However, micro-crack formation is not avoidable. Not only the cracks forming between the rods but also around the rods with consequent poor electric contact between the rods and the soil. To our knowledge, there is no “magic” solution for that.

I am afraid you are right.

RC1: “L154 “Are the crack volume parts of the sample volume?” – typo “Crack” – by convention dry bulk density is the oven dry mass of soil (dried at 105°C) devided by its volume when taken in the field, mostly at field capacity. So in this sense, when a clayey sample dries out and is cracking, the crack volume is part of the sample volume, and no substraction is needed. Therefore it is called “bulk density”, because it also includes pores, and channels, and cracks … in contrast to specific density of soil.”

Absolutely. Then volumetric water content is the volume of the water divided by the volume of the soil including its cracks, any SWC sensing is then extremely localization depending. On a shrinking soil like our station's soil, cracks are often larger than the SWC sensor diameter. In the case of the presence of the crack any relatively small volume sensing device such as FDR, TDR, and so on provide a biased SWC estimation. Also multiplying the sensors does not help a lot since these sensors need to be inserted into the soil and do not work when one or more rods are in a crack. This is clearly a limitation for FDR and TDR sensors use in vertisol. Sentences were added to the text (see section 4.1).

I fully agree with this.

RC1: “L160. Figure 4. It would be informative to show progressive crack formation upon drying and this SWC- diel. Permittivity relationship.”

Cracks formation observation is a challenge. There are three stages of the formation of the cracks: Vertical cracks formation visible on the surface, horizontal cracks formation inside the vertical cracks which are not visible from the surface, and vertical cracks formation inside the horizontal cracks which are not visible either. The link between the cracks and the permittivity would be a very interesting subject to study but it is definitively beyond the scope of our paper.

Indeed, maybe the topic for a next paper…

RC1: “This is probably linked with the fact that the tested soil samples originate from arable land that is homogenized by plowing. In forest and permanent grassland soils topsoil variability is usually greater and less homogenous.”

Effectively, the apparent homogeneity of a surface soil is most probably linked with the soil tillage. The corresponding sentence was added (see lines 322).

RC1: ” L170.(and L182) Figure 5 clearly shows overestimation of SWC by FDR, which has been reported by quite a lot of studies (e.g. https://doi.org/10.1016/j.agwat.2011.09.007)”

We agree that most of the studies showed an overestimation of the sensed SWC on clayey soil but not all. As the estimation error is determined by the factory-implemented calibration factors of the concerned sensors, everything is possible. Most of the sensors are factory calibrated for the most common soils and, with these settings, FDR sensors overestimate SWC assessments. However, the same sensors with different calibration constants may also underestimate SWC. It is just a question of settings.

RC1: "L195. How the relative error is calculated should be part of M&M section. Not in results."

Equation was moved to the M&M section (see line 228).

RC1: "L213. Once soil calibration is done, new calibration constants can be injected into the relations between SWC and the real part of dielectric permittivity. Clearly show how the recalibration is effectively performed, i.e; ; how soil-specific calibration coefficients are determined."

The specific calibration coefficients were determined by fitting the curves of "real soil water content versus indicated real part of the dielectric relative permittivity". Explanations were developed in M&M.

RC1: "L242. "calibration process is made during sample drying." For clayey soils, there is a hysteresis effect. Is calibration different when using the drying path compared to the rewetting trajectory ?"

The hysteresis is mainly due to the cracks' opening and closing. Cracks closing is favored by the internal soil pressure due to the surrounding soil. When a soil sample is used, there is no surrounding soil so the hysteresis observed with the soil samples is sensibly different from the hysteresis observed with real conditions. The rewetting was not attempted.

Yes, it is reasonable that under lab conditions real life hysteresis effects cannot be simulated, but it is likely that calibration will be different, no ?

RC1: "L258. Why are you not taking calibrated digital photo's to estimate the dimensions by digital image processing ? You are already taking photos for the cracks (L270)".

Sample diameter determination would be possible by digital photo processing but seems to us inaccurate especially when the sample soil is shrinking. The sample height would be not available as the samples are bucket surrounded.

RC1: "L38. "a soil-specific calibration may be required locally to determine the proper calibration of moisture versus dielectric permittivity constants" Is it better to do soil-specific calibration directly on the dielectric permittivity response of the sensors (as you did) or -in case of FDR, on derived sensor output signals like "period average" (or travel time in TDR) which also includes sensor characteristics ?"

As always, it is preferable to calibrate the whole process including as many characteristics as possible for precise calibration of a specific sensor. This calibration would be precise for only one model of a sensor. In case of any change in the sensor characteristic, all the calibration processes must be redone. The soil calibration allows to link dielectric permittivity with the SWC and does not allow to get rid of the sensor imperfection but is still valid for a "correctly" working sensor. "Correctly", means that the soil dielectric permittivity measurement by this sensor is accurate enough.

In this study, we are assuming that the main problem with SWC sensing comes from the relation between the permittivity and the SWC as this relation is soil-dependent. Indeed, factory injected coefficients cannot be universal and soil-suggested calibration factors are not yet successful. However, a soil-specific calibration with the soil coming from the planned sensor emplacement, even if it is long, is still possible.

Thank you so much for your rebuttal. Well done !