March 06, 2024

Differentiating between crop and soil effects on soil moisture dynamics

By Scholz et al.

Replies to comments from reviewers and editor

Editor

I agree with reviewer#1 on their point that emphasizing the new wireless technology for the sensor network merits some comments in the discussion on the data quality. Alternatively, this emphasis in the introduction could be toned down a bit.

Response: We added a paragraph in which we discuss the limitations and strengths of the WSN in combination with PCA.

I also agree that an overview figure at the beginning of the ms showing the soil moisture time series would set the scene better than now (with Fig 11 in the appendix).

Response: We worked on the Figure displaying the input data set and moved it to the Methodology section (now Figure 2).

Furthermore, it would be interesting to add to the discussion more interpretation of the differences between the crop types. Currently, this is treated abstractly and only becomes specific when addressing the case of winter vegetation cover. Can you comment on the other parts of the growing season too?

Response: Thanks for the suggestion, the section on crop effects was revised to better address the different crop covers.

Overall, we appreciate the possibility given by the editor to further improve and strengthen our manuscript. We have taken all remarks and suggestions of the reviewers into account and provide a point-by-point response letter to each of their queries.

Report#1

The authors have addressed many of the comments in my previous review, but the manuscript still gives the impression of being incomplete and not carefully revised. One graphic even seems to have been mixed up (Fig. 3 or Fig.7). I find it astonishing that not even the four co-authors have noticed this and it shows that the revision of the manuscript has not received the necessary attention. Unfortunately, the interpretations of the results with respect to the soil effects on the soil moisture dynamics are still not convincing. I suggest that the authors focus on the more clear effects due to crop type and crop management. The title should be changed accordingly. Therefore, the manuscript need to be restructured and rewritten in many parts and should also be checked by a native speaker.

I have listed the limitations in my general and specific comments below. I have tried to be as constructive as possible and hope that this time the authors will succeed in revising the manuscript so that it is acceptable.

Response: Thank you for your valuable comments, which have helped us to significantly improve our manuscript.

General comments:

One problem why the presentation of the PCA results is not easy to understand is that the measurement data is not introduced beforehand. Therefore, before starting with the PCA results, the measured soil moisture data should be presented together with the precipitation, potential ET and cumulative climatic water balance. The latter because it is used for the interpretation of the first PCA. Figure 11 shows all soil moisture time series together, which is very difficult to comprehend as the data exhibit very high spatial variability. To achieve a better overview, the soil moisture data should be presented for each sensor depth in separate subplots. I suggest to use the same color coding for the different crop groups as in Figure 1. The z-transformed soil moisture time series could also be plotted to show the effect of this procedure.

Response: We edited Figure 11 by plotting time series each soil depth separately and colored the time series by crop group. To improve the understanding, we shifted the Figure from the appendix to the Methods section. Please understand that we did not add plots of the z-transformed soil moisture time series to avoid overloading the manuscript.

Although the WSN used in this study is emphasized as very innovative, there is no further mention of it in the Results and Discussion sections. Instead, the WSN performance should also be described in the Results. For example, the WSN's failure rate of two thirds within a period of less than 9 months is quite exceptional. This and the high gap rate show that this WSN is very susceptible to failure, and a discussion of the pros and cons of this particular WSN and underground WSN in general would be useful for potential users of WSNs. For instance, an important point that was not taken into account in this WSN is the "handshake" procedure that confirms the success of a data transmission (Yildiz et al., 2015). In addition, the high attenuation of radio transmission through near water-saturated soil is a huge problem for underground WSN (see e.g. Bogena et al., 2009).

Response: Thanks for the valuable comments. Since the data quality and data processing was the prerequisite for applying the PCA, we decided to not shift the processing of the data to the results. We included information on performance in the new paragraph 4.3.

The SM time series shown in Fig. 11 indicate artefacts (e.g. spikes) in the data. Before each analysis, however, the data must be subjected to a quality check, e.g. on the basis of plausible value ranges and the plausibility of the temporal dynamics.

Response: Before computing the Principal Component Analysis, we removed spikes at 28.6 % soil moisture which are reported by the manufacturer as a known error. We were very reluctant to remove minor spikes which would either generate additional data gaps or would require arbitrary decisions on the kind of gap filling. According to our experience minor spikes in the data do not significantly affect the outcome of the PCA. Further details in the data processing were added into the Section 2.4 Data processing.

The discussion chapter contains sections with a literature review only, which is not the purpose of a discussion (e.g. L281-288). Instead, the results of this study should be discussed here, with appropriate comparisons with other studies added to support specific points. In addition, methodological limitations and future possibilities of the methods used in this study can be identified.

Response: We modified L281-282 as introductory sentences to the discussion of crop effects. L282-284 was moved to the introduction. L284-286 was shifted to a later passage in the introduction and compared to our study results. L286-288 was omitted.

A large number of different terms is used for the term "wireless sensor network" (i.e. soil monitoring networks; soil sensing network; long-range-wide-area network; underground LoRaWAN monitoring; Internet of underground Things (IouT) soil moisture monitoring network; wireless soil monitoring networks; wireless sensor network; LoRaWAN soil sensor system). I suggest using mainly "wireless sensor network" or short "WSN". Similarly, for the term "sensor" (i.e. TDR-sensor, Soil sensor, sensor, TDR sensor, electromagnetic soil moisture sensor) and WSN end divices (i.e. Dribox, boxes, LoRa nodes). I suggest using the term "soil moisture sensor" and "WSN node", respectively.

Response: Thank you, we decided to use the terms "wireless sensor network (WSN)", "LoRa nodes" and "soil moisture sensors" only. In some cases when the term "soil moisture sensors" was used in the sentence before, we used "sensors".

The section on soil texture analysis is very unclear (L133 – L145). In addition, since the manual analysis was not used, this part should be omitted.

Response: We rephrased this part and shifted parts of it to the results. Since we also refer to these data in the paragraph on limitations and strengths that we added, we decided not to omit the Methodology section of the soil texture analysis.

<u>Specific comments:</u>

L50-51: "geostatistical analysis" are also "data driven approaches". I suggest to delete this sentence.

Response: We deleted the sentence according to the suggestion.

L62-63: This statement should be supported by some references (e.g. Graf et al., 2014).

Response: The sentence has been rephrased so that the connection between disentangling space and time and the examples given beforehand is getting clearer. The reference has been added to the examples given in the sentence before.

L65: "soil water dynamics" instead of "soil-hydrological dynamics"

Response: We replaced the term "soil hydrological dynamics" with "soil water dynamics".

L70: You should state the installation depth of the transmission units of the wireless sensor network (i.e. 0.3 m).

Response: We adjusted the sentence accordingly: *"The deployment of transmission units in 0.3 m soil depth and 180 sensors in up to 0.9 m soil depth allows high spatio-temporal resolution wireless data transmission, and enables conventional farming practices like machinery traffic, tillage and mechanical weeding."*

L110: "boreholes" instead of "tunnels"

Response: We adjusted the sentence accordingly.

L106: I suggest using the term "LoRa nodes" instead of "Driboxes" throughout the manuscript.

Response: We replaced "DriBox" by "LoRa node" throughout the manuscript.

L107: "At two georeferenced locations within each patch (see Fig. 2), …"

Response: We adjusted the sentence as follows: *"At two georeferenced locations within each patch, soil moisture sensors were installed in 0.3, 0.6 and 0.9 m depth, respectively."*

L110: Instead of "Driboxes were autarkic in terms of energy supply", you should mention that the WSN is battery-operated with a running time of approx. xxx months.

Response: Additional details with regards to the energy supply were added as follows: *"Under optimum conditions, battery running time of the LoRa nodes can be up to 12 months but can be reduced to 8 months when radio transmission is attenuated (e.g. due to near water-saturated soil) which then increases power consumption (Bogena et al., 2009)."*

L133-134: Needs to be reworded as the Pürckhauer soil auger is used for sampling, not for the analysis. Also provide the number of samples and sampling sites.

Response: The sentence was adjusted: *"Soil texture class by layer was carried out by collecting 140 samples in eight of twelve analysed patches. Samples were taken with a 1 m-length Pürckhauer soil auger."*

L137-140: This sentence is difficult to understand. Please rephrase.

Response: We adjusted the sentence: *"To extrapolate the laboratory-based soil particle distribution to the soil textural classes manually determined at the field, the high and low yield potential laboratory samples were pooled separately. The average soil particle distribution was calculated for each soil textural class and assigned to the respective soil layer with that specific soil textural class. The soil texture analysis showed that soil texture variability increased with depth."*

L141: “content” instead of “share”

Response: We adjusted the sentence accordingly.

L148: “…, in which ERa sensors are coupled with a gamma-ray detector.”

Response: We adjusted the sentence as follows: “The *“Geophilus” system is based on sensor fusion in which ERa sensors are coupled with a gamma-ray detector.”*

L151: Are these different soil texture analysis than described above?

Response: The information on the laboratory analysis was added for Geophilus calibration samples and the manual soil texture extrapolation as follows:

With regards to the Geophilus samples:

“A total of four georeferenced reference soil samples were taken until 25 cm soil depth, and locations were selected based on the proximal soil sensor data (sensor-guided sampling; Bönecke et al., 2021).” [...] ”Reference soil samples were analysed via soil-particle size analysis according to DIN ISO 11277 (2002) and served as calibration information in order to estimate sand, silt and clay content in the top 0.25 m soil for the entire field.”

With regards to the manual soil texture samples:

“Additionally, representative soil samples were collected and analysed at the laboratory to determine particle size distribution for sand, silt and clay (soil texture, based on the German particle classification). Soil texture was analysed following the DIN ISO 11277 (2002) reference method by wet sieving and sedimentation, using the SEDIMAT 4-12 (Umwelt-Geräte-Technik GmbH, Germany). The sand fraction in this method is defined between 2 and 0.063 mm, according to IUSS Working Group WRB (2015).”

L160: Please clarify: These 81 days of data gap where for all measurement sites.

Response: We adjusted the sentence accordingly: *“Transmission failures due to discharged batteries, signal disturbances after rainfall, in patches with a high density of biomass (e.g. maize), and theft of parts of the WSN led to data gaps that affected in some cases all sensors of the WSN and amounted to 81 out of 257 days of the measuring period. The affected days were therefore skipped for the analysis.”*

L180: Which observed time series?

Response: We added details to the sentence: *“Every observed soil moisture z-transformed time series can be presented at arbitrary precision as a combination of various principal components.”*

L206: The loadings are more related to the crop groups than to the individual crop types.

Response: The sentence was adjusted accordingly: *“The loadings showed a crop group specific pattern.”*

L207-209: This statement is not correct. In fact, group 3 shows both shows both positive and negative loadings and therefore cannot be assigned to a specific category, i.e. the type of cultivation does not appear to have a clear influence on soil water dynamics.

Response: We apologize, this confusion must have come up because of the upload of the wrong Figure. We replaced the wrong Figure with the right one.

L241-242: This statement is difficult to understand and should be illustrated graphically to make it clearer.

Response: We added a scatter plot to the manuscript showing that especially for the deep layer (0.9 m) there is a strong relation between the antecedent soil conditions (z-transformed minima in December-February) and the strong negative loadings.

L242-244: This statement is not a good description of the differences in both time series. In fact, the negative loading on PC3 shows a higher temporal variability than the positive loading during this period.

Response: We added the higher temporal variability to the sentence: *"What distinguishes the orange line (negative loading on PC3) from the blue line (positive loading on PC3) are the higher temporal variability and the delayed reaching of maxima in the first half of the study period (Figure 8)."*

L246-248: The loadings of time series on the fourth principal component (Fig. 7) look exactly like those of the second PC (Fig. 3). Is this the wrong plot?

Response: Yes, we replaced Figure 3 with the right plot.

L253: This statement is unclear. Why should a more positive score indicate more sandy soil? In addition, all investigated plots have very sandy soils with only small variations.

Response: We adjusted the paragraph as follows to clarify that we describe the differences of draining behaviour between the two graphs rather than assigning specific patches to specific graphs in the Figure:

"Figure 10 illustrates the effect of the fourth PC on time series. The blue line (positive loading) shows a hydrological behaviour which would be typical for more sandy soils while the orange line (negative loading) depicts behaviour that one would expect in more loamy soils due to its delayed responses to rainstorms and subsequent less steep recovery. The patterns in the loadings thus show a differentiation between patches with winter crops and fallow patches in the winter months (Figure 9). However, it is not clear how winter crops on the one side and fallow on the other side could induce such a different soil water behaviour shown in Figure 10."

L266-267: The term "The hydrological signal" is misleading and the whole sentence should be rewritten, e.g. "The soil water dynamics show a dampening effect with increasing depth, which is represented by the loadings of the fifth PC". Here you could also refer to the new soil moisture figure that I requested above.

Response: We rephrased the sentence for a better understanding: *"The soil water dynamics show a damping effect with increasing depth (Figure 10) from little damping for sensors in the upper depth (orange line) to higher damping for sensors in greater depth (blue line)."*

L281-288: This section is a literature review that does not belong in the discussion chapter and thus needs to be moved to the introduction.

Response: Thank you for the suggestion, we modified L281-282 as introductory sentences to the discussion of crop effects. L282-284 was moved to the introduction. L284-286 was shifted to a later passage in the introduction and compared to our study results. L286-288 was omitted.

L310-311: This statement is not true for "group 3", as the loadings do not show a clear pattern.

Response: The sentence has been rephrased as follows: *"In contrast, the fourth component differentiated between fallow followed by summer crops and winter crops, whereas phacelia followed by summer crop did not show a clear pattern."*

L315-316: This statement should be substantiated with a figure showing the depth-dependent soil moisture dynamics.

Response: Please understand that we did not add another figure in order not to inflate the manuscript too much.

L315-321: This discussion is erroneous in many ways. First, soil organic carbon is only changing very marginally during such a short time period. Second, roots are part or the plants and not part of soil organic carbon. Third, the cited studies show the opposite influence on soil hydrology then is assumed. Scholl et al. (2014) found that plant roots increase porosity and thus permeability of the soil: "Also heterogeneity of the pore space was increased in the rooted columns indicating an increase in structural porosity. The volume of large transmission macropores as well as fine storage pore was higher in the rooted compared to the non-planted columns. From the reduction in pore space accessible to roots we concluded that pore clogging was only of minor importance, while enhanced structuring by enmeshment and aggregate coalescence were suggested as dominant processes." The results of the other studies cited go in the same vein: Zhang et al. (2021) stated that "Near the root, soil moisture bears weak persistence and short memory, while in the intermediating and outlying areas, soil moisture has strong persistence and long memory throughout the growth period." and Lange et al. (2013) stated that "…we draw the conclusion that the porosity carrying mobile water was indeed mainly generated by roots". Thus, all three cited references indicate that the roots increased the amount of larger pores and thus the permeability of the soil.

Response: Thank you your observations, the sentence was modified as follows to better reflect our findings and the findings from the used references: *"According to this component, soil hydrological dynamics in the fallow patches mostly resembled the typical behaviour expected for sandy soils, and winter crop patches showed a more damped behaviour that is usually observed in more loamy soils. Note that the term "fallow" refers to crop cover in autumn and winter only. Acharya et al. (2019) found that winter cover crops improved soil moisture from 3 to 5% in the top 0.3 m soil layer which is in line with the findings from Figure 10 that shows a higher water holding capacity for winter crops (orange line) in*

winter. However, it has also been observed that roots from winter crops can increase soil porosity and therefore, water mobility in the soil (Lange et al., 2013; Scholl et al., 2014).

Further soil-vegetation interactions might play a role for the delayed seepage fluxes of winter crop and part of cover crop patches, such as soil organic matter from cover crops and plant residues (Manns et al., 2014; Rossini et al., 2021). Usually, such effects are assumed to occur only at larger time scales, which is closely related to problems of detecting changes in SOC quantity or quality. So far, there is only anecdotal evidence for rather short-term SOC quality affecting soil hydraulic properties even at smaller time scales. Although this effect constituted only a minor share of soil moisture variance (Table 3), it was clearly discernible as a separate principal component. This effect would be worth to be tested in more detailed future studies."

L328-332: This section is a literature review that does not belong in the discussion chapter and thus needs to be moved to the introduction.

Response: Thank you for the suggestion, paragraph moved to the Introduction.

L335-338: This statement is incorrect, as the dampening effect can only be explained by the different depth of the soil moisture measurement without any change in texture.

Response: We adjusted the heading of the chapter by adding the soil depth effect as follows: *"4.2 Soil texture and soil depth effects"*

L334: Wrong figure.

Response: We referenced the right figure (Figure 5).

L339-348: Again, the dampening effect can only be explained by the different depth of the soil moisture measurement without any change in texture. These further elaborations are unnecessary.

Response: See comment on L335-338: We adjusted the heading of the chapter by adding the soil depth effect.

L350-354: You should focus on summarizing the results of this study. Also, to disentangle and to quantify different effects of environmental processes is not an indispensable prerequisite for tailored field and crop management. In fact, modern sensor-based agricultural techniques allow for a tailored crop management already (e.g. Chamara et al., 2022). Furthermore, mechanist models were not discussed in this paper. Therefore, this section should be deleted.

Response: Thank you for the suggestion, the Conclusion was modified to better reflect our results and the potential of the PC methodology.

L354-357: Rewrite in a more concise way.

Response: Thank you for the suggestion, the Conclusion was modified to better reflect our results and the potential of the PC methodology.

L359-363: Needs to be revised according to my comments above.

Response: Thank you for the suggestion, the Conclusion was modified to better reflect our results and the potential of the PC methodology.

L364-370: Too much blah blah blah. Shorten and rephrase in a more concise form

Response: Thank you for the suggestion, the Conclusion was modified to better reflect our results and the potential of the PC methodology.

Figures

In general, the figure captions should be more informative.

Response: Thank you for the suggestion, figure and table captions were revised to add further details.

Fig. 1: You should add a graph with the averaged soil moisture time series for the three depths and the cumulative climatic water balance. This is important because the reader should get a better impression of the original data and the climatic situation before looking at the PCE results. I also suggest using the color green instead of yellow to increase visibility.

Response: The averaged soil moisture time series for the three depths were added to Figure 11 in which the input data set is displayed and was thus not added to the climate graph. The yellow color was replaced by green.

L537: The colors refer to the crop groups (i.e. the plant cover/activity over the course of the year), not to the individual crops grown

Response: To better clarify this, the figure caption was modified as follows: *"Figure 1: Measured daily precipitation, mean temperature and cultivated crops - differentiated between winter crops (light blue bars), summer crops (green bars) and cover crops (pink bars) - from 2020-12-01 until 2021-08-15 at the patchCROP landscape laboratory, Tempelberg, Brandenburg, Germany. Specific crops for the studied timeframe stated at the left side of the horizontal bars."*

References

Bogena, H.R., J.A. Huisman, H. Meier, U. Rosenbaum and A. Weuthen (2009): Hybrid wireless underground sensor networks: Quantification of signal attenuation in soil. Vadose Zone J. 8(3): 755-761. DOI: 10.2136/vzj2008.0138

Graf, A., H.R. Bogena, C. Drüe, H. Hardelauf, T. Pütz, G. Heinemann and H. Vereecken (2014): Spatiotemporal relations between water budget components and soil water content in a forested tributary catchment. Water Resour. Res. 50(6): 4837-4857. DOI:10.1002/2013WR014516

Yildiz, H. U., Tavli, B., & Yanikomeroglu, H. (2015). Transmission power control for link-level handshaking in wireless sensor networks. IEEE Sensors Journal, 16(2), 561-576.

Thank you for the literature, we included their findings in our manuscript.

Report #2

General comments

This review report refers to the revised manuscript (version 2) "Differentiating between crop and soil effects on soil moisture dynamics" submitted by Scholz et al. I have also reviewed the first version. The authors have invested a lot of effort in the revision. As a result, the manuscript has been fundamentally improved. I suppose that Figure 3 in the current version shows a different diagram than intended by the authors. Apart from that, I have only some minor comments that can easily be edited.

Response: Thank you for your valuable comments, which have helped us to significantly improve our manuscript.

Minor comments

L66: Soil types are not adjusted, right? Suggestion: "… with increasing heterogeneity (e.g. soil texture) and site-specific adjustment of crops and field management which…"

Response: We adjusted the sentence as follows: *"This opens up great opportunities for contributing to the knowledge of changing soil water dynamics in complex diversified agricultural systems with increasing heterogeneity (e. g. soil texture) and site-specific adjustment of crop land field management which, to our knowledge, have hardly been studied so far. "*

L66, L74 and L135: Please check if the term "soil type" is used correctly in the manuscript. I think that you mean "soil texture" in L66, L74 and L135. The term "soil type" only fits in L81 where the soil at the site is classified as "Dystric Podzoluvisols".

Response: We used "soil texture" for L66, L74 and L135 and rephrased the sentences.

In line 66 we adjusted it as follows: *"This opens up great opportunities to improve the knowledge of changing soil water dynamics in complex diversified agricultural systems with increasing heterogeneity (e. g. soil texture and site-specific adjustment of crops and field management (...)"*

In line 74 we adjusted it as follows: *"The main objective of this study was to identify the drivers of soil moisture variability in a diversified cropping field in terms of soil texture, crop selection and field management by applying PCA."*

In line 135 we adjusted it as follows: *"Soil textural class was manually determined at the field by applying the protocol "Finger test to determine soil texture according to DIN 19682-2 and KA5" (Sponagel et al., 2005)."*

L93, Table 1: Mention in half a sentence why especially these twelve out of 30 patches were chosen.

Response: The following sentence was added with regards to the patch selection: *"Specific patches were selected to capture the soil heterogeneities in terms of soil texture, but also the seasonal patterns of the crop rotation that may have important effects on the soil water dynamics such as the crop types, presence of cover crops or fallow periods."*

In Table 1 only 11 patches are listed and the first row is empty.

Response: Thank you for pointing out to this, information from patch 81 was missing and has been added.

Table 2: Please add to the caption that the listed surface temperatures were collected on 2021-05-31.

Response: We added the information to the header of the table 2.

L137: What is meant by "traditional gravimetric sieving method"? Did you determine the sand fractions by sieving?

Response: The sentence was rephrased for better understanding and further information on the procedure was added as follows: *"Samples were taken with a 1m-length Pürckhauer soil auger. Soil textural class was manually determined at the field by applying the protocol "Finger test to determine soil types according to DIN 19682-2 and KA5" (Sponagel et al., 2005). Additionally, representative soil samples were collected and analysed at the laboratory to determine particle size distribution for sand, silt and clay (soil texture, based on the German particle classification). Soil texture was analyzed following the DIN ISO 11277 (2002) reference method by wet sieving and sedimentation, using the SEDIMAT 4-12 (Umwelt-Geräte-Technik GmbH, Germany). The sand fraction in this method is defined between 2 and 0.063 mm, according to IUSS Working Group WRB (2015)."*

L137-L140: I find it difficult to understand what has been done here.

Response: We adjusted the sentence: *"To extrapolate the laboratory-based soil particle distribution to the soil textural classes manually determined at the field, the high and low yield potential laboratory samples were pooled separately. The average soil particle distribution was calculated for each soil textural class and assigned to the respective soil layer with that specific soil textural class. The soil texture analysis showed that soil texture variability increased with depth."*

L141: Better use "fraction" instead of "share".

Response: We adjusted the sentence and replaced "share" by "content".

L180-L187: Just a comment: Adding this paragraph to the first version improved the manuscript. It helps readers to understand how the components are interpreted.

Response: Thank you for your positive feedback.

L205-210, Figure 3: It seems that the wrong diagram is shown in Fig 3. The descriptions in the text fit to the former Fig. 3 in the first manuscript version. In the current manuscript, Fig 3 and Fig 7 show the same diagrams. I assume that the old Figure 3 is generally still up to date. Please check and clarify.

Response: We replaced wrong Figure 3 with the right one.

L239-L241: What is meant by "The location of the patches roughly follows an east-west direction"? Do you mean that the loadings of PC3 change systematically along that gradient?

Response: We reformulated the passage as follows:

"The location of these patches shows a certain regional pattern, with the patches roughly following an east-west direction rather than showing a random location within the field. This may point to a topography or soil structure causing deviations from mean soil moisture behaviour for patches located near this gradient. However, this pattern cannot be assigned to topography or structures apparent on the topsoil map (Figure 2)."

Additionally, we added a sentence to the Results section as an interpretation of potential reasons for this regional pattern.

L360-362: "*(...) the regional pattern of the location of the patches following a west-east direction within the experiment might be an indicator of underlying soil structures causing this effect."*

L378: Suggestion: the headline of that section could be changed to something like "Effects of soil texture and soil depth".

Response: We adjusted the heading of the chapter as follows: *"4.2 Soil texture and soil depth effects"*

L285: Please use "at the scale" instead of "on"

Response: We adjusted the sentence as follows: *"Joshi and Mohanty (2010) investigated the spatial soil moisture variability at the field and regional scale in the Southern Great Plains."*

L322: Maybe rephrase to: "…the problem of detecting changes in the quantity or quality of soil organic carbon"

Response: Thank you for the suggestion, we rephrased this part and deleted this sentence.

L334: Maybe also refer to Figure 5 in this sentence

Response: Figure 5 is now referenced.

L351-L352: It might become clearer if the sentence is rephrased to: "Mechanistic models are a way to upscale findings from numerous studies relating single causes to single effects."

Response: Thank you for the suggestion, we rephrased this sentence as follows: *"Information from this study can also help to develop both parsimonious and tailored mechanistic models for model upscaling."*

L354-L357: Please split into two sentences.

Response: Thank you for the suggestion, we rephrased the sentences and moved it to the beginning of the Conclusion section as follows: *"The use of PCA has a high value for the application in environmental sciences, as it contributes to process understanding of soil water dynamics by disentangling the different effects of complex spatially and temporally diversified cropping systems."*