First of all, we would like to thank the Anonymous Referee #2 for the comments. In the revised paper, all these comments will be carefully taken into account. The comments made by the Anonymous Referee #2 are in italic, our answers are in bold.

Before specific answers, we would like to note that a great number of comments refer to the same topics. Notably, there are numerous comments about the fact that no statistics were performed even though the term "significant" is used. In fact, when we use "significant", it refers to statistical results. But since these comparisons are not the point of the paper, details about statistical tests were not provided. It seems to the authors that it is a common practice to state statistical differences without providing the p-value but using the term significant when this value is below 0.05. In fact, it is the guideline we used. However, a Table with statistical results is given below (see (b)).

General comments

The present paper addresses relevant scientific questions within the scope of HESS. The idea of coupling X-ray CT parameters to more classical lab measurements is not new, but still in progress. I suggest not publishing the paper in its actual form, as many of the conclusions are based on interpretations that cannot be supported by the data. Moreover, there is a number of sentences that are not clear and difficult to grasp. There are ambiguities when the authors mention or discuss macroscopic and microscopic processes and measurements. As an example, according to the authors, "microfauna produces large pores".

(a) We agree that there are ambiguities about the terms micro- and macro-. The sentence about microfauna has indeed to be replaced by "pedofauna could produce large pores". We would like to include more explicitly the way we use the expressions "micro-" and "macroscopic measurement" in this paper. "Microscopic measurements" refers to measurements with X-ray microtomography that supply characterization at the pore scale. The expression "macroscopic measurements" is used here in opposition to the previous: it gathers all the measurements that are not at the pore scale (for example, at the sample scale).

There is no statistical analysis of the differences between the two treatments for the parameters, measured or calculated, which induces strange statements from the authors: "outliers seem to be a rule in RT2 populations". Soil strength, Ksat, k(h) are highly variable in the field and this variability should be assessed. Comparing parameters measured at different scales as in the present study needs to assess the variability of each parameter!

(b) In fact these analyses were made and the term "significant" refers to them. The variability was assessed through errors bars given for each measurement. Variability at the plot scale for soil measurements is not denied here. All the measurements were made with 8 repetitions to obtain a good approximation of the global behaviour for each object. We add in Table 1 a summary of the statistical differences for these measurements.

Table 1 : Results for statistical analyses of retention and hydraulic parameters measurements. Different letters on the same row means significant differences. The number of stars gives the level of significance (*<0.01;**<0.05;*<0.1). Ksat = Saturated hydraulic conductivity; K(x) = unsaturated hydraulic conductivity at tension x; PE = Total porosity between pF1 and saturation; R = Richards' procedure; µCT = microtomography procedure.**

	CT	RT1	RT2
Ksat	A**	B	B
K(-9)	A***	B	
K(-6)	A**	B	
K(-3)	A***	B	
PE-µCT	A	A	A
PE-R	A	A	B**

The part dealing with soil strength does not fit with the objectives dealing with hydraulic functioning and should be removed.

(c) **Since textural aspects are identical for the different plots, only structural aspects can differentiate the objects. We think that soil strength profiles can help the reader to visualise our measurements location and to give a first insight of these structural differences.**

Finally, all the work concerning the hydraulic curves for RT1 and RT2 (Fig 3) should be removed from the paper, as k(h) measurements (near-saturated hydraulic conductivity) were influenced by both layers and represent an average hydraulic behaviour for the RT treatment, the "coupling" with microCT (specific for each layer) is then invalid.

(d) **RT1 presents a shallow and variable thickness (max 10 cm, see Figure 1). Besides, due to the roughness of its surface, we had to remove some part of this layer to obtain the mandatory plane surface for tension-infiltrometer measurements. Second, we observe a good fit of the model on RT2 K(h) curve with these measurements. All these elements converge to the assumption that K(h) measurements for RT can be attributed mostly to RT2. This assumption matches as well with our knowledge of the field and the measurements. This fact can be discussed more clearly in the revised paper.**

Specific comments

Title

The second part of the title doesn't make sense to me: what do you mean by "a method to enhance near saturation functions"?

(e) **We show the potential of microtomography information to improve modelling of the soil hydrodynamic behaviour through a better knowledge of water retention and hydraulic curves near saturation. The first step, presented here, uses it to improve the modelling of water retention and hydraulic conductivity curves. Microtomography enhances the shape of these functions, even if there is still a gap between retention functions and K(h) obtained with tension-infiltrometer. This gap could be due partially to high variability of the measurements. But it could also be due to the fact that these functions do not take other structural properties into account.**

PCA shows that soil with structural differences can be differentiated using 7 structural parameters obtained thanks to X-ray microtomography. The first part of the present study (improving water retention and hydraulic conductivity curves) could be done with other tools (see P.4814 L16-24), but direct measurements of 3D structural parameters can only be achieved through visualisation of the pore system, e.g. through microtomography analysis.

Abstract

P4802 L4: you claim improving the soil water characteristic and near-saturated hydraulic conductivity by scanning soil samples? I don't understand what you mean.

See (e)

Introduction

P4802 L4: I don't agree, you can describe in a mechanistic way (using mechanistic models) soil hydraulic functions at the plot scale, and also at the catchment scale, it has been done a lot the last many decades!!

The sentence refers to the modifications in hydrodynamic behaviour due to tillage reduction, not directly to hydraulic functions.

P4803 L22: what do you mean by "enhance near saturation characterisation"? Same wording problem as in the title. Are you referring to macroporosity, i.e. the functional pore space close to saturation ? Please explain.

For the first part of the sentence, see (e).

We are referring to pores with a radius bigger than 150 µm (corresponding to a tension h=-10cm).

P4803 L29: "concurring mastered and redundant macroscopic observations" what do you mean? Please explain.

Macroscopic measurements (see (a)) are used frequently in other studies to show the effect of tillage intensity on soils. These measurements are linked together and can lead to different estimations of a same parameter. That's what we consider as redundancy.

P4804 L2: "fundamental processes highlighted by macroscopic measurements" what do you mean by macroscopic measurements? SWC, Ksat and k(h) are not macroscopic!!

See (a)

Material and methods

P4804 L5: see my previous comment about macroscopic measurements.

See (a)

P4804 L14: How many replicated plots? Where are the statistical calculations to test the effect of treatment on the different parameters???

One plot for each treatment for the measurements presented here. For the statistical calculations, as we said in (b), we used 8 replications to assess the parameters.

P4805 L4: only one area per treatment?

Yes, one area of 160x80 cm². We estimate that this area is sufficient to take into account the effect of the tillage practices and so far the variability between treatments. The surface area and its position were thus chosen considering the characteristics of the agricultural management practices (Roisin, 2007).

P4807 L16: at which soil water potential were the samples scanned?

(f) Indeed, this piece of information is missing. We would like to add here: "In the laboratory, in order to *empty* the pores, samples are exposed to a 15 bars pressure according to Richards' procedure (1948; DIN ISO 11274, 2012)." Samples are therefore around the wilting point: pores with a radius above 0.1 µm are meant to be free of water. Since it is far below the size of the pores we are looking at (i.e., pF < 1 and radius > 150 µm), it does not impact the part of the porosity we are studying in this paper.

P4809 L21: could you define what you mean by "supplementary pore system"?

This expression comes from the paper of Durner (1994). He states that errors in hydraulic predictions can come from the fact that pore distribution are sometimes differing from the unimodal distribution assumed by the van Genuchten (1980) model. So it is relative to the fact that pore distribution can show a bimodal distribution, each mode being relative to one "pore system".

P4811 L1: which parameters are included?

Parameters are given in the section 2.2.4 P.4809 L.5-14 and in section 3.4 P.4814 L.26-27. We will introduce the latter here: "Principal component analysis (PCA) is performed on our samples, taking into account 7 parameters (cf. Sect. 2.2.4.): Vol, *N*c, Sfc, SS, *R*, Def and SC."

Results and discussion

Penetrometry: if you don't discuss these results later against the other parameters you should remove this part.

As we said in (c), this part was included to back up structural differences between objects. Since the methodology for soil strength profiles establishment is detailed in Roisin (2007), we propose to move figure 1 and this part of the text to the "Material and methods" chapter.

Retention functions: There is a need of comparison between the two treatments (three horizons), I suggest presenting the three SWC on the same graph as a new figure.

Since we are discussing the best model to fit, this can be done with the measurements alone. The following figures present the comparison of retention data for the 3 objects as suggested by the Reviewer#2. The first figure (Figure 1*) gives results for the entire tension range while the second figure (Figure 2*) gives it for the range pF1 to saturation. Nonetheless, for the readability of these results, we propose to maintain figures as in the draft. Besides, the point of our paper is not to

compare structural differences between our objects, but to highlight the usefulness of microtomographty to complete them near saturation.

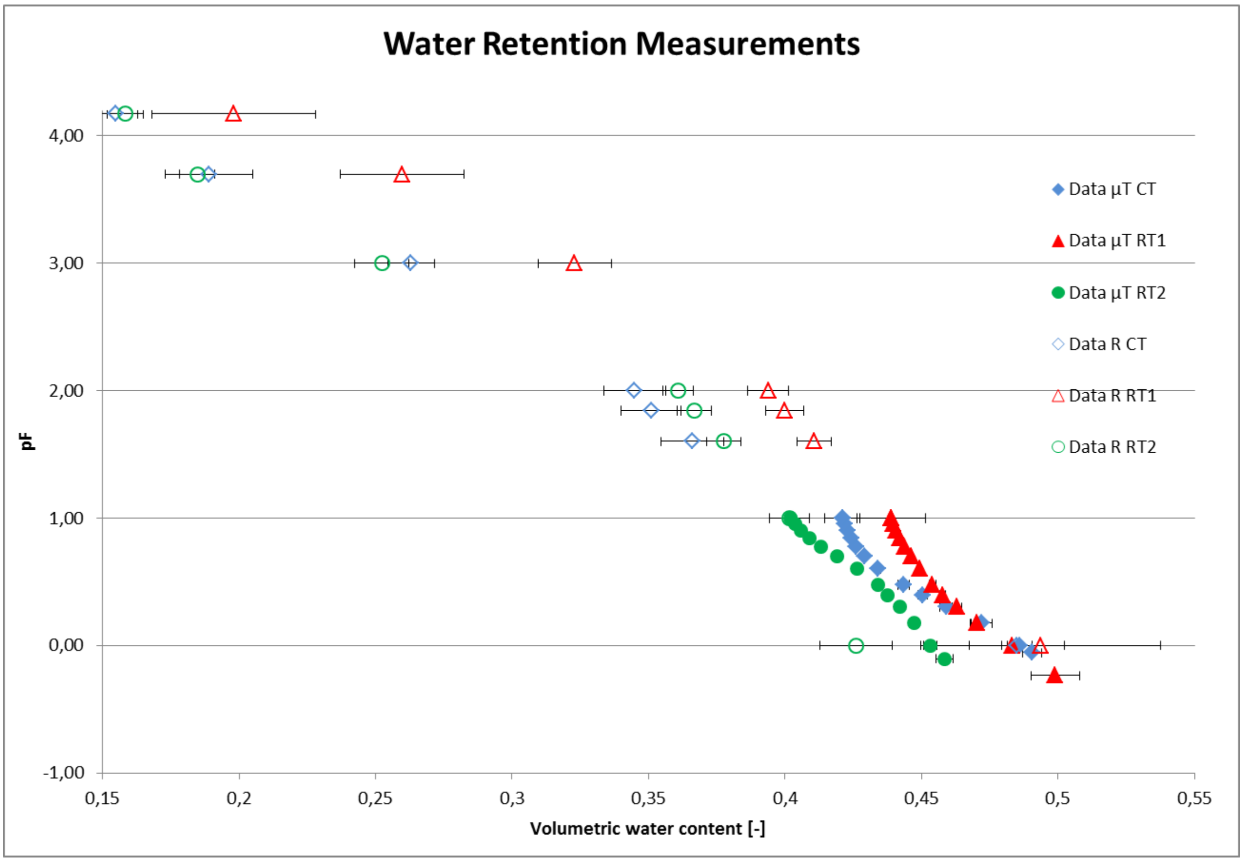

Figure 1*: Water retention data for the three objects (CT-RT1-RT2) obtained with the Richards' procedure (empty dots) and with microtomography (full dots) for the entire tension range.

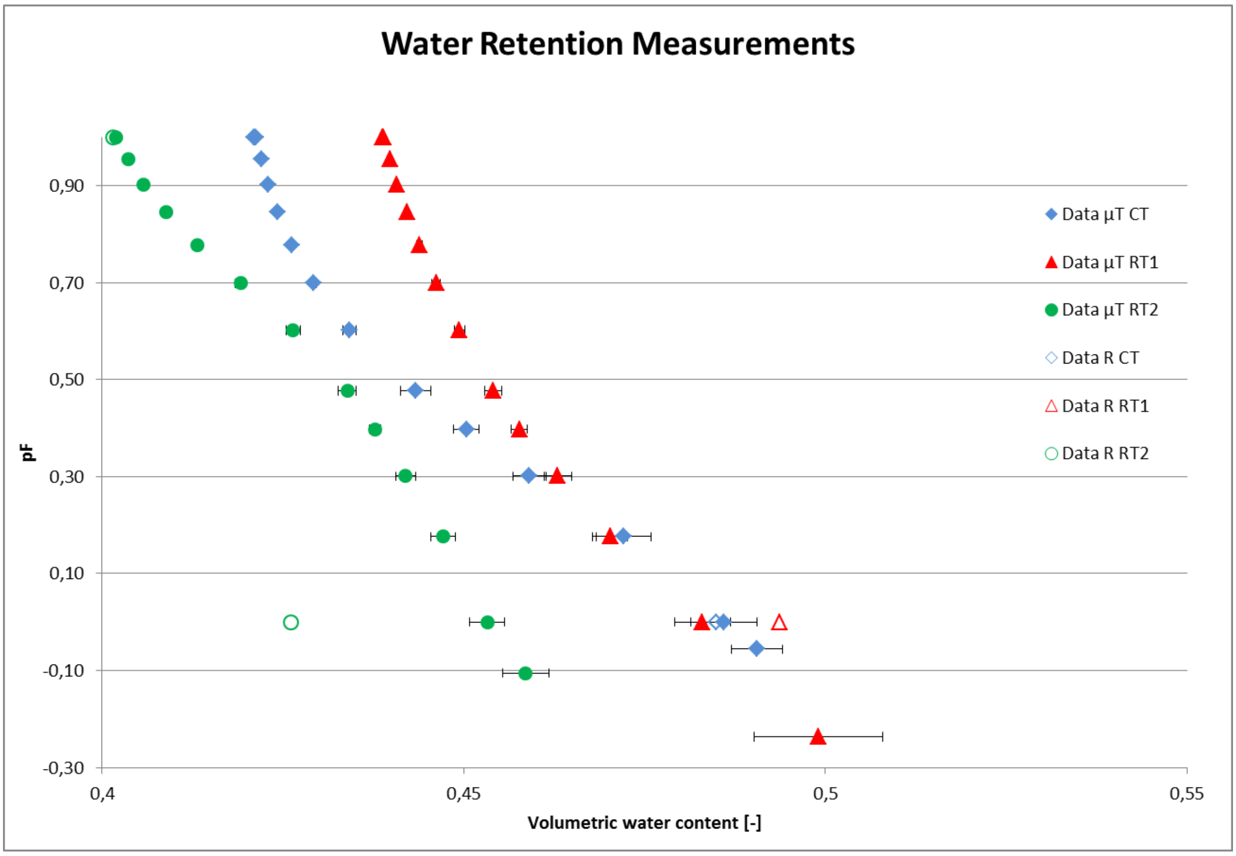

Figure 2*: Water retention data for the three objects (CT-RT1-RT2) obtained with the Richards' procedure (empty dots) and with microtomography (full dots) for the tension range between pF 1 and saturation.

Then, you should discuss the discrepancies between Richard and microCT very close to the saturation, as the two methods are based on two completely different approaches. For example, there is not hysteresis effect for microCT measurements. At which soil water potential were the samples for scanning? This is very important here!!

All the samples were saturated first, and then an increasing pressure was applied to dry them (See (f)). As a result, both the data sets are measured during desiccation.

There is no description of how you used the microCT to get the point on the curves, this should be included.

(g) A first part of the explanation is given P.4805 L15-21. It explains that we use the capillary theory to link the pressure head to the pore radius for the range pF1 to saturation. It means that we do not take into account pores with radius below 4 pixels (r= 150 µm), because we consider having a lot of noise below this threshold. Then P.4809 L3-10, we explain that we apply an algorithm to decompose the pore space into individual pores (see Plougonven, 2009 for more details), a radius for each pore is then calculated.

Where are the statistics of the fit by the different models (R2, p value, etc.)?
P4812 L1: how do you calculate the RRMSE? I know the RMSE and the Normalized RMSE but not the Relative RMSE. Relative to what?

(h) The relative Root Mean Square Error is calculated as below (following Alkasawneh et al., 2007). :

$$\boldsymbol{RRMSE} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{n}}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{n}}\left(\frac{\boldsymbol{d_i} - \boldsymbol{D_i}}{\boldsymbol{D_i}}\right)^2}$$

With *n* the number of measurements, d_i the estimated value and D_i the observed value. It is thus based on the relative error rather than the absolute. In the literature, the term "rRMSE" can be found, as well as the RMSE ("relative" being tacit, as in the paper of Alkasawneh et al., 2007). The only difference between RMSE and RRMSE is units. The advantage of the Relative RMSE is that it is expressed as a percentage. As a consequence, observations with different units can be compared. Besides, in general, it is more convenient and easier to compare values as percentages.

We use only the (R)RMSE to quantify the quality of the fit, and not the R^2. RMSE (to be understood here as a generic term) is a common parameter to quantify the goodness of the fit. As examples, we can give the following references for which RMSE is used as a factor to quantify the goodness of fit of water retention and hydraulic functions: Schaap and van Genuchten (2006); Weynants et al. (2009); Vereecken et al. (2010) among others.

This choice allows us a fair comparison. In fact, we compare models fitted on different amount of observations considering retention data. Besides, at least for K(h) measurements, the measurement variability is greater near saturation. Finally, for the comparison between the models and the measurements for K(h), we only have 3 points.

P4812 L6: "significant" but never tested!!!

It was tested. We use the word "significant" only when the result is supported by a statistical analysis. See also reply (b) and Table 1.

Figure 2: how can pF be negative? how can you estimate a microCT porosity for pF<0????

Since pF is the common logarithm transformation of the matric potential in cm (Davidson and Schofield, 1942), this value is negative when pressure head is below 1 cm. Radcliffe and Simunek (2010), in their book "Soil physics with Hydrus", present water retention curves on a pF scale with negative values.

The microtomography porosity estimated for pF < 0 is established thanks to the capillary theory (see (g)). For example, the last point of the RT2 treatment is at pF = -0.1. It corresponds to a pressure head of h=-0.8 cm and to a radius of r=1900 µm.

The text on this figure is too small and impossible to read.

It will be adapted.

Table 1 and table 3: both have the same caption but address something different? No statistics here again!! You need to test that you really have CT>RT2>RT1

Table 1 is relative to the fitting of the retention curves while Table 3 is referring to the fitting of the hydraulic curves. This will be added in the captions.

For the second sentence, we assume that it refers to the results P.4813 L5-10. In this case, the macroporosity efficiency is calculated on average Ksat and average macroporosity since it is not possible to link each Ksat measurement to a single macroporosity measurement. As a result, we have one single value for each object and no statistic test can be performed. The ranking is given as a trend, not as a significant difference between objects.

P4813 L18: no statistics again to compare the models!!!

See (h)

P4814 L21: "And the algorithm…enhancement" I don't understand this sentence…

The sentence refers to the use of the algorithm of Plougonven (2009) to separate pores. Number of software identifies pore as object surrounded by void on all sides. When well-connected soils are studied, methods of pore distribution calculation based on this definition fail: they will result in some pores plus one large pore representing a great part of total porosity (as an example, of about 90% in our case). It is useless to calculate individual structural parameters, or radii, on such a big pore. Different methods based on the different definition of a pore (which is not obvious and is still discussed in the scientific community) palliate this situation. Among these methods, Plougonven (2009) developed the one we use. Our point with this sentence is thus to say that pore size distribution obtained with this method and the fit of an elliptic cylinder on pores converge to obtain good results.

PCA: I suggest including hydraulic parameters (from table 2) in the PCA or remove this part, according to the objective, it is useless to analyse only the microCT parameters.

First, PCA was applied on pores and for each sample. Parameters from Table 2 are parameters calculated on average and cannot be introduced in the PCA as is. Besides, our point here is to show that structural parameters quantified thanks to microtomography are able to help differentiating soils known to be structurally different.

P4815 L10: you cannot see that from your measurements.

(i) We propose to replace L9-15 by the following:
"Vogel and Roth (1998) demonstrate that realistic pore network representation has to take into account its connectivity and tortuosity. Our PCA is consistent with their results since specific surface and specific connectivity are highly correlated with F1. The importance of these structural parameters in our objects differentiation strengthens the idea that macroporosity is not the only parameter to consider for conductivity characterization."

P4815 L13: you mention tortuosity but you did not quantify this parameter, why?

We did not perform it because we consider that it is redundant with two other parameters we included in PCA: *Deformation* and *Specific surface*. Both these parameters are well defined while tortuosity is expressed in different ways in the literature and its definition is still discussed.

P4816 L1: see my general comment.

See (b)

P4816 L3: see my general comment.

See (a)

Conclusions

P4816 L9-10: which data support this conclusion?

See (h) - RRMSE values

P4816 L10-11: please define globally and locally.

"Globally" is to be understood at the sample scale while "locally" means at the pore scale.

P4816 L16: isn't this secondary pore system due to the fact that two different methods (Richard and microCT) were combined to get the SWC? It might only be an artefact!!

We don't think so. Supplementary pore systems have been put in evidence by Durner (1994): "…predictions methods are frequently used where the shape of the conductivity function is estimated from the more easily measured water retention characteristic. […] This second error source [*an incorrect prediction of the retention data*] is particularly important for soils with heterogeneous pore systems that cannot be adequately described by the usually used retention functions."

Taking into account this secondary pore system improves (in terms of RRMSE) the match between hydraulic curves and hydraulic measurements even if we consider Richards' measurements alone (see Table 3 columns 1 and 2). Same statements were expressed by Durner (1994): "[…] reported disagreements between measured and estimated conductivities may in some cases be due to an inadequate description of the retention data […]." Besides, referring to P. 4814 L16-24, we are saying that microtomography is not the only tool that allows the visualization of this secondary pore system. In fact this is not why microtomography is interesting. But the fact that microtomography puts this in evidence, as well as it allows a better prediction of the unsaturated hydraulic conductivity, are clues for a validation of microtomography information.

P4816 L17: what do you mean by "near saturation pore distribution"? Consider rewording.

"…and expands our knowledge of the pore size distribution between pF 1 and saturation."

P4816 L25 to P4817 L2: not supported by the data.

See Erreur ! Source du renvoi introuvable.

P4817 L3 to end: what do you mean??

We mean that, one of the great advantages of microtomography -in comparison with other soil routine measurements – is that this information is durable. For example, with the permeameter, the soil samples cannot be kept for a long time. As a consequence, no other measurement can be performed on the same samples. For microtomography it is not true because images are not damaged by the calculations. More information can be obtained as the computer resources increase or as algorithms are developed.

Tables

There are many units missing for the parameters presented in the three tables!!

We did not give units when they are relative (e.g. cm^3/cm^3), like for the RRMSE. It will be included for the revised version.

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