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Reply to anonymous Reviewer #2

RC2 #1: The paper presents different ways to predict the water retention curve of binary mixtures (i.e., mixtures of two materials with different particle size distributions). The study was carried out within the context of the need to understand the hydraulic properties of constructed technosols that result from mixtures of geogenic materials of different particle size distributions. Willaredt et al. define two models and predict the water retention curves of different mixtures previously characterized in previous studies. The authors also fit the data to the bimodal water retention cure model, using an approach similar to Durner's (Durner, 1994). The manuscript is clearly organized ad relatively well-written. I reckon proofreading by a Native from English spoken countries. I have some concerns that should be addressed before potential publication:

We thank the reviewer for her/his time and effort dedicated to substantially improving our manuscript and appreciate the positive feedback regarding the quality of the structure and language of the manuscript. We paid detailed attention to all comments and formulated concerns and will address them as follows. The manuscript was proofread by a native English speaker (see the acknowledgments) and the revised manuscript will be again proofread.

RC2 #2: The topic of the paper lies partially in line with the area of hydrology. This study is clearly more geotechnical than hydrological. I join the feeling of the first reviewer concerning this aspect. I suggest strengthening the link with hydrological processes.

To our opinion, this paper is rather hydrological than geotechnical. Regarding its relevance for hydrology, we agree that especially the consideration of hydraulic conductivity (not only saturated) will improve it greatly. We are convinced that the knowledge of the soil hydrology of constructed Technosols plays a key role in urban greening (green roofs, raised beds, facade greenery) and its services regarding urban water management (drought resilience, stormwater retention, grey water management) (see also reply RC1 #9). We will elaborate on this relevance more explicitly throughout the revised manuscript, e.g. by considering the unsaturated hydraulic conductivity as we describe in RC2 #3.

RC2 #3: In the end, the authors propose an application of their model that is more related to hydrological sciences. They show how their model may be used to predict water content in technosoils for growing plants and trees. Using capillary models, they could increase the link with hydrology by predicting the unsaturated hydraulic conductivity from predicted water retention curves.

We are very thankful for this comment, we will improve the manuscript by considering unsaturated hydraulic conductivity. Due to the lack of hydraulic conductivity observations for most data sets, we will apply the prediction scheme of complete unsaturated hydraulic conductivity functions, including the capillary bundle model, based on the theory developed by Peters et al. (2023) (HESSD https://hess.copernicus.org/preprints/hess-2022-431/). See also our reply to reviewer 1 (RC1 #2). This will enable modelling transport processes in constructed Technosols.

RC2 #4: I suggest moving the appendix to the main text since it presents important mathematical aspects. This move would ease reading the result section, in which links to equations and models need to be more straightforward.

We thank the reviewer for this suggestion. We make use of the parametric fitting models in this study rather as a means to represent the measured data for further processing. For a more detailed discussion on fitting water retention models to binary mixtures and a comparison of their performance, we propose to refer the reader to Willaredt and Nehls (2021). In this study, we aim to highlight the compositional model and therefore will leave the detailed equations of the fitted models in the supplementary material.
We agree, however, that the structure of the methodological section can be improved and will rearrange the Material & Methods section:

2. Materials & Methods

2.1 Compositional models

2.1.1 Adapted Clarke model

2.1.2 Basic scheme CM1

2.1.3 Extended scheme CM2

2.2 Data sets of binary mixtures and their mathematical representation

2.2.1 Data sets

2.2.2 Mathematical representation

2.3 Testing

2.4 Model application

2.4.1 Estimation of the distribution of water and air in constructed Technosols

2.4.2 Prediction of hydraulic conductivity functions

Furthermore, we will clarify the terminology in the revised manuscript: i) fitted functions for prediction ('fit4pred'), ii) predicted functions using the compositional models ('pred'), and iii) fitted functions to the measured data of the mixtures as reference for the predictions ('fit4ref') (see also our response to RC1#4).

RC2 #5: Several variables and models are only sometimes clearly presented in the appendix and the main text. Please, define all the variables and their related units.

We apologize for this negligence and are thankful for this comment. We will define all variables and their units in the revised manuscript.

RC2 #6: Regarding the optimization process, when fitted data are compared to observed data, the equations should be reminded, and the optimized parameter should be listed and discussed. No discussion of parameters is proposed.

We believe that the models are clearly addressed. We do not want to pay too much attention to the values of the single parameters since only the shape of retention curves as a whole is of interest (see also our reply to reviewer 1 (RC1 #5)). We refer to the list of all optimized parameter values in the Appendix (Table A1-A4).

RC2 #7: The physics should also be discussed. In several mixtures, the fine components have bimodal pore size distributions. Theoretically, this could lead to three modes for the mixture pore size distribution, with two for the fine part and one for the coarsest part. This aspect should be discussed.

We are thankful for this comment and you are right that theoretically, we could achieve 3 modes. This will depend mostly on the difference in the maximum pore size of the single components and their homogeneity. It is certainly a very interesting and important topic. We will discuss this issue briefly in the revised manuscript: i) for the special case of mixing bricks with an inner pore-size distribution (PSD) mixed with other components, the inner pore-size distribution is not changed by the mixing. ii) Not every mode in the single component's PSD is necessarily visible in the mixtures because the PSD may intertwine in a way that cannot be described straight-forward on a physical basis.

RC2 #8: The impact of the symmetrical and multimodal pore size distributions of components should be discussed concerning their impact on the bulk water retention of the mixture.

We refer to our reply to RC2 #7.

RC2 #9: More detailed comments: The authors will find a list of suggestions and comments in the enclosed pdf document.

We appreciate all suggestions for editorial improvements by the reviewer given in the manuscript and will consider them in the revised version. We are also thankful for highlighting the strong points of our manuscript. The replies to the comments in the manuscript are given in the following.

Title: I join reviewer 1 in his comment. Water retention is important, but additional impacts on the prediction of the saturated hydraulic conductivity could have been better.

We agree and refer to the reply to RC2 #3. We will update the title to "Predicting Soil Hydraulic Properties for Binary Mixtures – Concept and Application for Constructed Technosols"

l.11 the two modes of the …

Here we refer to the pore-size distributions (PSD) of the single components and do not want to address the shape but only the maxima of the PSD. Regarding the consideration of the modality of the PSD we refer to RC2 #7 and RC2 #8.

l.15: This conclusion seems to be more related to geotechnical issues than hydrological issues. Define here the targeted application.

In RC2 #2 and RC2#3 we elaborate on the link with hydrology of this study and how we intend to strengthen it, e.g. by including the prediction of soil hydraulic conductivity.
In the abstract, the last sentence will be: "The knowledge of the soil hydraulic properties of any mixing ratio facilitates the choice of a Technosol composition that matches e.g. specific urban water management purposes and meets the required hydraulic properties to supply water to urban green."

l.38: Please, give more details on these variables, or at least their names (like "bulk density" for "BD").

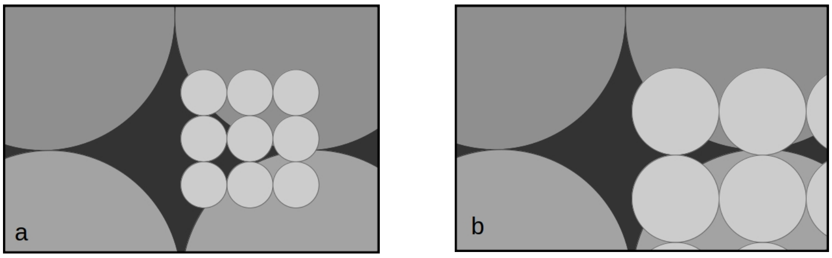
Thank you for this indication. Will be done.

l.40: and also the hydraulic conductivity

Will be done.

Figure 2: To my point, this figure is not explicit enough. You should avoid the 3D perspective and do a figure with a 2D perspective instead.

We appreciate the assessment that Figure 2 can be improved and changed the opacity to reduce the appearance of a third dimension.



l.101 a) why in italics?

Thanks. The typo will be changed.

l.101 b) not very clear sentence

We acknowledge the reviewers' critic and will revise this section carefully (see also our reply to RC1 #3).

l.110 This corresponds to the zero mixing model, right?

Yes, indeed. We will state it directly in the following sentences: "This approach corresponds to the "zero-mixing" concept and is a weighted superposition of the WRCs of the two components to predict the […]"

l.117 The input of this model is not very clear.

Thank you for this remark, we will reformulate the description as follows:
"For the extended scheme of the compositional model, an additional WRC is required for predicting a mixtures' WRC. The additional WRC should represent a mixture of similar shares of both components. Therefore it is referred to as the WRC of an intermediate mixture θ_m. We apologize for the inconsistency in our nomination. The variable x_i will be replaced with x_m and stands for the bulk volumetric share of component a in the intermediate mixture. We will update Equation 4 to:

$$\theta_{pred}=\begin{cases}\frac{x_a}{x_m}\theta_m+\left(1-\frac{x_a}{x_m}\right)\theta_b, if\ x_a<x_m\\ \frac{1-x_a}{1-x_m}\theta_m+\left(1-\frac{1-x_a}{1-x_m}\right)\theta_a, if\ x_a>x_m\end{cases}$$

l.140 Could you define xi,m above and elaborate more on this (even though this is quite straightforward)?

We appreciate this remark, the variables $x_{i,m}$ and $x_{i,v}$ will be clearly defined in the revised manuscript.

l.157 I reckon to put the appendix here, to have the whole information in the same place.

We refer to the reply to RC2 #4.

l.158 We need the equations of the water retention functions. Please, add equations in the appendix here.

We refer to the reply to RC2 #4.

l.166 The type of models (uni-modal versus bi-modal) should be considered based on physical considerations instead of the number of points.

The reviewer is certainly right, that the physical structure of some components leads to multi-modal PSD, however, such PSD can simply not be detected with a very limited number of data points.
Especially for a small number of data points, fitting a small number of parameters results in more robust fitting and consequently in more robust prediction. We refer to the data of Willaredt and Nehls (2021), which contain the information for more complex retention functions.

l.167 It would help if you gave the equations to allow the reader to understand the differences. I know the constraint (m=1-1/n), but that needs to be mentioned clearly, and the reader may need clarification.

We will refer to equation A3 in the revised manuscript. This will make it clear.

l. 184 Not clear. Why this value? In addition, do you consider this value at one boundary of the profile and then compute over the whole profile (considering hydrostatic water pressure head).

We apologize that we forgot to clearly define the underlying assumptions. At the lower boundary we assumed full saturation and hydrostatic equilibrium for the matric head distribution in the container. Thus, pF 1.7 will occur at the top of the container. We will revise the manuscript accordingly.

l.214 Unclear, please, elaborate

see reply to comment on L 166.

Figure 4. For the line "fit", please remind the corresponding equation (or model).

Thanks for that comment. We will refer to the according equation given in the appendix.

l.238 ??

The sentence could be improved to “For constructed Technosols containing coarse particles with inner porosity, the Clarke model could be applied in a modified version, that accounts for additional water retention within the coarse particles.“

l.249 Which one? Again, remain the corresponding model (I guess PDI).

We thank the reviewer for this remark and suggest specifying the model by changing the sentence as follows: “The deviations here reflect the comparably poor fit of the uni-modal constrained van Genuchten model used to represent the data of the pure peat (RMSE 0.029 m^3m^{-3}).”

Figure 6: You should provide the parameter estimate for the fitted data. These may be discussed and give further ideas about the activation of porosity.

Regarding the parameter estimates we refer to Table A1-A4 in the Appendix, where we provide the values of each parameter together with the RMSEs describing the fitting quality for each mixture. Regarding the activation of porosity, we, unfortunately, do not understand the meaning.

Figure 8: Which model? PDI model? Give details here.

We refer to the reply to RC2 #4 and suggest accordingly replacing the terms “observed and fitted water contents” with “reference water contents” and “the parametric fittings” with “reference curves”.

l. 283 "for the CM1 model, "

We appreciate the suggestion and will include it in the revised manuscript.

l. 284 "deviations, apart from a few exceptions". Then, you need to list them.

We appreciate the suggestion and intend to improve these sentences to “The extended model approach leads to smaller RMSE and also to smaller absolute deviations, apart from a few exceptions: in the wet range for the mixture C7B3 of the data set by Willaredt and Nehls (2021) and in the medium to dry range for the mixture C2E8 of the data set by Deeb et al. (2016)”

Figure 9. Be more precise. Where is this value applied? At the top of the container?

We suggest addressing this remark by changing the sentence to: "Distribution of volumetric water and air content over different depths at hydrostatic equilibrium in a container (corresponding to pF = 1.7 at the top of the container) [...]" see also our reply to your comment in l. 184.

l.308 How can we change this unphysical feature?

You are right, that is unphysical. The preparation method of the samples in the study of Deeb et al. (2016) led to rather high deviations between the bulk densities of the replicates. We calculated the porosity of their mixtures therefore based on a mean bulk density. We will define the porosity as max(θ_s, 1-BD/PD), this will avoid negative air contents.

l.318 Do you refer to the CM2 model when you state this?

We thank the reviewer for this remark and propose to express the conclusion more precise by reformulating the sentence to:
"The introduced compositional model approach, in the basic, as well as, extended scheme, was shown to be applicable to mixtures of components characterized by a small difference between their pore space distribution maxima (ΔPSD_{max}). It can be concluded that the compositional model approach performs best, based on water [...]"