We would like to thank Wolfgang Durner for its very useful review.

Especially, thank you for pointing out the improved version of the Van Genuchten proposed by Iden et al., 2015 which we were not aware of.

We integrated these new closing equations and run new simulations. The results are very good, and we will incorporate them into a new version of the article.

As we mentioned in our article, although Van Genuchten (1980) proposed an improvement in the closure equation compared to Brooks & Corey (1966) , the meteorological and climate modeling community that uses Land Surface Models (LSMs) usually use the Brooks & Corey closure equations, as they are more numerically stable and necessitate less parameters. The introduction of a proposed Iden et al. (2105) air-entry suction allows a major advance for LSM modeling.

This progress is made possible by your involvement in this peer review process and we are very grateful

In the following we provide details answers to your questions and comments.

The goal of this study is to use a LSM to reproduce soil water mass, volumetric water content and drainage flux observed in seven lysimeters during a period of more than five years. The simulations are performed with three different parametrizations for the soil hydraulic properties, namely the common functions of (i) Brooks and Corey (1966) [BC66], (ii) van Genuchten-Mualem (1980) [VG80], and additionally (iii) a previously proposed “hybrid” approach, where the VG80 retention function is combined with the BC66 conductivity function [VGBC]. Considering standard diagnostic variables, the authors find a best performance with the VGBC approach and a worst performance for the VG80 approach. Ancillary studies further investigated the replacement of heterogeneous, layered soils with uniform properties. The authors note that all the results deteriorate compared to the tests with a heterogeneous profile and conclude that the vertical heterogeneity of the soil hydrodynamic parameters must be taken into account. Finally, the use of PTF-derived hydraulic properties in the simulation is compared to the use of parameters based on in-situ measurements of water content and matrix potential. Basically, the in-situ derived VG80 parameters n differ strongly from the PTF-derived values, leading to significantly different simulation results, which are worse for the PTF-based simulations.

General Comment

Using lysimeter data in soil hydrologic analyses is always exciting because it shows us what we do and do not understand about soil hydrologic processes.

And it gives us clues about the reliability or unreliability of local soil moisture sensor readings. So this work is a very good exercise, and the use of lysimeter data for this type of study has merit. Furthermore, the paper is well written and a pleasure to read. However, I have a problem with the main idea of the paper, which is to propose the use of a VGBC parameterization in soil hydrology.

The approach taken by the authors here may be nice from a numerical point of view, but from a physical point of view it must be considered unsuitable. The reason, in short, is that a smooth, continuously derivable soil water retention function (WRC) is combined with an incompatible shaped hydraulic conductivity function (HCC). This does not make physical sense. Furthermore, the comparison of the three functional approaches is most likely biased by problems with the VG80 model when it is used to parameterize the WRC of a fine-grained soil or a soil with a broad pore size distribution (indicated by a parameter value of n close to 1). In such cases, the VG80 hydraulic conductivity curve (HCC) exhibits an abrupt drop near saturation (Durner, 1994). This drop (i) leads to a severe underestimation of the hydraulic conductivity when the prediction of HCC is based on the measured saturated hydraulic conductivity (Vogel et al., 2001) and (ii) negatively affects the performance of the numerical solvers, i.e., their stability and accuracy during the transition between saturated and unsaturated conditions (Ippisch et al., 2006). This could be the reason why the authors of this study limit the smallest value of n to a threshold value (arbitrarily chosen for numerical reasons) of n > 1.09 and also find in the performance comparison that the VG80 model leads to overly wet soil profiles. To eliminate the well-known artifact of the VG80 conductivity curve for soils with small n three main approaches have been proposed in the past. They are (i) shifting the entire pore-size distribution by an air-entry value (Kosugi, 1994), (ii) introducing an explicit air-entry pressure into the van Genuchten model (Vogel and Cislerova, 1988; Vogel et al., 2001; Ippisch et al., 2006), or (iii) truncating the pore-size distribution (Malama and Kuhlmann, 2015; Iden et al., 2015). Some other workarounds have also been proposed (e.g.Schap and van Genuchten, 2006). The second approach is historically the most commonly used. It effectively eliminates the drop in HCC near saturation and the associated negative effects on the behavior of the numerical solvers of the Richards equation. The drawback, however, is that the resulting WRC is no longer continuously differentiable, i.e., the soil water capacity function becomes discontinuous, which in turn can cause problems with numerical solvers of the Richards equation in some situations. The VGBC approach adopted by the authors in their study is basically a variant of approach iii, i.e., they leave the RETC in its original smooth form, but limit the conductivity to a constant maximum value reached at an "air entry" value (somehow arbitrarily constructed for soils with small n values).

It is certainly fair to try such an approach. However, the paper fails to convince me that this approach is worth pursuing. An important reason for this opinion is the fact that the results in the paper are not fully comprehensible to the reader, since crucial information about the modeling scenario and especially the hydraulic properties of the soil is missing. So we have to believe the results or not. In addition, the paper has shortcomings, especially in the methods section of soil hydrology (Section 3.1), as will be presented later in this review. As is so often the case in soil hydrology, the devil is in the details, and therefore I recommend reviewing the study again in detail, taking into account the comments below. Specifically, I recommend repeating the analysis (or adding a scenario to the analysis) with modified BC80 HCC functions the remove the above mentioned VG80 artifact. This is probably most straightforward using the HCC functions of Iden et al.(2015, Eq. 18 therein). If desired, I [Wolfgang Durner] would be willing to provide the authors with the respective HCC functions for their lysimeter's retention curves.

SPECIFIC COMMENTS

1. Basic approach:

As mentioned before, I believe that a mixture of VG RETC and BC HCC is not a good solution to solve the problems with VG80, even though others have tried it and it leads to smooth simulations. The reason is that this is simply unphysical. Above the air entry value, we have significantly increasing water contents, but constant conductivity. This contradicts the soil hydrological evidence.

The model ISBA-SURFEX uses, like many soil–vegetation–atmosphere–transport schemes (SVAT) models, the relation of BC66. Compared to data from lysimeters, it is obvious that this relationship is not the most correct to reproduce WRCs close to saturation. This is why we decided to use the relations of VG80, but the HCC relation of VG80 requires new parameters, and is unstable close to small values of n.

The BCVG relation is one solution to solve this numerical problem; This approach was used in previous studies (Braud et al., 1995, Valiantzas, 2011). It,consists in combining VG80 WRC and BC66 HCC. We are well aware that BCVG seems not very physical from a theoretical point of view, but it is realistic from a statistical and pragmatic point of view, SWC and HCC can reproduce the observations on lysimeters very well. One advantage of this approach is also the limited number of parameters, which is important for regional or global application of SVAT model.

In your detailed review, you suggested to test an intermediate approach that has a better physical consistency. We have tested the HCC functions of Iden et al., 2015s. This corrected form , which further clarifies our statement is unknown to hydrometorological and climate modelers. We are very pleased to be the first to include this formulation in a physical land surface model used in both hydrology and climate research. This approach gives very promising results.

So we propose to include this new approach (called VGc) in this detailed answer and in the revised version of our article. To this end, we modified the figures by adding a new experiment called VGc in addition to the 3 previous functions used.

We also proposed to modify the title of the article like this : “Evaluation of four Hydraulic Conductivity Curves in the Land Surface Model ISBA with data from several lysimeters.”

For example, the 4 following figures show the results obtained with VGc with hc=1cm, as suggested by Iden et al., 2015.
Figure R3.1 shows that the general agreement of VGc with the observation is good.
Figure R3.2 is the new version Figure 10 of the article. Figure R3.3 is the new version ofs Figure 11. The agreement of VGc with the soil saturation profile is good. In June 2016 the soil profile is a little more saturated for VGc than for BCVG and drainage is similar for O1 lysimeter, and a little more reactive for G2 lysimeter. However, in terms of statistics, the two approaches are similar, and a bit weaker than for BCVG during the event of February 2016.
Figure R3.4 shows the statistical results for all events and all variable, with good results obtained by VGc.
We proposeto add this new approach in all the figures of the revised version of the article.

In the VGc simulation, we used the fitted n value of Van Genuchten with no restriction to n=1.1 as in the VG80 simulation. This might leads to differences in the matrix potential compared to VG.

The results show that this approach is a real asset for this study.

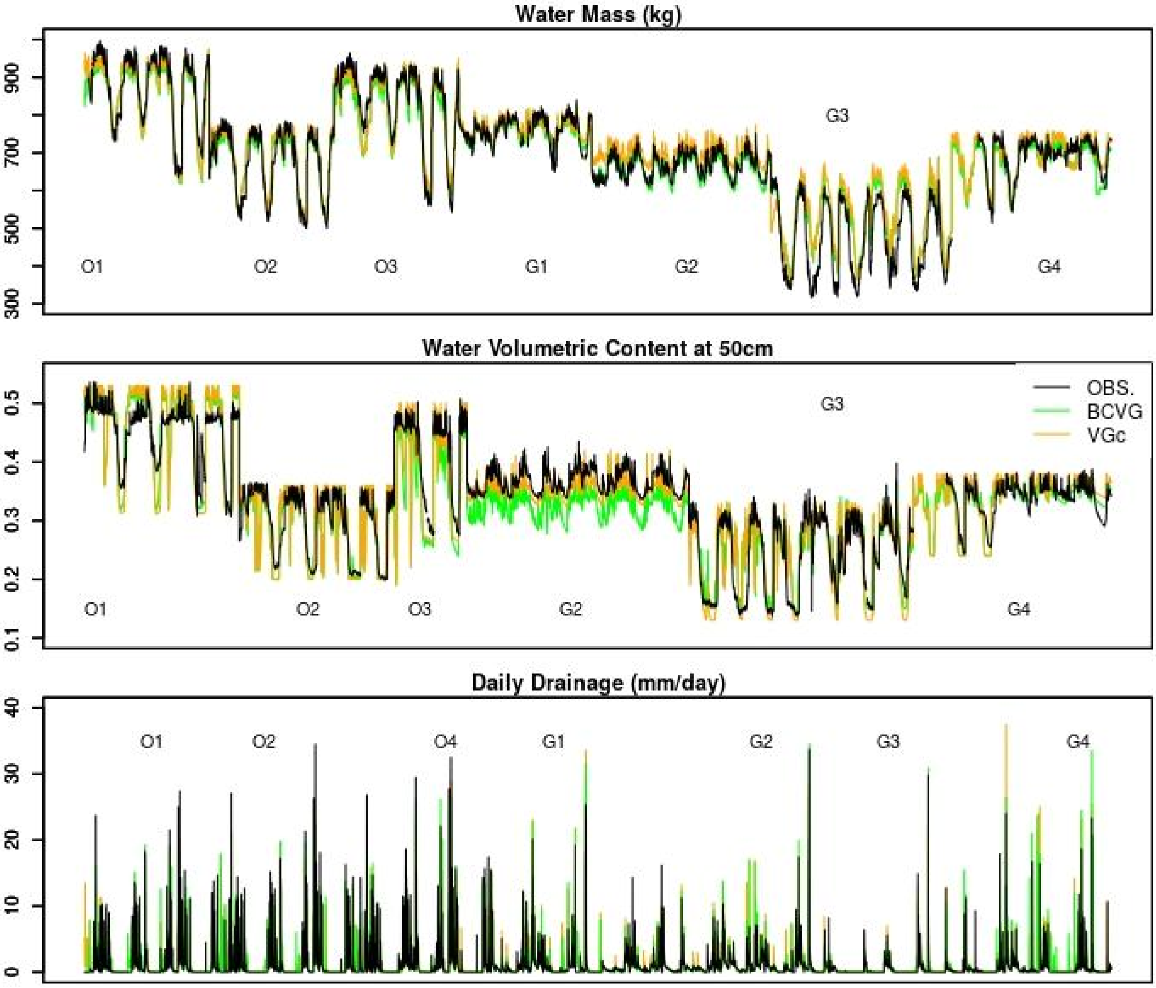

Figure R3.1 : Chronicles of Water Mass, water volumetric content at 50cm, and Drainage for each lysimeters, for observation, BCVG and VGc.

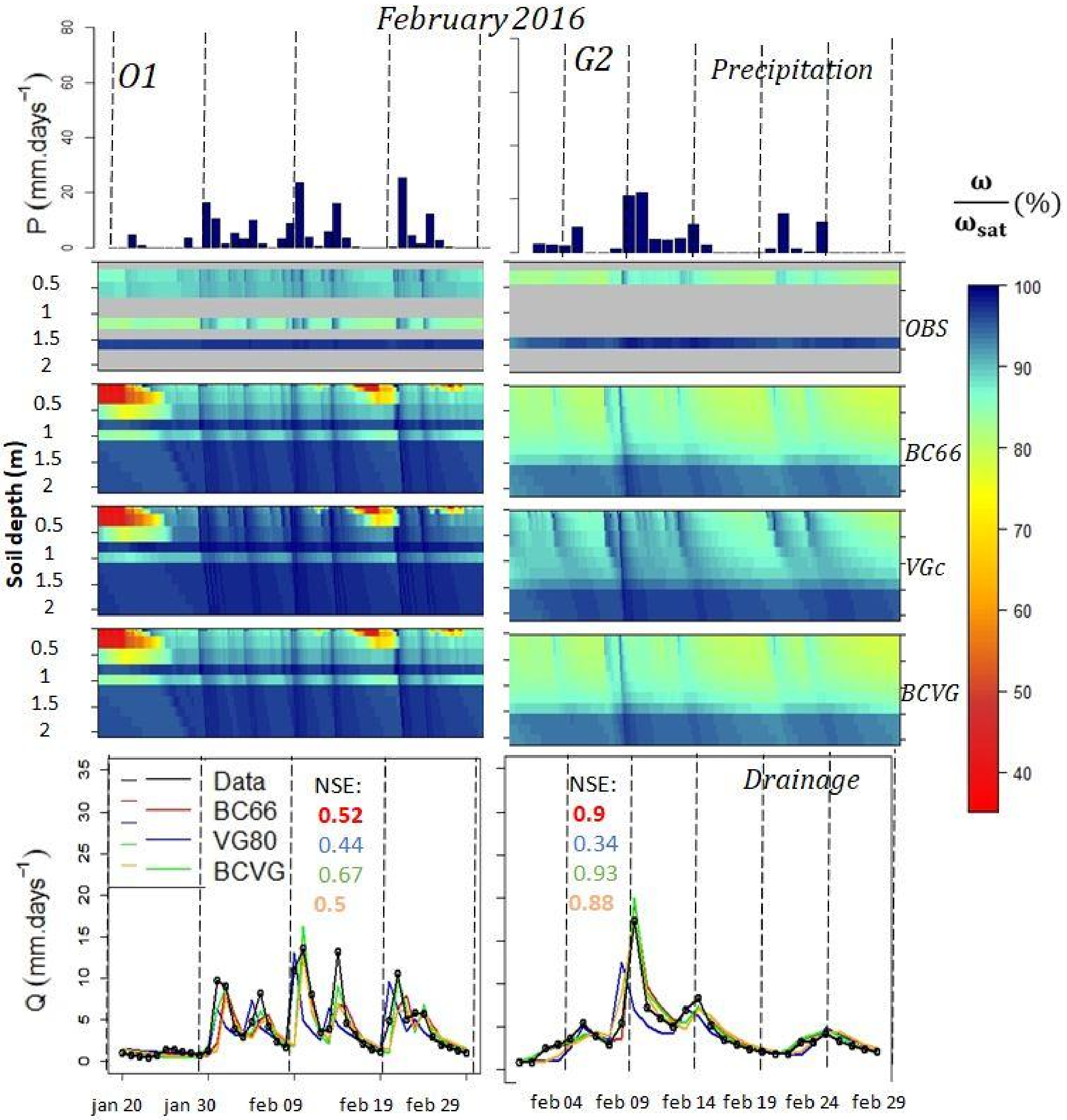

Figure R3.2 : Daily precipitation (mm.day−1), hourly effective wetting saturation profile (%) observed (OBS) and simulated by BC66, VGc and BCVG, and daily drainage (mm.day−1) observed (in black), and simulated by BC66 in red, VG80 in blue, BCVG in green and VGc in orange during intense drainage in February 2016 for lysimeters O1 and G2. The Nash Sutcliffe efficiency (NSE) for each simulated drainage is also given.

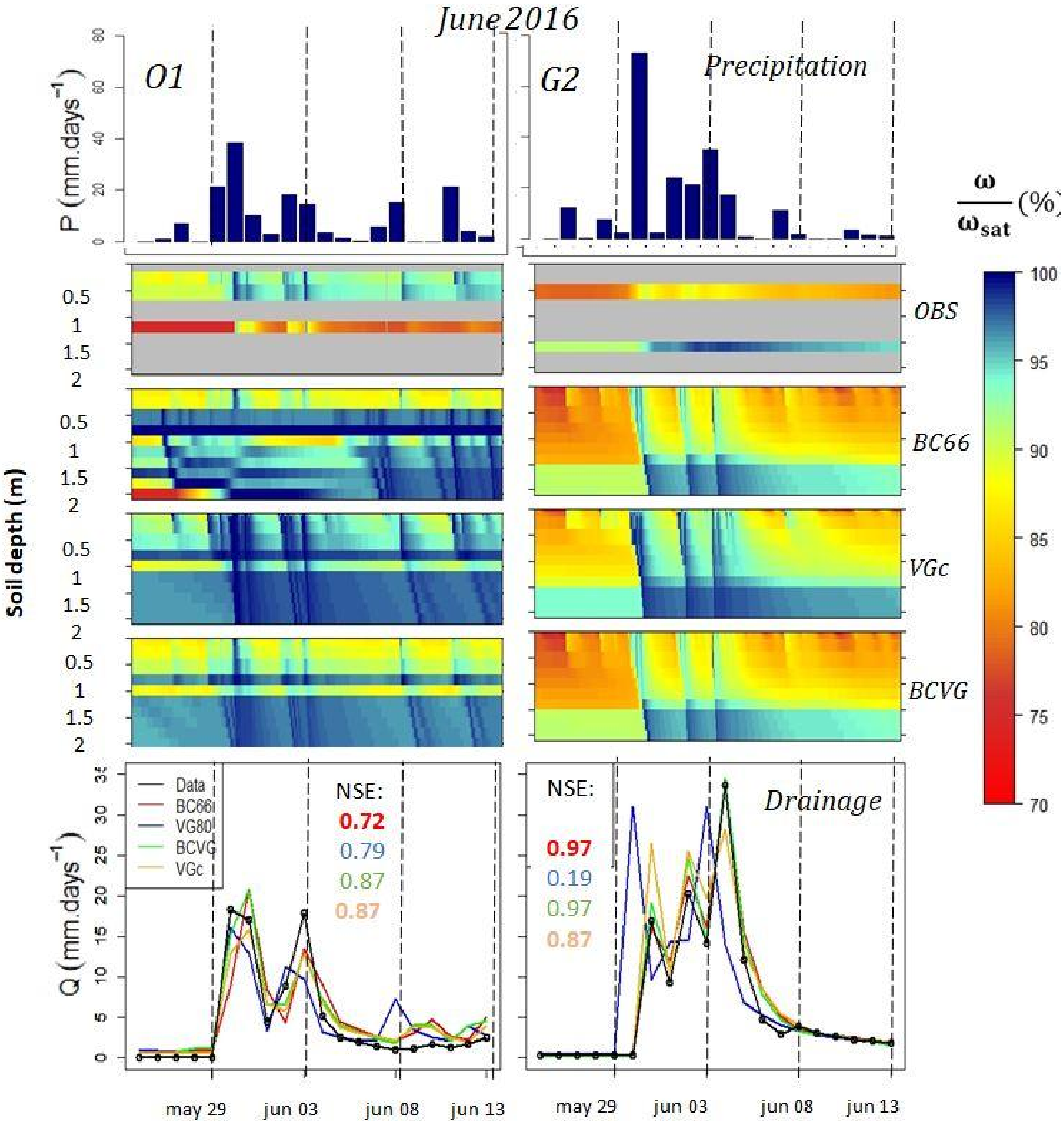

Figure R3.3 : Daily precipitation (mm.day−1), hourly effective wetting saturation profile (%) observed (OBS) and simulated by BC66, VGc and BCVG, and daily drainage (mm.day−1) observed (in black), and simulated by BC66 in red, VG80 in blue, BCVG in green and VGc in orange during intense drainage in February 2016 for lysimeters O1 and G2. The Nash Sutcliffe efficiency (NSE) for each simulated drainage is also given.

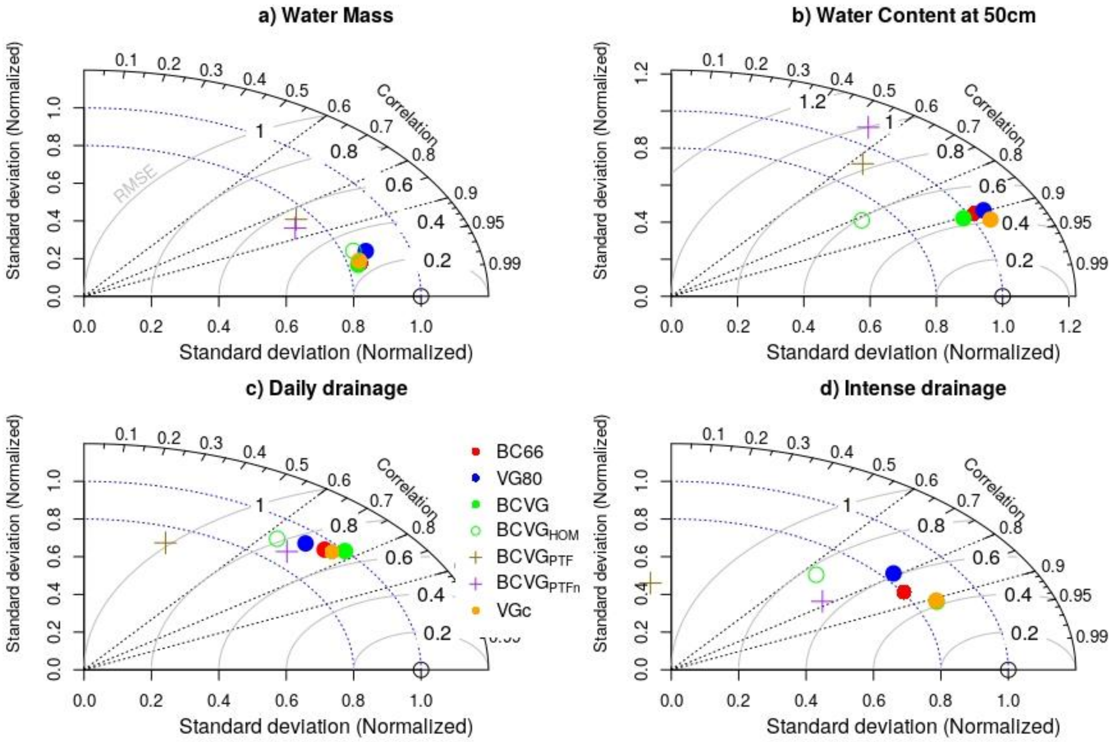

Figure R3.4 : Taylor diagrams for hourly Total Water Mass (a), hourly Volumetric water content at 0.5m depth (b), Daily drainage (c) and Daily intense drainage events (d). Experiment BC66 is plotted in red, VG80 in blue, BCVG in green and VGc in orange. Additional experiments with an homogeneous soil profile (BCVGHOM) are represented as an open green circle, with parameters estimated from usual PTFs (BCVGPTF) by a brown cross, and with parameters estimated with PTF except n estimated in situ (BCVGPTFn) by a purple cross. The Pearson correlation coefficient, the root-mean-square error (RMSE), and the normalized standard deviation are summarized in this diagram.

2. Equations:

The equations of the model used in the study must be either directly stated or clearly referenced. A statement such as "A complete description of the model equations used to simulate water transport can be found in xxxx (xxxx)" would be appropriate, especially for the soil hydrology processes that are the core of the paper. I have not found this. I understand that the mixed-form Richards equation was used, but with what kind of boundary conditions? This is especially of interest for the lower boundary condition, where Figs. 9, 10 and 12 indicate drainage under apparently unsaturated conditions, which is not possible when the lysimeters are operated with the traditional lysimeter boundary condition (i.e., seepage).

We agree with you. We ‘ll add the sentence proposed before each equation in the revised article version.

The boundary condition of the surface is the atmospheric boundary, and the boundary lower is free drainage.

Thanks for detecting an error in the plot: a 10-day lag between the water saturation profile and drainage in Figures 9,10, and 12 crept in for lysimeter G2. By correcting this error (see figures R3.2 & R3.3), the drainage appears well in phase with the saturation profile.

3. Data:

Which sensors were used? Since in science the reproducibility of results is of utmost importance, the high quality journals nowadays require that all necessary data are given. This bloats the manuscript itself too much, but it is possible to either put the data in data archives or publish them separately in appropriate data journals or attach them directly to articles as additional information. As a specific example, I would actually be interested in repeating the June 2016 G2 lysimeter scenario because the sudden breakthrough of water to the drainage seems difficult to explain with the VG80 data provided.

However, with the information currently available, it is not possible to perform such a test and judge the validity of the scientific statements.

On the GISFI site, TDR probes are RIME-PICO32 sensors with internal TDR-electronics. They are set horizontally and record the water content in cm3 cm− 3 (± 0.01) on an hourly basis. The calibration was performed on two measurements, one in dry and one in water-saturated condition. In the OPE site, soil moisture sensors used (UMP-1Umwelt Geräte Technik GmbH) are based on frequency domain reflectometry (FDR) method and measure local change in dielectric permittivity.

We will provide this information in the revised version of the article.

The data were provided by the GISFI and the OPE. The data can be accessible on requests, but, as the data are protected by a convention, the authors cannot provide access to the data. We will add contact coordinates so that anybody could ask access to these datasets.

4. Results.

Some of the results are shown as examples, which is fine. However, the reader should have access to the full results. So please use the supplementary material to list data not shown in the manuscript! For me, especially diagrams like figure 1 for lysimeters O1 and G2 are of great interest, also for the five other lysimeters.

We understand your point of view. We are committed to use the appendix or supplementary material to show the diagrams w-psi/w-k for each lysimeter and a table summarizing the parameters.

5. Lower boundary condition:
In line 181 authors state “By assuming the unit-gradient assumption, the drainage at 2 m can be considered equal to the hydraulic conductivity. ksat is then assumed equal to the observed drainage when the soil water content is saturated“ --- The statement is correct if really unit-gradient conditions prevail in the lysimeter. In typical lysimeters, where the water flows freely into the atmosphere, this would require full saturation of the entire lysimeter(!). In suction controlled lysimeters it is different, but I did not find a statement about this in the paper. Do you have any indication that this assumption can be (approximately) true if the whole lysimeter is not saturated? Or any reference where the validity of this approximation has been shown?

Yes it is the case. In the Figure R3.5, variation of the total hydraulic pressure head between depths 50 and 150 cm ($\frac{dH}{dz}$) is represented for each lysimeter. Lines blue and red represent a gradient equal to 1 and 0 respectively. We can observe that the gradient is most often equal or very close to 1. Some variations exist, in particular for lysimeter G3, because of strong and deep roots. are presents. Nevertheless, when the saturation of volumetric content in the soil is reached, the gradient is equal to 1, and we can assume at these moments, ksat is equal to observed drainage.

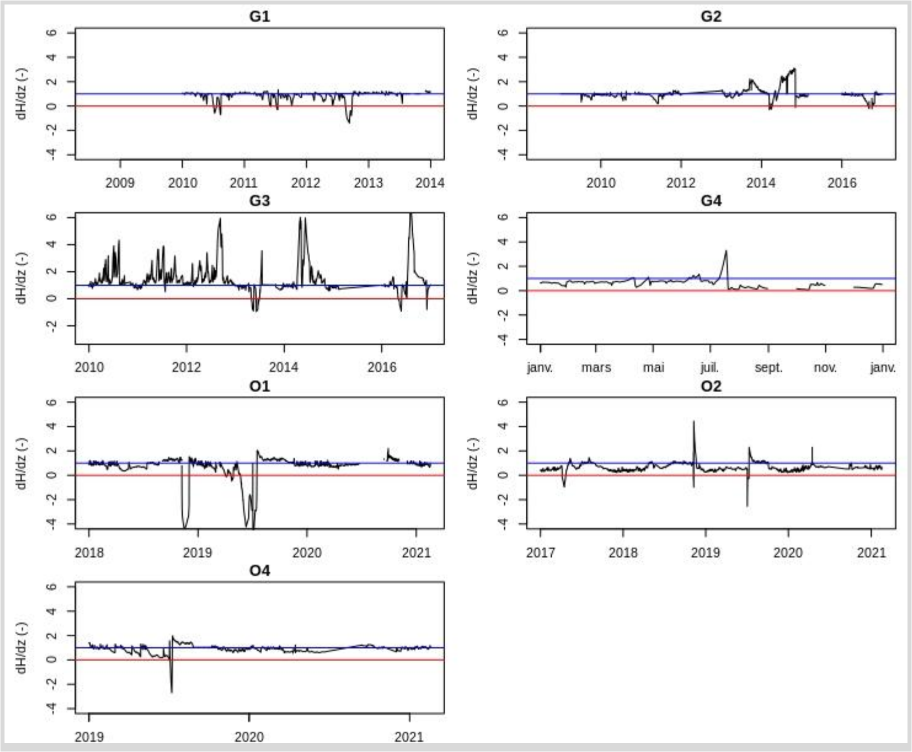

Figure R3.5 : Variation of the total hydraulic pressure head between 50 and 150 cm ($\frac{dH}{dz}$) of depth is represented for each lysimeter. Lines blue and red represent a gradient equal to 1 and 0 respectively.

6. Conductivity functions.

Conductivity functions are key to the outcome of the simulations. As always with simulations, we can say, "What you put in determines what you get out." I would like to see the functions used in this comparison in appropriate graphs. The single Figure 1 is difficult to read and not sufficient. Please see my comments on Figure 1, below. Also, the coefficients of the hydraulic functions used in the simulation study should be listed in a table (perhaps in the supplemental material), as the information in Figure 2 is not sufficient to reproduce the functions.

We illustrated in Figure R3.6 the HCC estimated from volumetric water content at each depth and the drainage for at least 3 total years. As stated in the answer to your question #4, we'll provide all the plot in supplementary material of the revised article.

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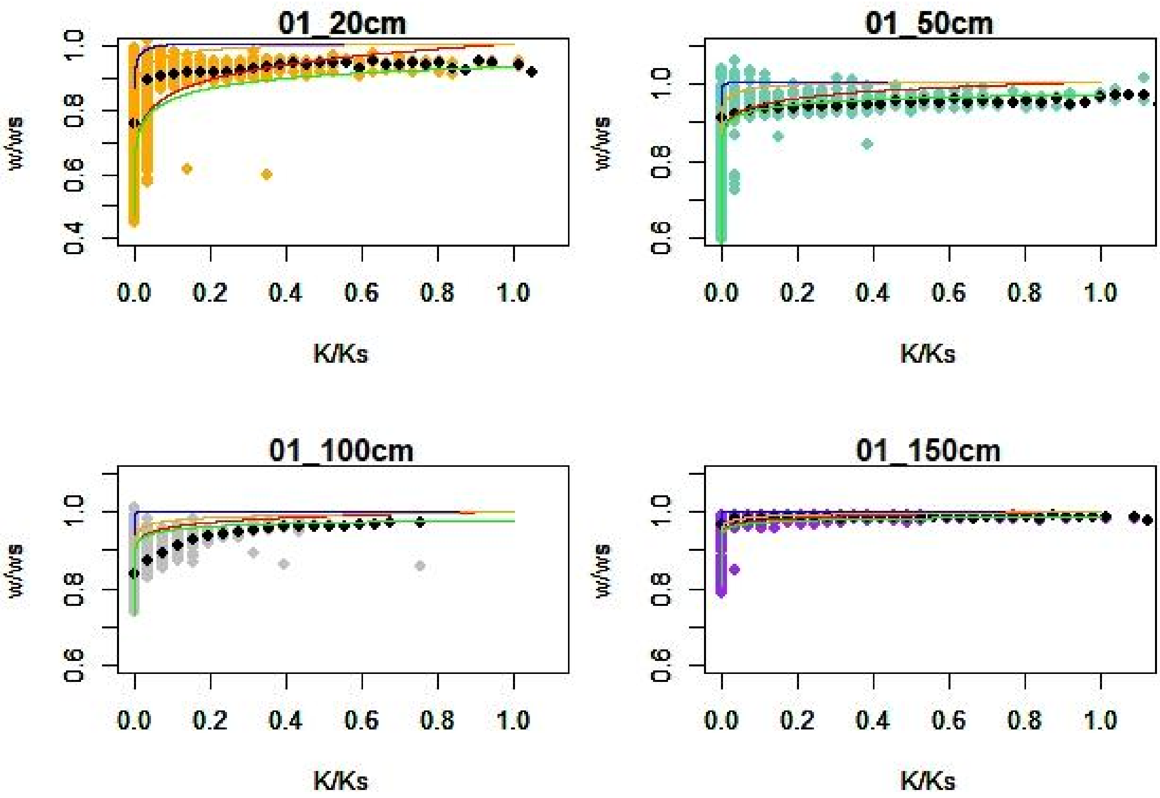


Figure R3.6 : Hydraulic conductivity curves for O1 lysimeters at different depths (20, 50,100 and 150 cm) . Observations are the points, curves fitted with BC66, VG80, VGc and VGBC are in red, blue, orange and green respectively. The black points are the mean of water content for each value of hydraulic conductivity

COMMENTS RELALTED TO SPECIFIC TEXT PASSAGES

1. INTRODUCTION

line 45. “Vereecken et al. (2019) suggested a number of directions for improvement: introduce more physical processes such [...] improve the representation of [...] soil parameters,” --- Agreed. But I do not really see the VGBC approach as an improvement of soil parameterizations in the above-mentioned sense.

You are right, VGBC is more an improvement of physical processes in ISBA compared to BC, since it helps better reproducing the water content close to saturation. This sentence will be modified, especially since we will introduce the VGc approach in the revised version of the article.

line 56 “These relationships are simple to parameterize and very stable numerically.” --- There is some irony in the fact that Rien van Genuchten actually developed his parametrization to solve the problem of a discontinuous water capacity function that causes numerical problems in simulations with the

Richards equation. So, VG80 should be numerically stable except for cases with very small n.

Yes, we proposed to reformulate these sentences like : “However, the VG80 relationships are less stable than BC66 for small values of n.”

line 60 “However, the VG80 relationships are less stable than BC66 for coarse-textured soil, mainly because of the complexity of the hydraulic conductivity function (Vogel et al., 2000).” --- In fact, I am not aware of this statement in the Vogel paper. I know VG80 is problematic for coarse grained soils in the dry moisture range, but in that range there is not much difference to BC66.

Yes, VG80 is problematic for coarse grained soils, with problems of stability. Even if the differences between the hydraulic conductivity of BC66 and VG80 are generally much less severe for coarse-texture soils.

line 73 “We derive their hydrodynamic parameters directly from observation” --- This is certainly the key to all subsequent results. As already indicated, the documentation on this important point is not sufficiently presented in the paper.

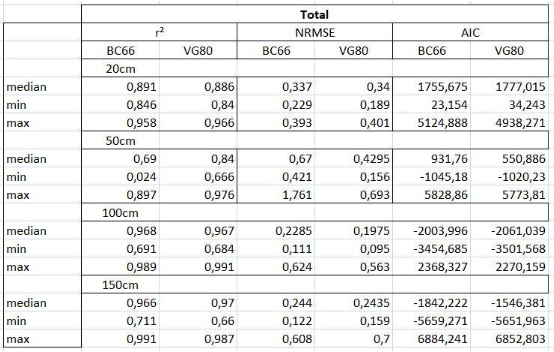
Thank you for these useful comments. Indeed, we did not provide details on the soil parameters calibration procedure, as we mainly focused on the difference between the soil parameters derived from in-situ data to those derived from pedotransfer functions. We will add the details in the revised version of the article.

The calibration of the soil parameters was performed using two methods: i) an objective least squares function which minimizes the sum of the squares of the deviations and corresponds to maximizing the likelihood with a normal distribution (function nls of rstudio). ii) the package SoilHyP (Dettmann et al., 2022) which uses the Shuffled Complex Evolution (SCE) optimization.

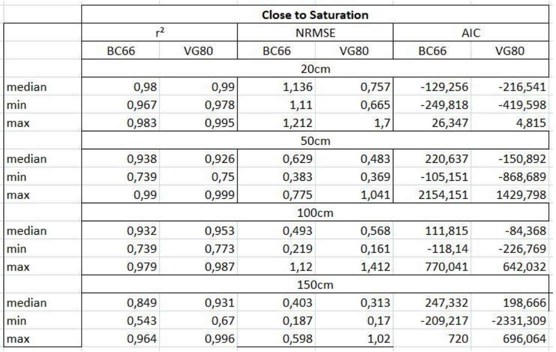
The two methods converge on very closed estimated parameters ($\delta b: 1.6;\ \delta n: 0.01; \delta wsat: 0.0085\ (m^3 m^{-3}); \delta\alpha: 2\ (m^{-1});\ \delta\Psi sat: 0.019\ (m)$).

Statistical scores and errors metrics on the estimation of the soil water retention curves (WRC) are presented in Table R3.1 for the BC66 and VG80 relationships at each depth. On the entire fit and close to saturation ($> \omega_{sat} * 0.9$), values median, minimal and maximal are presented. The fitted are generally better in depth, and a better r² for VG80 than for BC66 near to saturation. Near saturation, the NRMSE is also better for VG80 than BC66.

Table R3.1 : Statistical scores (regression, r²) and errors metrics (Normalized Root Mean Square Error, NRMSE, and Akaike information criterion, AIC) for the BC66 and VG80 relationships at each depth (20-50-100 and 150 cm) on the total entire fit (Total) and close to saturation ($> \omega_{sat} * 0.9$) for all lysimeters for soil water retention curves (WRC).



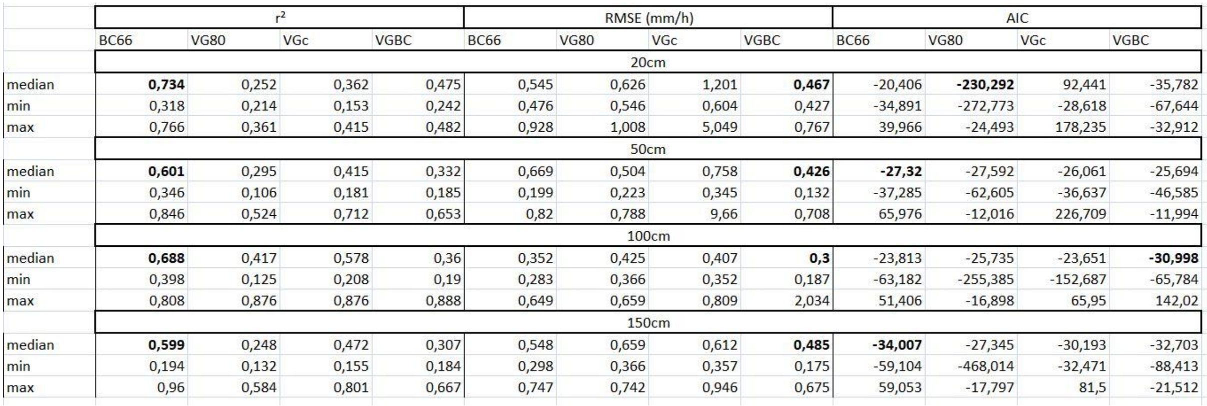
	Total					
	r^2		NRMSE		AIC	
	BC66	VG80	BC66	VG80	BC66	VG80
	20cm					
median	0,891	0,886	0,337	0,34	1755,675	1777,015
min	0,846	0,84	0,229	0,189	23,154	34,243
max	0,958	0,966	0,393	0,401	5124,888	4938,271
	50cm					
median	0,69	0,84	0,67	0,4295	931,76	550,886
min	0,024	0,666	0,421	0,156	-1045,18	-1020,23
max	0,897	0,976	1,761	0,693	5828,86	5773,81
	100cm					
median	0,968	0,967	0,2285	0,1975	-2003,996	-2061,039
min	0,691	0,684	0,111	0,095	-3454,685	-3501,568
max	0,989	0,991	0,624	0,563	2368,327	2270,159
	150cm					
median	0,966	0,97	0,244	0,2435	-1842,222	-1546,381
min	0,711	0,66	0,122	0,159	-5659,271	-5651,963
max	0,991	0,987	0,608	0,7	6884,241	6852,803



	Close to Saturation					
	r^2		NRMSE		AIC	
	BC66	VG80	BC66	VG80	BC66	VG80
	20cm					
median	0,98	0,99	1,136	0,757	-129,256	-216,541
min	0,967	0,978	1,11	0,665	-249,818	-419,598
max	0,983	0,995	1,212	1,7	26,347	4,815
	50cm					
median	0,938	0,926	0,629	0,483	220,637	-150,892
min	0,739	0,75	0,383	0,369	-105,151	-868,689
max	0,99	0,999	0,775	1,041	2154,151	1429,798
	100cm					
median	0,932	0,953	0,493	0,568	111,815	-84,368
min	0,739	0,773	0,219	0,161	-118,14	-226,769
max	0,979	0,987	1,12	1,412	770,041	642,032
	150cm					
median	0,849	0,931	0,403	0,313	247,332	198,666
min	0,543	0,67	0,187	0,17	-209,217	-2331,309
max	0,964	0,996	0,598	1,02	720	696,064

The calibration of the hydraulic conductivity curves (HCC) was also realized. For each depth, we estimated the hydraulic conductivity at saturation with the water volumetric content and the drainage at 2m for at least 3 years by averaging the drainage values for each water volumetric content value. Statistical scores are shown in Table R3.2 for the four relations. RMSE are better at depth with closer differences than at surface, and always better for VGBC (<0.5 mm/h). AIC are relatively closed between the four relations.

Table R3.2 : Statistical scores (regression, r²) and errors metrics (Root Mean Square Error, RMSE, and Akaike information criterion,AIC) for the BC66 and VG80 relationships at each depth (20-50-100 and 150 cm) for calibration for hydraulic conductivity curve (HCC).



	r^2				RMSE (mm/h)				AIC			
	BC66	VG80	VGc	VGBC	BC66	VG80	VGc	VGBC	BC66	VG80	VGc	VGBC
	20cm											
median	**0,734**	0,252	0,362	0,475	0,545	0,626	1,201	**0,467**	-20,406	**-230,292**	92,441	-35,782
min	0,318	0,214	0,153	0,242	0,476	0,546	0,604	0,427	-34,891	-272,773	-28,618	-67,644
max	0,766	0,361	0,415	0,482	0,928	1,008	5,049	0,767	39,966	-24,493	178,235	-32,912
	50cm											
median	**0,601**	0,295	0,415	0,332	0,669	0,504	0,758	**0,426**	**-27,32**	-27,592	-26,061	-25,694
min	0,346	0,106	0,181	0,185	0,199	0,223	0,345	0,132	-37,285	-62,605	-36,637	-46,585
max	0,846	0,524	0,712	0,653	0,82	0,788	9,66	0,708	65,976	-12,016	226,709	-11,994
	100cm											
median	**0,688**	0,417	0,578	0,36	0,352	0,425	0,407	**0,3**	-23,813	-25,735	-23,651	**-30,998**
min	0,398	0,125	0,208	0,19	0,283	0,366	0,352	0,187	-63,182	-255,385	-152,687	-65,784
max	0,808	0,876	0,876	0,888	0,649	0,659	0,809	2,034	51,406	-16,898	65,95	142,02
	150cm											
median	**0,599**	0,248	0,472	0,307	0,548	0,659	0,612	**0,485**	**-34,007**	-27,345	-30,193	-32,703
min	0,194	0,132	0,155	0,184	0,298	0,366	0,357	0,175	-59,104	-468,014	-32,471	-88,413
max	0,96	0,584	0,801	0,667	0,747	0,742	0,946	0,675	59,053	-17,797	81,5	-21,512

2. EXPERIMENTAL PROTOCOL

- line 85 “These two sites are separated by a distance of 97 km.” --- Please state here the basic hydro-meteorological parameters: total precipitation (comes too late at the end of the section), total estimated ETp, height above sea level, mean temperature.

We propose to move the paragraph from line 110 after the first paragraph of this section by adding the information on height above seal level, mean temperature :

“ The height above sea level is 350 and 224 m for OPE and GISFI sites, respectively. The sets of atmospheric forcing variables (wind speed, precipitation rate, short-wave incident radiation, air temperature, air humidity, atmospheric pressure) are observed in situ at an hourly time step by two local meteorological stations, one at OPE and one at GISFI. Long-wave radiation is derived from the equation of Prata (1996). Atmospheric data gaps are filled by regressions on available data using two neighboring meteorological stations. The gaps represent up to 12% of the observations for the GISFI site (Table 2). The mean temperature is 10.8 °C and 10.2 °C for the GISFI site.
Annual precipitation is 20 % higher at OPE compared to the GISFI experimental station (876 mm.year^{-1}, and 727 mm.year^{-1}, respectively, Table 2). The atmospheric forcing is assumed to be identical for all the lysimeters of each site.”

- line 101 “with different layers of limestone more or less cracked” --- uuh, taking an undisturbed lysimeter in such material is difficult. Described somewhere in literature?

For the extraction of exact soil monoliths, the procedure used is the one developed by Umwelt-Geräte-Technik GmbH and proven nationally and internationally. The core can be extracted with high precision and without disturbing the soil structure without the use of heavy extraction technology.
Please, see this website where all the information are described :
https://www.ugt-online.de/en/products/lysimeter-technology/excavation-techniques

- line 104 “They are equipped with suction and temperature probes as well as time-domain reflectometry (TDR) probes” --- please specify the used instruments/sensors.

Each lysimeter was placed on weighting cells (10 g resolution). Tipping counters (Umwelt Geräte Technik GmbH) were used for drainage monitoring. Matrix potential was measured through suction in ceramic filters by tensiometers (Tensio 160, Umwelt Geräte Technik GmbH). On the GISFI site, TDR probes are

RIME-PICO32 sensors with internal TDR-electronics. They are set horizontally and record the water content in cm3 cm− 3 (± 0.01) on an hourly basis. The calibration was performed on two measurements, one in dry and one in water-saturated condition. In the OPE site, soil moisture sensors used (UMP-1Umwelt Geräte Technik GmbH) are based on frequency domain reflectometry (FDR) method and measure local change in dielectric permittivity.

We'll add these details in the full text.

- line 113 "The gaps represent up to 15% of the observations for the GISFI site (Table 2)." --- I tried to figure that out from table 2, but find there a different value, 12%.

Sorry for this mistake. The good value was provided by Table 2, the gap of the observation for the GISFI is well 12%. Thank you for this comment.

- Line 115 "atmospheric forcing" – how expressed? How is the upper soil hydraulic boundary condition expressed in the model?

Atmospheric forcing includes all the variables cited:To be clearer, we'll precised hourly 10m wind speed (m/s), 2m air temperature & humidity (K, Kg/kg) precipitation rate Kg/m2/s), short-wave incident and long wave radiations (W/m2), surface atmospheric pressure (Pa) .

As ISBA is a SVAT scheme, the concept of upper soil hydraulic boundary conditions is not often considered like that. But, it can be stated that the upper soil hydraulic boundary conditions expressed in ISBA are variable flux boundary conditions.

ISBA compute the water and energy balance at a 5-minute time step. The precipitation can first be intercepted by the vegetation. Then, the water that drops to the soil can infiltrate. The Green-Ampt approach is used to determine the maximum amount of water that infiltrate the soil. If the precipitation cannot infiltrate, there is some runoff. In the present study, as the maximum rate of precipitation is not that much, and the area is flat, there is no runoff.

- line 117: "ISBA model" --- I would like to see some more equations related to the main hydrological processes in the soil. For example, I have not found the implementation of the boundary conditions, and perhaps the calculation of isothermal vapor conductivity via a function of soil texture could somehow be shown without having to consult Braud et al. (1995).

The most important equation is Richards' equation, that's why we put it in front. We agree to add some new equations in the appendix for more comprehension.

For the Implementation of the bottom boundary condition, we just stated that it’s a free drainage condition.

The isothermal vapor conductivity is active when the soil is close to the wilting point, and therefore when the soil is dry, which is not our case; therefore we do not find it necessary to put the equation in this article. We propose to remove its mention in the article.

- line 154. As a soil hydrologist, I am somewhat surprised at this type of notation. Why psi(w) and K(psi), instead of expressing both w and K as a function of psi (which is common, at least in the soil hydrology community)? Of course, this is meant only as a comment and is not of any consequence....

This seems to depend on the scientific community. In the atmospheric community, these relations are generally expressed in this way (Viterbo and Beljaars, 1995, Decharme et al., 2011).

- line 157: “the more complex closed-form equations from van Genuchten (1980)” --- No. The equations may look a bit more complicated, but VG's approach is certainly not "more complex". The fact that a simple algebraic equation is very short in one case, while it looks a bit more complicated in the other case, should not be interpreted as "complex" in 2022.

We agree and we will remove this expression.

- line 162 “α (m$_{-1}$) [is] the inflection point where the slope of the soil-water retention curve (dω/dψ) reaches its maximum value,” --- This is wrong. $1/\alpha$ is in between the inflection point and the air-entry value.

Yes, you are right.

- “line 163. “l [is] the Mualem (1976) dimensionless parameter that determines the shape of the hydraulic conductivity curve” --- No, It does not determine the “shape” of the conductivity curve, but rather the slope of the log K vs. log psi curve in the unsaturated range. The “shape” of the function is unaffected, log K (log psi) remains linear.

Yes, you are right. We proposed to simply states that Mualem (1976) dimensionless parameter that determines the slope of the hydraulic conductivity curve”

3. ESTIMATION OF PARAMETERS

- Line 173 “The rich data sets collected by the lysimeters allow the derivation of the soil hydrodynamic parameters”; “For instance, Fig. 1 plots“ --- Figure 1 is central to the entire paper and its findings. I have a number of comments on it, which are included at the end of my comments here. These data must be given for all lysimeters, as they determine the outcome of the simulations and thus affect all conclusions of the paper.

Please, see above (response to point of line 73).

- line 179: “ω_{sat} is determined by the 99th percentile of the observed soil volumetric water content” --- to be sure: this is 6 years * 365 days * 24 values = > 52'000 water content data for each layer? Just make this clear.

Yes. That’s correct. We propose to add the number of observations in the Table 2.

- line 178: “observed ψ-ω relationship at each depth” --- I assume the depths listed in Table 2? Are the layer boundaries of the different materials in the simulation chosen to be at the mean distance between these observation depths?

Yes. That’s correct, the measurement depths are given in Table 2. The soil resolution in the model was missing, and we’ll add it: 13 soil layers are used, with nodes at 0.01, 0.04, 0.1, 0.2, 0.4, 0.6, 1.0, 1.2, 1.4, 1.6,1.8 and 2 m.

- line 182 “By assuming the unit-gradient assumption, the drainage at 2 m can be considered equal to the hydraulic conductivity.“ --- Did you ever observe fully saturated unit gradient conditions in the lysimeter? Saturation just at the base is not a sufficient condition.

Please see above my answer to your question 5.

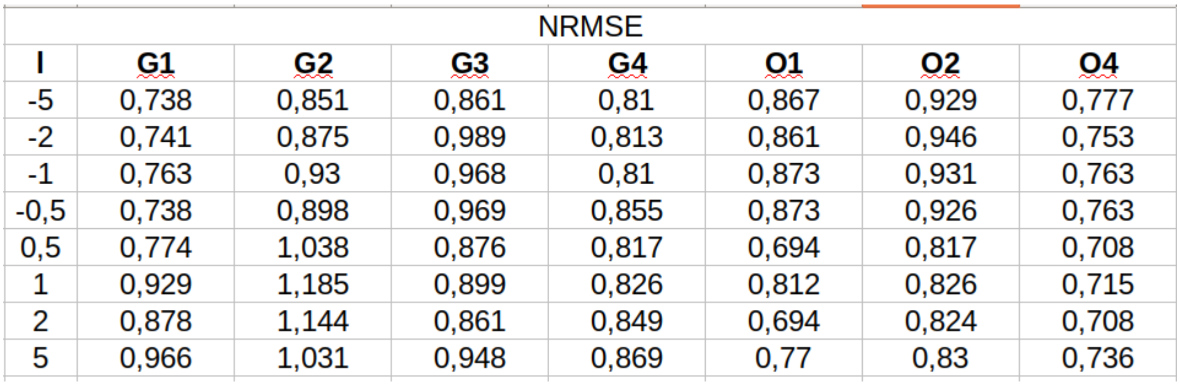
- line 193” Vogel et al. (2000) determined a limit of $n < 1.3$ below which Eq.(5) is numerically unstable.” – Well, that’s a complex issue. See remarks at the begin of the review.

Yes.That’s correct. Please see the response in the part Specific Comment Basic Approaches.

- line 195. “The l parameter in Eq. (5) from VG80 is estimated with a simple calibration via ISBA sensitivity experiments with l ranging from -5 to 5. “ --- This is incomprehensible: What exactly was done in this "simple calibration via ISBA sensitivity experiments"? Also, it is suspicious that the optimized values for the GISFI lysimeters are all at the limit of a permissible range. Furthermore, with l= -5, we are outside the physically permissible range for many sets of hydraulic functions and might face even increasing conductivity in dry soil (see Peters et al., 2011).

Thank you for raising this point. Although a negative l is losing its physical meaning, such negative values are often used as notices by reviewers 1 and 2.. Therefore, we span all the values between -5 and 5 to calibrate this parameter. The NRMSE score on the comparison between observed and simulated drainage of the sensitivity tests are presented in Table R3.4. Best results were obtained for a tortuosity fixed at 0.5 for OPE lysimeters (O1-O2 and O4); and -5 for GISFI lysimeters (G1-G2-G3-G4).

Table R3.4 : Normalized Root Mean Square Error (NRMSE) scores from simulations with VG80 for each lysimeters, with variation of the parameter l.



	NRMSE						
l	**G1**	**G2**	**G3**	**G4**	**O1**	**O2**	**O4**
-5	0,738	0,851	0,861	0,81	0,867	0,929	0,777
-2	0,741	0,875	0,989	0,813	0,861	0,946	0,753
-1	0,763	0,93	0,968	0,81	0,873	0,931	0,763
-0,5	0,738	0,898	0,969	0,855	0,873	0,926	0,763
0,5	0,774	1,038	0,876	0,817	0,694	0,817	0,708
1	0,929	1,185	0,899	0,826	0,812	0,826	0,715
2	0,878	1,144	0,861	0,849	0,694	0,824	0,708
5	0,966	1,031	0,948	0,869	0,77	0,83	0,736

- line 200: “The derived parameters are presented in Fig. 2“ --- As mentioned above, the parameters (ω_{sat}, ψ_{sat}, α, n, b, l and k_{sat}) should be listed (additionally) in a Table, maybe in supplementary material.

Yes.The values are given in the Figure 2 of the article. We agree to add also the derived parameters in a Table in supplementary material.

- line 215 “if the volumetric water content presents a slow decrease in summer at a given depth, it is considered that the roots have not yet reached this depth. The root depth is thus fixed at 2 m for lysimeters G3 and O2” --- Hm, this is really a very large depth for the grass roots. Unusual.

The lysimeter G3 is covered by dense alfalfa (Mathers et al., 1975, Johnson et al., 1998). For O2 lysimeter, vegetation is not controlled and there was not only grass, but a mixed of vegetation. We imposed a maximal depth of root, where a root density profile is defined according to Jackson et al.,1996, with roots denser at the surface than at the maximal depth.

- line 216 “varies for lysimeters G4, O1 and O3.“ --- Would be nice to see this illustrated.

Please see table R3.5 that provides the maximal root depth imposed for these lysimeters.
The roots in ISBA have a density profile: there are more root in the top soil, but, although there are less root at the maximum root depth, their impact can be seen in the soil moisture during the dry period.

Table R3.5 : Evolution of the root depth (cm)

Depth (in cm)	2009-2013	2013-2016	2018-2020
G4	1.5	0.4	
O1-O3		0.8	2.0

- line 222: “(not shown”) – Why not shown? In digital format, we do not have space limits in the supplemental information!

It was not shown to keep the article short, but, it is true this can be put in the supplementary info. We propose to add the following figure with a mean annual cycle of the LAI simulated for lysimeters with vegetation (Figure R3.7) and also the daily simulation of the simulated LAI (Figure R3.8).

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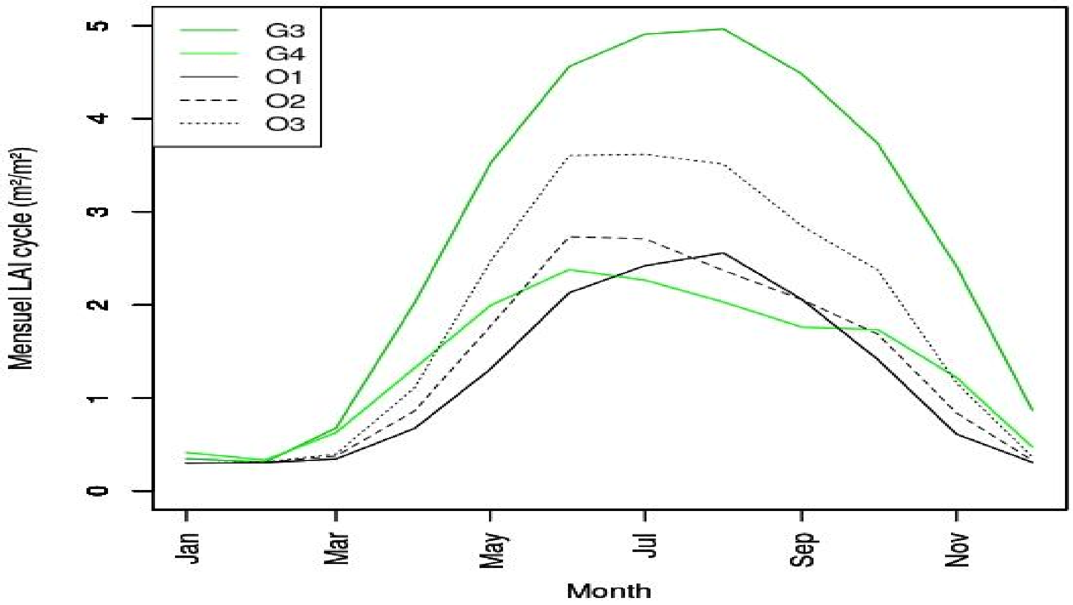

Figure R3.7 : Mean LAI cycle simulated for lysimeters with vegetation for each lysimeter

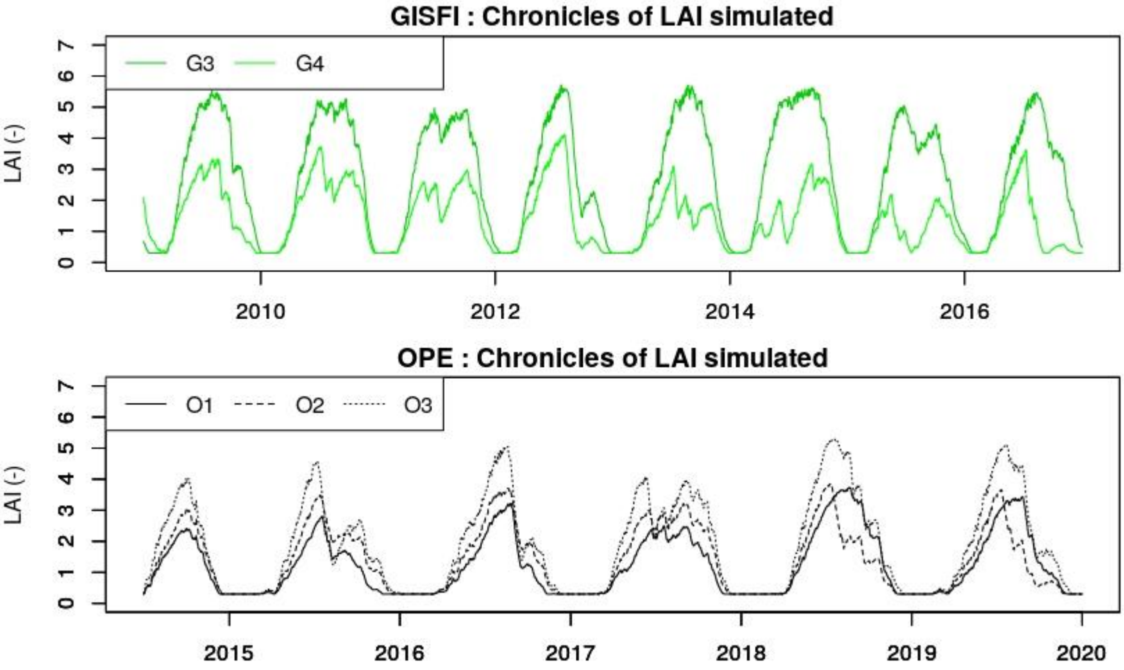

Figure R3.8 : Daily evolution of the LAI simulated for each vegetated lysimeter

4. RESULTS

- line 240 “we arbitrarily consider that the initial observed and simulated total water masses are equal for the BC66 experiment” --- ... and how do you get the initial simulated total water mass? Based on what initial conditions in the simulation? And is the initial water content of the VG80 identical to that of the BC66?

A one-year simulation spin-up is performed (we’ll add this information in the text) and the outputs of the simulation are used as initial conditions. The hypothesis we made, to consider that the initial total mass in BC66 is equal to the observed makes it possible to estimate a mass of the “dry lysimeter”, ie, the lysimeter without any water: total mass=dry mass + total mass of water estimated by BC66. Then we used this dry mass to estimate the total mass of VG80 by considering the same dry mass, but accounting for the total water mass simulated by VG80.

- line 249 “BCVG experiment obtains better scores than the other experiments in more than 42 % of cases“ --- Certainly true, but the differences between the model variants seem to be insignificant. With the exception of lysimeter G4, where the BC66 parameterization leads to a different picture than the others, we can say that the variants give more or less the same results. The fact that in G3 all three model variants overestimate the water mass might hint on a problem with the initial conditions or the soil mass.

Yes you are correct. This is why for the total mass, we added comments on square correlation R2, since the correlation doesn’t depend on the initial mass hypothesis. It can also be seen that although the initial value was derived from the BC66 experiment, the biases are similar for the 3 experiments. The important overestimation of simulated mass with lysimeter G3 can be explained by the fact that alfalfa was planted during the observed period, and it can generate an important biomass as well as important variation of mass between minimal and maximal values, and so the differences are more important.

- line 258 “VG80 obtains weaker statistical scores in 96 % of the cases, because soil water saturation is reached too rapidly”--- This could be an indication of an incorrect conductivity curve. As mentioned in the introductory section of this study, the use of VG80 is not acceptable for such small values of n, and this result is a strong indication of an incorrect conductivity curve. The study should be supplemented with a modified VG80 conductivity as suggested above.

Yes, you are right, there is a clear improvement with the VGc simulation (see figure R3.1-2-3-4).

Table 1

Please add some more key information: USDA soil type (e.g., sandy loam), monolithic or filled, bulk densities.

We proposed to modify the Table R3.6 as follow : Description of lysimeters : filling method, soil type, vegetation cover, number of texture observations, and textures (in % of clay sand, and silt) ,at different depths. HyCa stands for Hypereutrci Cambisol.

Table R3.6

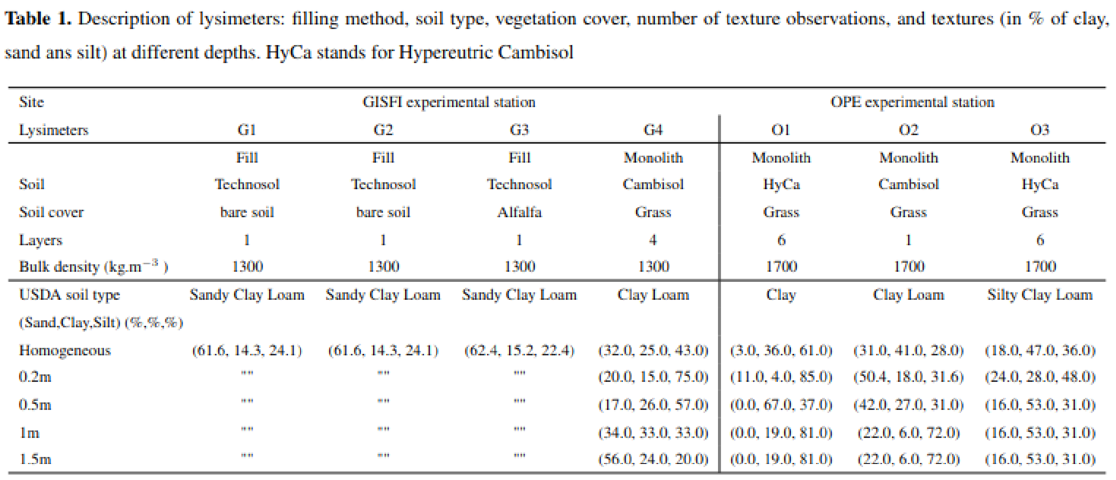

Table 1. Description of lysimeters: filling method, soil type, vegetation cover, number of texture observations, and textures (in % of clay, sand ans silt) at different depths. HyCa stands for Hypereutric Cambisol

Site	GISFI experimental station				OPE experimental station		
Lysimeters	G1	G2	G3	G4	O1	O2	O3
	Fill	Fill	Fill	Monolith	Monolith	Monolith	Monolith
Soil	Technosol	Technosol	Technosol	Cambisol	HyCa	Cambisol	HyCa
Soil cover	bare soil	bare soil	Alfalfa	Grass	Grass	Grass	Grass
Layers	1	1	1	4	6	1	6
Bulk density ($kg.m^{-3}$)	1300	1300	1300	1300	1700	1700	1700
USDA soil type	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Clay Loam	Clay	Clay Loam	Silty Clay Loam
(Sand,Clay,Silt) (%,%,%)							
Homogeneous	(61.6, 14.3, 24.1)	(61.6, 14.3, 24.1)	(62.4, 15.2, 22.4)	(32.0, 25.0, 43.0)	(3.0, 36.0, 61.0)	(31.0, 41.0, 28.0)	(18.0, 47.0, 36.0)
0.2m	""	""	"""	(20.0, 15.0, 75.0)	(11.0, 4.0, 85.0)	(50.4, 18.0, 31.6)	(24.0, 28.0, 48.0)
0.5m	""	""	"""	(17.0, 26.0, 57.0)	(0.0, 67.0, 37.0)	(42.0, 27.0, 31.0)	(16.0, 53.0, 31.0)
1m	""	""	"""	(34.0, 33.0, 33.0)	(0.0, 19.0, 81.0)	(22.0, 6.0, 72.0)	(16.0, 53.0, 31.0)
1.5m	""	""	"""	(56.0, 24.0, 20.0)	(0.0, 19.0, 81.0)	(22.0, 6.0, 72.0)	(16.0, 53.0, 31.0)

Table 2

Layout is puzzling: two columns for GISFI water content sensors, one column for the respective matric potential sensors.

We try to avoid putting too much data by not repeating the values. With your comments, we proposed to modify the table.

Table R3.7 : Description of the available observations for each lysimeter: observation period, mean Annual precipitation (Precip) and drainage

(Drain). For each type of data, the available depths are indicated (cm). Quality of measurements is given as percentage of missing data: meteo gap for the meteorological forcing, defect for the lysimeters measurements.

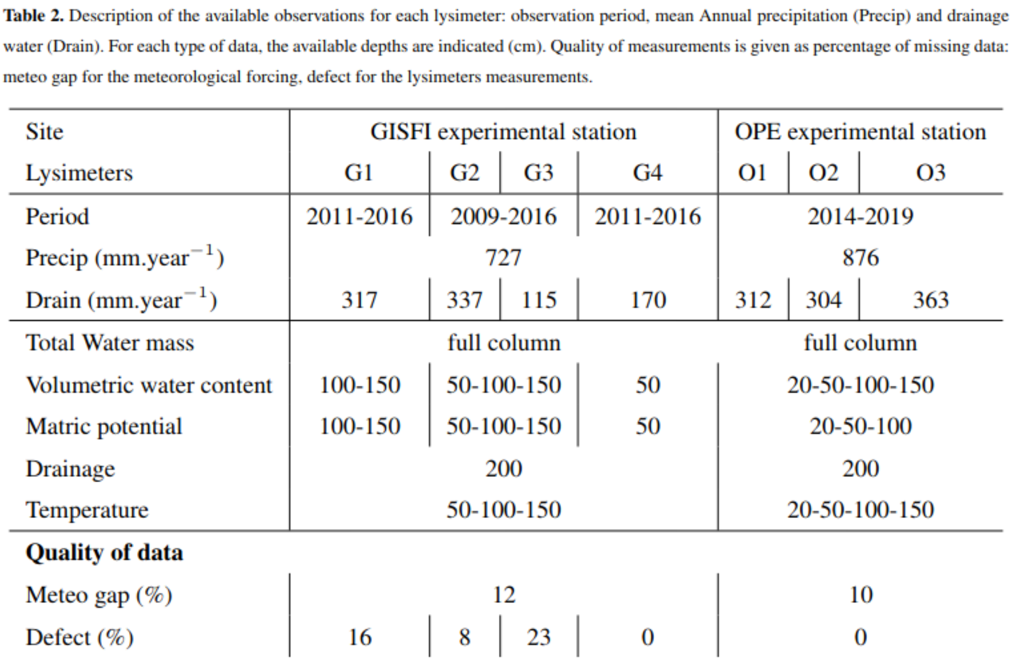

Table 2. Description of the available observations for each lysimeter: observation period, mean Annual precipitation (Precip) and drainage water (Drain). For each type of data, the available depths are indicated (cm). Quality of measurements is given as percentage of missing data: meteo gap for the meteorological forcing, defect for the lysimeters measurements.

Site	GISFI experimental station				OPE experimental station		
Lysimeters	G1	G2	G3	G4	O1	O2	O3
Period	2011-2016	2009-2016		2011-2016	2014-2019		
Precip (mm.year^{-1})	727				876		
Drain (mm.year^{-1})	317	337	115	170	312	304	363
Total Water mass	full column				full column		
Volumetric water content	100-150	50-100-150		50	20-50-100-150		
Matric potential	100-150	50-100-150		50	20-50-100		
Drainage	200				200		
Temperature	50-100-150				20-50-100-150		
Quality of data							
Meteo gap (%)	12				10		
Defect (%)	16	8	23	0	0		

Fig.1

a) Are these data from five years in-situ measurements (hourly resolution)? Why is there no hysteresis?

It is a measurement of hourly resolution, but not on the entire chronicles because measurements of matric pressure are not always available. This represents on average 3220 of observations by lysimeters and by depth. There is no hysteresis because we averaged the values by pressure to have a better solution with the objective function used for estimated hydraulic properties.

b) How are the depicted conductivity data derived? From the paper, I learned that Ksat is derived from a unit-gradient assumption, and relative K-function in the unsaturated range is predicted by the BC66 reps. VG80 model.

With parameters estimated via the relation $\psi - \omega$, we can plot the relation between volumetric water content and the drainage, and thus estimate Ksat when $\omega=\omega_{sat}$. Such a method was then compared to the quantile 99.9 of hourly observed drainage value. Both estimations are in agreement.

c) Why do conductivities decrease with decreasing suction (@1 m, soil G2, grey dots)

This could be due to measurement errors.

d) How are the RETC data for O1 @1.5 m derived? Such experimental data cannot be obtained this far into the unsaturated range! Moreover, a water content of 35% is impossible at a suction of 1E+5 m. Note that this suction condition I beyond oven dryness, i.e., ω = 0!

Yes you are right. There is water content at this suction. There was an error on the data processing. Please see the updated figure below (Figure R3.9.)

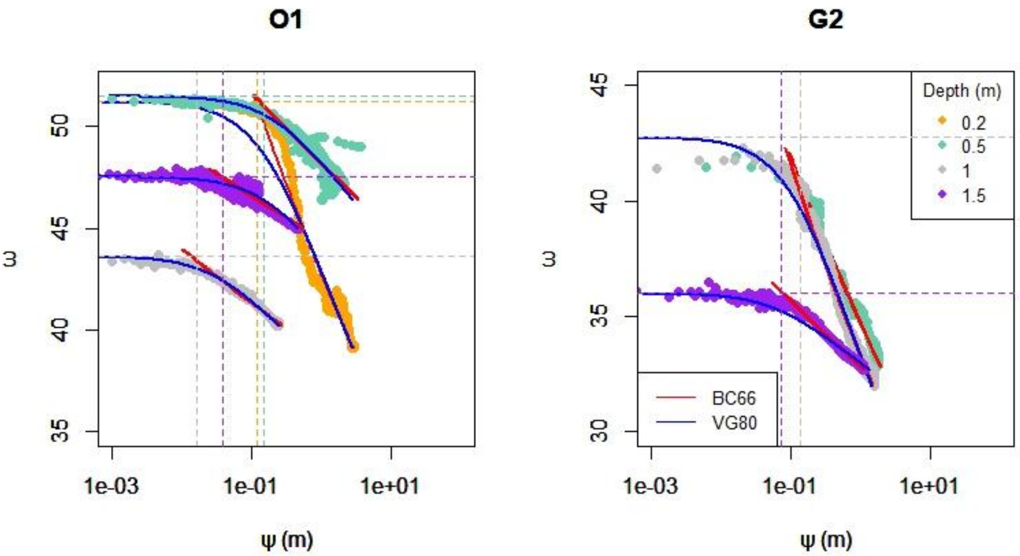

Figure R3.9 : Relationships between volumetric water content (ω) and logarithm of the absolute value of the soil matric potential (ψ) for lysimeters O1 and G2. Observations at 0.2, 0.5, 1 and 1.5 m depth are in dot (orange, aquamarine, grey and purple respectively), estimations are in red and blue for BC66 and VG80 experiments, respectively.

e) What's the meaning of the dotted lines (I assume psi_s and ω_s, but name it in the legend or caption!)

Yes, you are right, it is well ψ_{sat} and ω_{sat}. We will explain it clearly in the caption.

> f) Why do we find such strongly different slopes of RETC in a packed lysimeter (G2) with homogeneous)!) soil? What are the bulk densities?

It is perhaps due to a modification of the soil during the filling process of the lysimeters. The bulk density is 1300 and 1700 kg/m^{-3} for GISFI and OPE lysimeters, respectively.

> g) Where are the data for O2, and O3, and for G1, G3 and G4? supplemental material.

We well put the corresponding figures in supplemental material.

Fig. 2

a) Ksat – I am not able to decipher the unit. 10_6 m/s ??

Yes, the unit is $10^6 m/s$. We'll improve the axis in the Figure.

b) The n values are very low, close to 1, but in this figure it is impossible to distinguish values near one. Please list the values also in a table.

Yes. As we said previously, we add the values in appendices.

Fig. 9

a) Why do we observe outflow in a system that does not reach saturation at the bottom? Are these suction lysimeters?

Thank you for your detailed reading. Indeed, there was an error in the plot: a 10-day lag between the water saturation profile and drainage in Figure R3.10 crept in for lysimeter G2. By correcting this error, the drainage appears well when the profile is at saturation.

n.

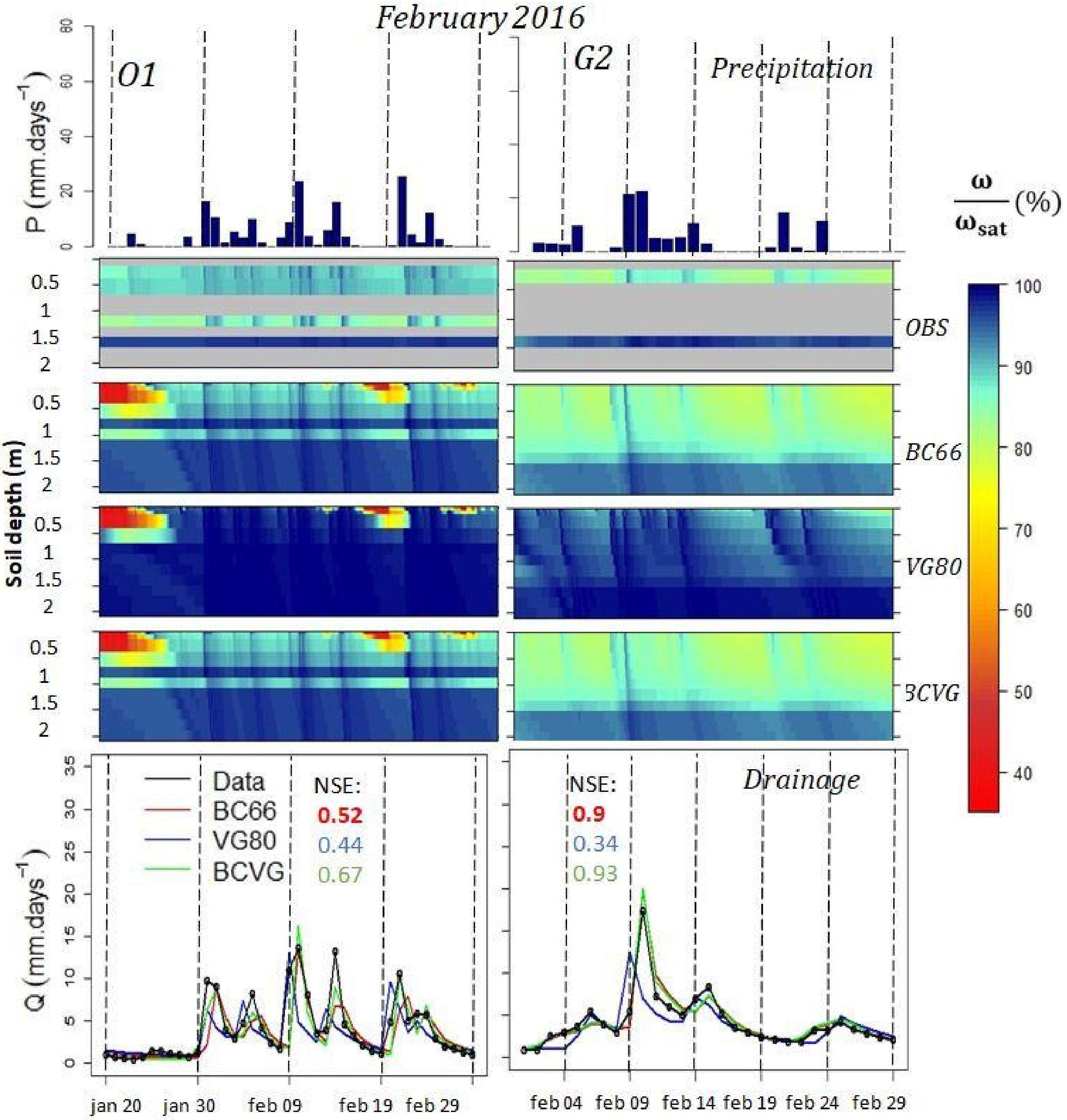

Figure R3.10 : Daily precipitation (mm.day−1), hourly effective wetting saturation profile (%) observed (OBS) and simulated by BC66, VG80 and BCVG, and daily drainage (mm.day−1) observed (in black), and simulated by BC66 in red, VG80 in blue, BCVG in green and VGc in orange during intense drainage in February 2016 for lysimeters O1 and G2. The Nash Sutcliffe efficiency (NSE) for each simulated drainage is also give

TYPOS AND MINOR ISSUES

- Terminology. For me it is puzzling to speak of "experiments" when actually different simulations are meant. The "experiment" to me is the physical experiment where a system is manipulated to observe a response. Perhaps "model variants" or "model approaches" is more appropriate?

We understand your point of view. We proposed to change the term “experiments” with “model approaches”.

- line 83: This is an international journal with many readers not familiar with french terrestrial research units: please define GISFI and OPE upon first occurrence.

GISFI : “French Scientific Interest Group on Industrial Wastelands”
OPE : “Perennial Environmental Observatory”

- line 95: which bulk density?

1300 and 1700 kg/m^{-3} for GISFI and OPE lysimeters, respectively.

- line 200: Typo “lystimeters“.

Thank you for this note.

- line 203: replace “deep” by “depth”.

Thank you for this note.

- line 243 „average biases of 18.1 kg (19.18 and 21 for BC66 and VG80)” --- Keep an eye on your digits: Better “18.1 kg (19.2 kg and 21.0 kg for BC66 and VG80”

Thank you for this note.

- line 277 “if” ??????????

We want to say : “If the year 2016 is excluded, as a large rainfall event occurred in May_June 2016”

- line 304 “dynammic“

Thank you for this note.

Literature cited

Brooks, R. H. and Corey, A. T. Properties of Porous Media Affecting Fluid Flow, Journal of the Irrigation and Drainage Division, 92, 61–88,455 https://doi.org/10.1061/JRCEA4.0000425, 1966

Durner W. Hydraulic conductivity estimation for soils with heterogeneous pore structure. Water Resour Res, 30, 211–23. doi:10.1029/93WR02676, 1994

Ippisch O., Vogel H-J., Bastian P. Validity limits for the van Genuchten–Mualem model and implications for parameter estimation and numerical simulation. Adv Water Resour, 29, 1780–9. doi:10.1016/j.advwatres.2005.12.011, 2006

Jackson, R. B., J. Canadell, J. R. Ehleringer, H. A. Mooney, O. E. Sala, and E. D. Schulze, 1996: A global analysis of root distributions for terrestrial biomes. Oecologia, 108, 389–411, https://doi.org/10.1007/BF00333714.

Johnson, L. D., Marquez‐Ortiz, J. J., Lamb, J. F. S., & Barnes, D. K. (1998). Root morphology of alfalfa plant introductions and cultivars. *Crop Science*, *38*(2), 497-502.

Kosugi K. Three-parameter lognormal distribution model for soil water retention. Water Resour Res, 30, 891–901, 1994

Malama B., Kuhlman KL. Unsaturated Hydraulic Conductivity Models Based on Truncated Lognormal Pore-Size Distributions. Ground Water, 53, 498–502. doi:10.1111/gwat.12220, 2015

Mathers, A. C., Stewart, B. A., & Blair, B. (1975). *Nitrate‐nitrogen removal from soil profiles by alfalfa* (Vol. 4, No. 3, pp. 403-405). American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Peters, A., Durner, W., Wessolek, G. Consistent parameter constraints for soil hydraulic functions. Advances in Water Resources, 34(10), 1352-1365, 2011

Schaap, M. G., Van Genuchten, M.T. (2006). A modified Mualem–van Genuchten formulation for improved description of the hydraulic conductivity near saturation. Vadose Zone Journal, 5(1), 27-34.

van Genuchten M.T. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci Soc Am J, 44, 892–8, 1980

Vogel T., Cislerova M. On the reliability of unsaturated hydraulic conductivity calculated from the moisture retention curve. Transp Porous Media, 31, 15, doi:10.1007/BF00222683, 1988

Vogel T., van Genuchten M.T., Cislerova M. Effect of the shape of the soil hydraulic functions near saturation on variably-saturated flow predictions. Adv Water Resour, 24, 133–144. doi:10.1016/S0309-1708(00)00037-3, 2001

Viterbo, P., and A. C. M. Beljaars (1995), An improved land surface parametrization scheme in the ECMWF model and its validation, J. Clim., 8, 2716–2748, doi:10.1175/1520-0442(1995)008<2716: AILSPS>2.0.CO;2